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ABSTRACT

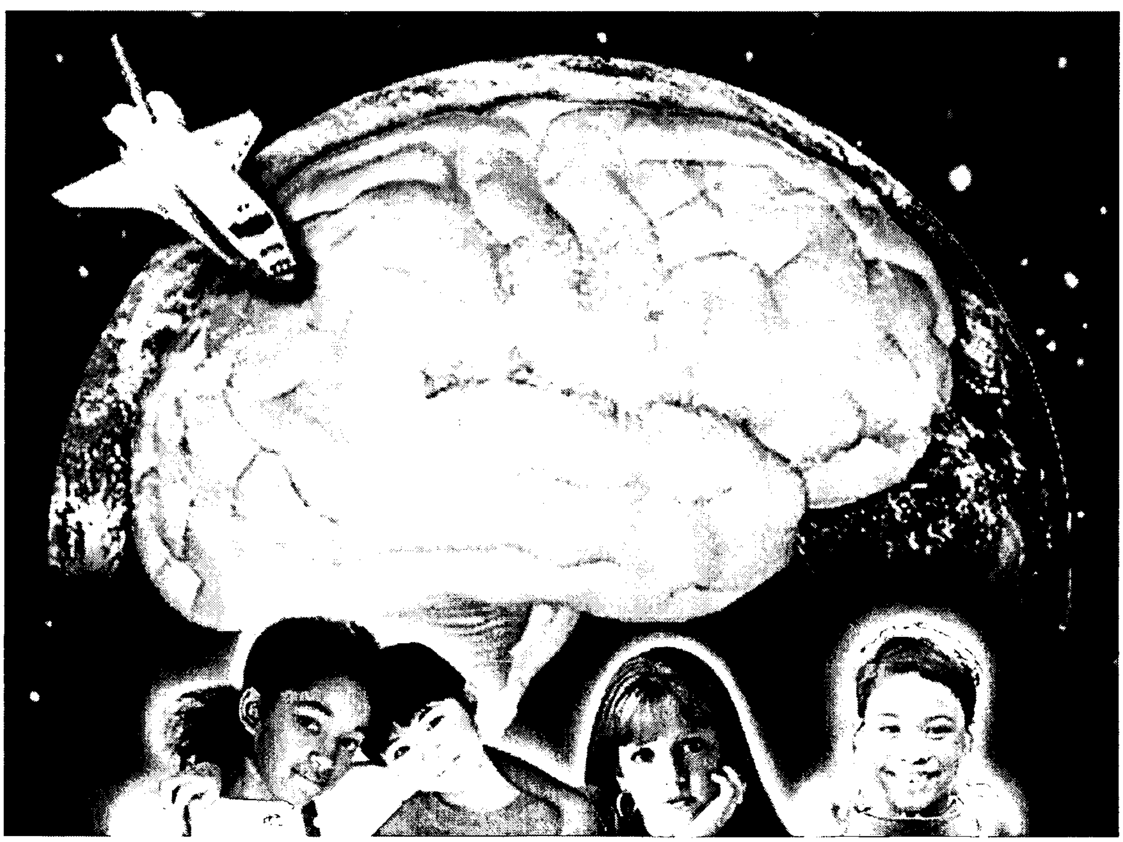
This educators guide discusses the brain and contains activities on neuroscience. Activities include: (1) "The Space Life Sciences"; (2) "Space Neuroscience: A Special Area within the Space Life Sciences"; (3) "Space Life Sciences Research"; (4) "Neurolab: A Special Space Mission to Study the Nervous System"; (5) "The Nervous System"; (6) "Introduction to the Scientific Method"; (7) "What Cells Can I See in Muscle and Spinal Cord Tissue?"; (8) "Target Recognition and Synapse Formation During Development"; (9) "Motor Skills Development"; (10) "Visualizing How the Vestibular System Works"; (11) "Vestibular-Ocular Reflex"; (12) "Finding Your Way Around Without Visual or Sound Cues"; (13) "Pitch, Roll, and Yaw: The Three Axes of Rotation"; (14) "Building a Magic Carpet"; (15) "Building a 3-D Space Maze: Escher Staircase"; (16) "Measuring Blood Pressure in Space"; (17) "Changing Body Positions: How Does the Circulatory System Adjust?"; (18) "Baroreceptor Reflex Role Play"; (19) "The Geophysical Light/Dark Cycle"; (20) "How Quick Are Your Responses?"; (21) "Measuring Your Breathing Frequency at Rest"; (22) "How Long Can You Hold Your Breath?"; and (23) "Raising the Level of Carbon Dioxide in Your Blood". (MVL)

National Aeronautics and Space Administration

Educational Product	
Teachers	Grades 5–12

The BRAIN in Space

A Teacher's Guide With Activities for Neuroscience



The Brain in Space

A Teacher's Guide With Activities for Neuroscience

National Aeronautics and Space Administration

Life Sciences Division
Washington, DC

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Recommended Guide Usage

The lessons and activities in this guide will engage your students in the excitement of space life science investigations after the Neurolab Spacelab mission. It is our goal that the information in this guide will inspire both you and your students to become interested and active participants in this space mission. Few experiences can compare with the excitement and thrill of watching a Shuttle launch. This guide provides an opportunity for you and your students to go one step further by conducting the experiments on Earth that are relevant to the research conducted in space.

The Brain in Space teacher's guide is written for you, the teacher. The activities presented in The Brain in Space are most appropriate for middle and high school life sciences teachers and their students. The NASA Neurolab Space Shuttle flight, STS 90, was scheduled for lift-off in April 1998.

National Science and Math Education Standards

The Brain in Space activities are compatible with the National Science and Math Education Standards. Because many of the activities and demonstrations apply to more than one subject area, a matrix chart relates activities to national standards in science and mathematics and to science process skills. In each matrix, the science and math content standards are listed along the left margin. Activities within a given section that fulfill a listed standard or include the development of a listed skill are designated with the symbol "•" in the appropriate column.

Scientific Method

Since scientists' jobs frequently call for effective communication of scientific results to the community, special emphasis is placed on involving students in activities that require the development and delivery of scientific presentations. Appropriate scientific processes are modeled throughout The Brain in Space guide to assist students in acquiring basic investigative skills.

Using The Brain in Space Activities

The Brain in Space activities focus on specific effects of weightlessness and other aspects of the space environment on:

- developmental and cellular neurobiology,
- vestibular function,
- spatial orientation and visuo-motor performance,
- autonomic nervous system regulation, and
- sleep and circadian rhythms.

Before beginning any hands-on activities with your students, you may want to learn more about the nervous system and how it is affected by the microgravity environment. This information is covered in the following introductory sections: "The Space Life Sciences" (page 3), "Space Neuroscience" (page 5), and "The Nervous System" (page 13). Additional information is provided for you in the "Things to Know" and "Background" sections in Part II.

This guide begins with an overview of Neurolab and background information on space life sciences, space neuroscience, and space life sciences research. The sections on space life sciences focus on changes in organisms under conditions of microgravity, whether or not organisms can withstand these changes, finding ways to make space flight safer, and applying space technologies to solve scientific and medical problems on Earth.

Following Part I are lessons and activities that demonstrate and/or examine the effect of weightlessness and other aspects of the space environment on the nervous system. The many activities contained in this guide emphasize hands-on/minds-on involvement, prediction, data collection and interpretation, teamwork, and problem-solving. Most of the activities utilize basic and inexpensive materials. In each activity, you will find diagrams, material lists, and instructions. A brief science background section within each activity amplifies the concepts covered.

The length of time required for each activity varies according to its degree of difficulty and the developmental level of the students. Many of the activities can be completed in a single class period. Others require several periods for the completion of an investigation.

The guide concludes with a glossary of terms, NASA educational resources, and a printed "Teacher Reply Card." We would appreciate your assistance by completing and mailing in the Teacher Reply Card at the end of this guide.

National Science Education Standards
Grades 5–8 Content Standards

Correlation of Science Themes and Activities in The Brain in Space: Activities for Neuroscience		Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
PHYSICAL SCIENCE	Objects have observable properties	•	•	•	•	•
	Substances react chemically	•				•
	Chemical elements					•
	Describing and measuring motion of an object			•		
	Forces and movement of objects			•		
	Energy (heat, light, electricity, motion, sound, etc.)					
	Heat transfer					
	Light (transmission, absorption, scattering)		•			
	Electrical circuits	•				
	Sun as source of energy on Earth					
LIFE SCIENCE	Organization of living systems	•	•	•	•	•
	All organisms are composed of cells	•	•	•	•	•
	Functions of cells necessary for life	•	•	•	•	•
	Specialization of functions (cells, tissues and organs)	•	•	•	•	•
	Basic human body systems	•	•	•	•	•
	Disease	•	•	•	•	•
	Reproduction (asexual and sexual)					
	Heredity, learning and characteristics of organisms					
	Resources needed by organisms	•				•
	Regulation of the internal environment	•			•	•
	Behavior	•	•	•		•
	Populations and ecosystems					
EARTH SCIENCE	Structure of the Earth					
	Earth forces	•	•	•		
	Soil					
	Water					
	Atmosphere and weather					
	Earth history and the fossil record					
	Earth in the solar system					
	Movement and gravity	•	•	•		

National Science Education Standards

Grades 5–8 Content Standards (Continued)

		Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
SCIENCE AND TECHNOLOGY	Methods of science and technology	•	•	•	•	•
	Different contributions by people to science and technology	•	•	•	•	•
	Trade-offs and unintended consequences in technological designs	•	•	•	•	•
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES	Personal health (exercise, safety, nutrition, tobacco, alcohol)	•	•	•	•	•
	Environmental health	•	•	•	•	•
	Degradation of environments					
	Natural and human-induced hazards					
	Risk analysis					
	Influence of science and technology on society	•	•	•	•	•
	Scientists and engineers work in many settings	•	•	•	•	•
	Ethical codes governing research with human subjects	•	•	•	•	•
	Limitations of science and technology to solving problems					
HISTORY AND NATURE OF SCIENCE	Contributions of men and women to science	•	•	•	•	•
	Science requires different abilities	•	•	•	•	•
	Nature of science (method, research, evaluation)	•	•	•	•	•
	History of science	•	•	•	•	•

National Science Education Standards
Grades 9–12 Content Standards

Correlation of Science Themes and Activities in The Brain in Space: Activities for Neuroscience		Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
PHYSICAL SCIENCE	Structure of atoms	•	•			
	Structure and properties of matter (elements, chemical bonds)	•				
	Properties of carbon-containing compounds	•			•	•
	Chemical reactions (energy, electron transfer, role in living systems)	•			•	•
	Motion and forces (gravitation, electric forces, charges, magnetism)	•	•	•		
	Conservation of energy and entropy		•			
	Interactions of energy and matter (waves, electromagnetic waves, conductance)	•	•	•		
LIFE SCIENCE	Cells (structure, chemical, functions, differentiation)	•	•	•	•	•
	Molecular basis of heredity	•				
	Biological evolution	•				
	Interdependence of organisms (energy flow in ecosystems, populations)	•	•	•	•	•
	Matter, energy and organization in living systems	•	•	•	•	•
	Behavior of organisms (nervous system, role of stimuli)	•	•	•	•	•
EARTH SCIENCE	Energy in the Earth system (role of sun, energy transfer, global climate)					•
	Geochemical cycles					
	Origin and evolution of the Earth system					
	Origin and evolution of the universe					
SCIENCE AND TECHNOLOGY	Aspects and abilities related to technological design	•	•	•	•	•
	Scientists in different disciplines use different methods	•	•	•	•	•
	Role of new technologies in advancing science	•	•	•	•	•
	Purposes of science and technology	•	•	•	•	•

National Science Education Standards
Grades 9–12 Content Standards (Continued)

		Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES	Role of personal and community decisions in health (nutrition, disease, accidents)	•	•	•	•	•
	Population growth and carrying capacity					
	Natural resources (use and limitations)					
	Environmental quality					•
	Natural and human-induced hazards					
	Role of science and technology in solving local, national and global problems	•	•	•	•	•
HISTORY AND NATURE OF SCIENCE	Contributions of individuals and teams to science	•	•	•	•	•
	Ethics in science	•	•	•	•	•
	Nature of scientific knowledge	•	•	•	•	•
	History of science (cultural perspectives, how science advances)	•	•	•	•	•

National Council of Teachers of Mathematics Curriculum and Evaluation Standards

Grades 5–8

	Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
Problem solving	•	•	•	•	•
Communication	•	•	•	•	•
Reasoning	•	•	•	•	•
Connections	•	•	•	•	•
Number relationships	•		•	•	
Computation and estimation	•	•		•	•
Patterns and functions		•	•	•	
Algebra					
Statistics		•		•	
Probability					
Geometry	•	•	•		•
Measurement	•	•	•	•	•

Grades 9–12

	Developmental and Cellular	Vestibular Function	Spatial Orientation	Autonomic	Sleep
Problem solving	•	•	•	•	•
Communication	•	•	•	•	•
Reasoning	•	•	•	•	•
Connections	•	•	•	•	•
Algebra					
Functions		•		•	
Synthetic perspective					
Algebraic perspective					
Trigonometry					
Statistics		•		•	
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Discrete mathematics					
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Mathematical structure					

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Neurolab: A Special Space Mission to Study the Nervous System

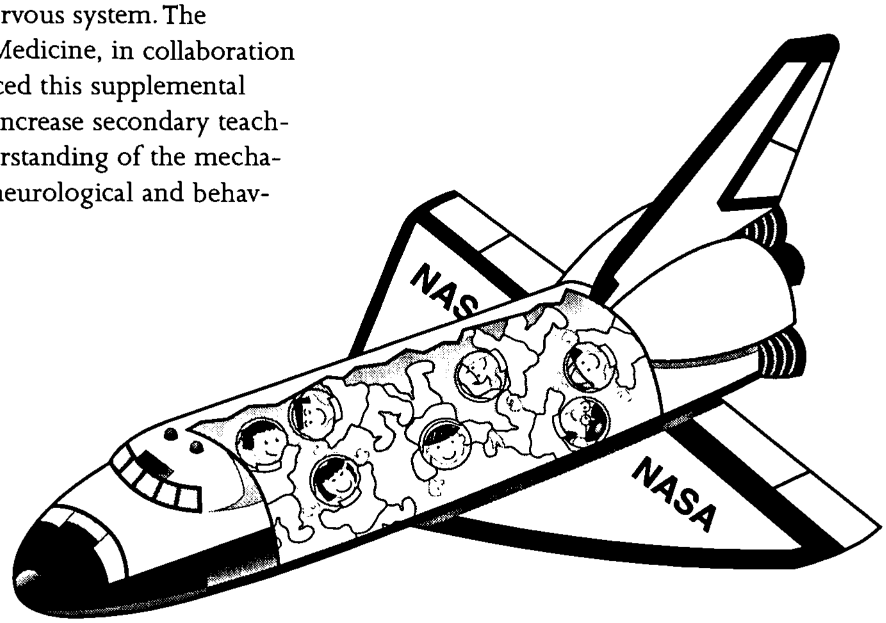
The Nervous System

Part I

Overview: Neurolab and The Brain in Space

In recognition of the tremendous advances that have been made in neuroscience and the behavioral sciences, the President and Congress designated the 1990s as the "Decade of the Brain." In response, the National Aeronautics and Space Administration (NASA) decided that an important and significant contribution could be made to the national research effort through a Shuttle/Spacelab mission (Neurolab) dedicated to research on the nervous system and behavior.

Neurolab was a seventeen-day life sciences Space Shuttle mission. It carried a payload of 26 neuroscience experiments in celebration of the "Decade of the Brain." Five additional "Neurolab Program" experiments will fly on other missions. Seven astronauts (plus two alternates) were selected to fly aboard the Neurolab mission, STS 90, launched in April of 1998. The Neurolab science payload examined the effects of weightlessness and other aspects of the space environment on the nervous system. The Morehouse School of Medicine, in collaboration with NASA, has produced this supplemental instructional guide to increase secondary teachers' and students' understanding of the mechanisms responsible for neurological and behavioral changes in space.



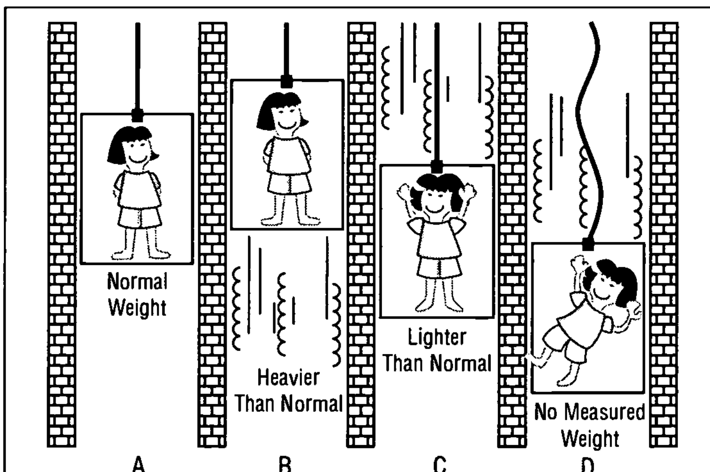
The Space Life Sciences

Life evolved on Earth under a unique set of conditions. These conditions, which make up Earth's environment, are very different from the environment of space. Some of the most notable differences between conditions on Earth and in space are related to gravity, temperature, daily and seasonal cycles, atmosphere, radiation and magnetic fields. Systems for human space flight compensate for many of these differences. The space life sciences use space flight as a unique laboratory to study the effects of very low levels of gravity ("weightlessness") on humans and other biological systems and look for ways to counteract those effects that can be detrimental to human space crew members.

Gravity is an invisible attractive force that is basic to all matter. The amount of gravity, or "pull," exerted by an object depends both on its mass and its distance from other objects. Earth's gravity is responsible for keeping in place the cloud of gases surrounding the planet, known as the atmosphere, and for holding objects on the surface. Even the moon and man-made satellites are kept in their elliptical orbits around the planet by Earth's gravitational field.

However, as one moves farther away from the surface, the pull exerted by Earth's gravity becomes weaker. In a typical Space Shuttle orbit, gravity's pull is about 94 percent the pull experienced at Earth's surface. However, astronauts inside their spacecraft appear to float because the Space Shuttle and the astronauts inside are in "free fall." The orbit they are traveling in is a curved path that is the result of the forward motion imparted by rocket engines during launch and the pull of gravity. By achieving the right forward speed, the shape of the Shuttle's falling path matches the curvature of Earth. Consequently, the Shuttle remains at a nearly constant altitude as it falls. Another way of stating this is that the gravitational pull of Earth is offset by a centrifugal force in the opposite direction related to the acceleration of the spacecraft.

A falling elevator car, as shown in Figure 1, is an example of the effect of "free fall." This condition can be imagined by considering what would happen if the cables on an elevator were to break. The elevator and any passengers inside would fall toward Earth at the same rate.



A. Individual experiences normal weight.
B. Because of the upward acceleration, the individual's apparent weight increases somewhat.
C. Because of the downward acceleration, the individual's apparent weight decreases somewhat.
D. Because of free fall, no weight is measured.

Figure 1 Diagram of free fall.

Since gravity is not completely offset at all points within the space vehicle, the term "microgravity" is used to describe the condition of near weightlessness in space. Space life scientists are able to conduct experiments under microgravity aboard Space Shuttle missions. Thus, astronauts circling the planet in a spacecraft do not feel the effects of gravity.

Space life scientists are interested in learning about changes in organisms under conditions of microgravity. These changes take place at the cellular, systemic, and organismal levels.

Studying cellular systems helps scientists to learn about some of the changes that occur within whole biological systems in space. Most are disrupted in some way when exposed to microgravity. Space life scientists hope to understand how and why changes in cellular and body systems take place so that they can understand how gravity has influenced evolution, development, and function on Earth. In terms of human space travel, there is also a need to develop effective "countermeasures," or treatments, to lessen or eliminate the possible detrimental effects caused by the space environment.

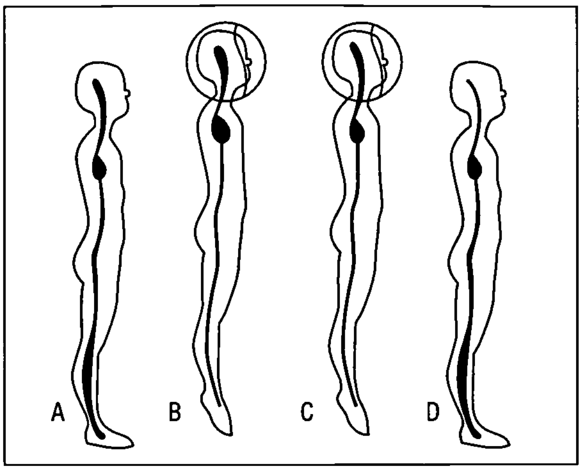
A particular focus of space life sciences research is seeking answers to questions about changes that occur in the human body when it is launched from Earth's surface, remains in the microgravity environment of space, and then returns to Earth.

Some of the questions that space life scientists ask are:

- How does the human body adjust to microgravity? We know, for example, that body fluids redistribute within the body in microgravity. What happens to the human heart and blood vessels under these conditions?
- What are some of the changes that take place in cells and tissues, and why do the changes take place? For example, we know that muscles lose mass and that bones lose minerals after periods of weightlessness. Space life scientists would like to know why and how this happens, and whether these processes can be prevented.
- Do cells reproduce and function normally in microgravity?
- Why do some people have motion sickness during the first few days in space?
- How do the timing clocks that set the body's biological and physiological rhythms change in microgravity?

As an example of the types of questions examined by space life scientists, consider how the human heart adjusts to shifts in the body's fluids in microgravity. On Earth, gravity pulls fluids toward the lower parts of the body (Figure 2A). In microgravity, bodily fluids move from the feet, legs, and lower trunk toward the upper body, trunk, and head. This redistribution of fluids causes the heart to become temporarily enlarged because of the increased upper body blood volume (Figure 2B). The body reacts to increased blood volume by eliminating fluids. This elimination decreases the total amount of fluid within the cardiovascular system and allows the heart to return to a smaller size (Figure 2C). When astronauts return to Earth, gravity once again pulls body fluids toward the lower parts of the body (Figure 2D).

The amount of fluid within the heart and cardiovascular system is no longer sufficient for



Figures 2A, 2B, 2C, 2D Diagram of fluid shift. Used by permission (Ronald J. White, 1990)

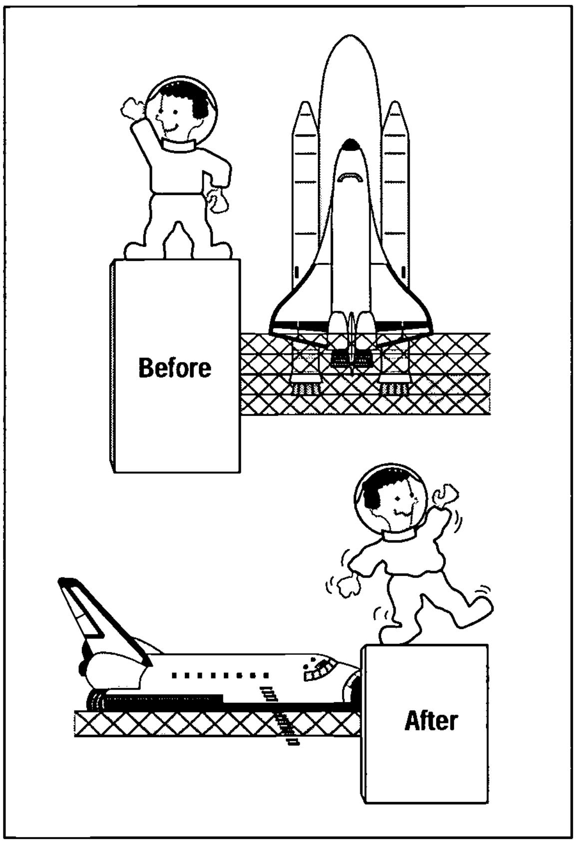


Figure 3 Diagram of astronaut showing signs of dizziness and disorientation after space flight.

normal functioning. Not enough oxygen-containing blood is pumped to the brain and sometimes people returning to Earth tend to faint.

Space life scientists are interested in studying these types of changes because it is important to ensure the health of astronauts in space and facilitate the quick resumption of their normal lives when they return to Earth. Many of the bodily changes that occur in space resemble those we associate with aging. For example, in space, humans lose density in their bones and mass in their muscles. They may also suffer loss of balance, dizziness, and disorientation when they come back to Earth (Figure 3). Space life science research into these conditions has the potential to provide information that could be helpful to physicians as they cope with problems in people as they age on Earth.

Space Neuroscience: A Special Area Within the Space Life Sciences

Space life scientists also would like to learn how space flight and microgravity affect the nervous system. This area of research is known as space neuroscience.

The study of the ways in which the body's brain, spinal cord, and network of nerves control the activities of animals and humans is called neuroscience.

Space neuroscientists, for example, are interested in understanding how microgravity creates conflicts in the sensory systems of animals. Animals use signals from their sensory systems —vestibular (balance), visual, skin, joint, and muscle—to maintain a stable vision, spatial orientation, eye-head coordination, posture, and locomotion. In microgravity, the stimuli are changed. Until they adapt to these changes, humans experience illusory motions in themselves or in their environments, space motion sickness, difficulty in eye-head-hand coordination, and trouble maintaining balance. These disturbances often reoccur after people return to Earth.

Space Life Sciences Research

In the early years of space life sciences research, 1948 to 1957, scientists wanted to learn whether animals could withstand the hazards of space flight before they attempted to send human beings into space. The first successful space flight with live animals took place on September 20, 1951, when the former Soviet Union sent a monkey and eleven mice into space and back in a rocket. (Rockets, unlike spacecraft designed for orbital flights, are thrust into the atmosphere and then drop back to Earth without going into orbit.) The first unmanned orbital flight took place on October 3, 1957, when the former Soviet Union launched Sputnik 1. (Sputnik is a Russian word meaning "satellite.") It was followed by Sputnik 2, launched November 3, 1957. Sputnik 2 carried a dog named Laika housed in a pressurized compartment. Laika survived for one week only, but the beating of her monitored heart in space proved that animals could survive the launch. Other studies with animals in space successfully returned their passengers to Earth. These experiences paved the way for human space travel by disproving prevailing scientific theories that some vital organs might not function in microgravity.

Soviet cosmonaut, Yuri Gagarin, was the first person to orbit Earth, which he did on April 15, 1961. The first piloted United States flight was Mercury, Freedom 7, which lifted off on May 5, 1961, carrying Alan Shepard, the first American to fly into space. Subsequent Mercury flights proved to medical scientists that human beings could fly into space safely. However, these flights also made it clear that the human body experiences changes, such as fluid redistribution and weight loss, during space travel.

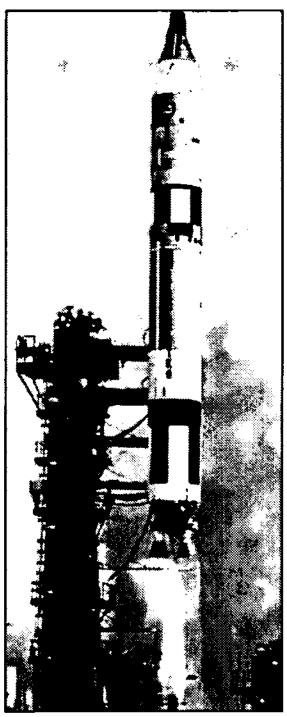


Figure 4 Photograph of Gemini.

The United States-sponsored Gemini (Figure 4) missions took place during 1965 and 1966. In-flight medical studies revealed that additional physiological changes, such as loss of bone density and muscle mass, occur during space flight. Medical scientists concluded that these changes would not prevent human beings from traveling to the Moon, and in May 1961, President John F. Kennedy declared that the United States of America would do just that.

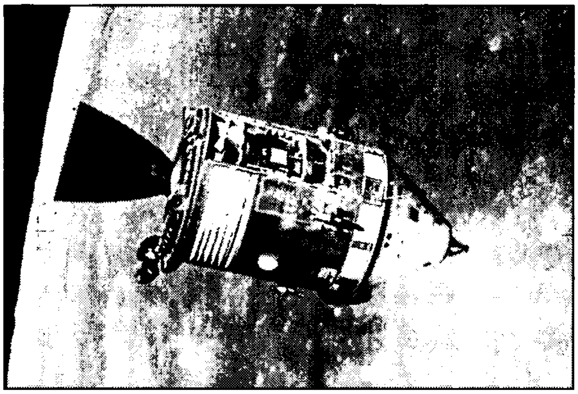


Figure 5 Photograph of Apollo.

Between 1968 and 1972, 11 manned Apollo (Figure 5) flights were launched, carrying out lunar exploration and demonstrating that humans can survive and work on the Moon, which has one-sixth the gravity of Earth. The program included 29 astronauts, 12 of whom spent time on the lunar surface. Apollo-era astronauts reported two major changes in their bodies during their space travel: motion sickness and changes in sleep patterns.

The close confines of the early Mercury, Gemini, and Apollo capsules ruled out sophisticated experimentation because these spacecrafts were too small to accommodate research equipment. It was not until 1973, with the advent of NASA's Skylab program, which allowed astronauts to remain in space for periods of up to 84 days, that scientists were able to conduct detailed monitoring of astronauts' bodies in space. Scientists observed a variety of changes, including shifts in body fluids, disturbances in the vestibular system, muscle atrophy, loss of red blood cells, and decreases in bone density. The scientific data from the three Skylab missions remain a significant source of descriptive information for space life scientists for making predictions about human bodily changes in space.

In 1981, the Space Shuttle (Figure 6) was introduced. This reusable spacecraft made it possible for space life scientists to conduct more elaborate experiments in a special laboratory module, called Spacelab, which is housed in the payload bay of the Space Shuttle. This laboratory is a pressurized module designed for scientists to conduct experiments in space. It is made up of two segments: the core segment, which contains computers and utilities, and the experiment segment, which contains working laboratory space and floor-mounted racks that house specimens, hardware, equipment, and supplies.

Two very important life sciences research programs with origins in the Skylab project were conducted during Spacelab missions in the Shuttle era. The first mission, flown in June 1991, provided the first opportunity since Skylab to study fully the changes that occur in human physiology when the body is in microgravity. The second mission, which lasted for 14

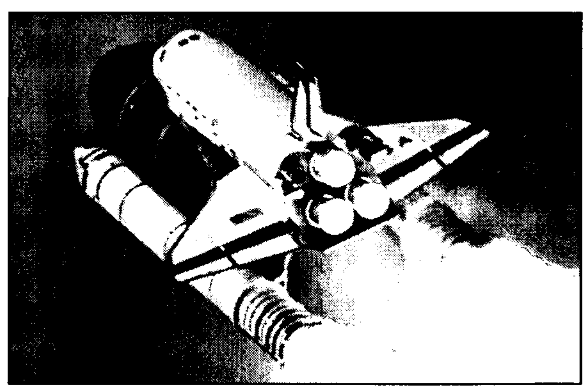


Figure 6 Photograph of the Space Shuttle.

days, was a continuation of the first mission, and studied cardiovascular, pulmonary, nervous, musculoskeletal, and metabolic systems of humans and rodents.

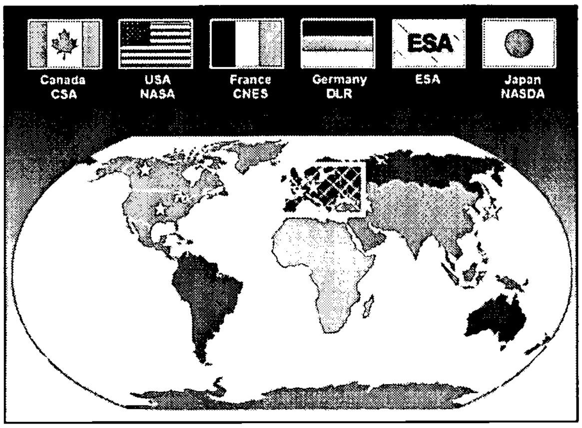


Figure 7 *Diagram of Neurolab's six participating space agencies.*

NEUROLAB SPACE AGENCIES

Six space agencies (Figure 7) participated in Neurolab and otherwise have led the way to greater collaboration in space life sciences research. They are the United States National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), the Canadian Space Agency (CSA), the Centre National d'Etudes Spatiales (CNES) of France, the German Space Agency—Deutsches Zentium fur Luf-Und Raumfahrt (DLR), and the National Space Development Agency of Japan (NASDA). In June 1995, these agencies developed the International Strategic Plan for Space Life Sciences, outlining how the field of space life sciences could be best developed from the present into the 21st Century.

The National Aeronautics and Space Administration (NASA) of the United States

NASA was established in 1958, in response to the Soviet Union's launching of Sputnik 1. Its space life sciences research program seeks to support long-term human exploration of space and use the unique characteristic of space as a research tool to study basic biological processes.

The European Space Agency (ESA)

ESA, headquartered in Paris, France, is an international organization comprised of fourteen member states: Austria, Belgium, Finland, France, Denmark, Germany, Italy, Ireland, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom (Figure 8). The Agency was instituted in 1975 with the merger of two organizations that were already involved in Europe's space program since the early 1960s.

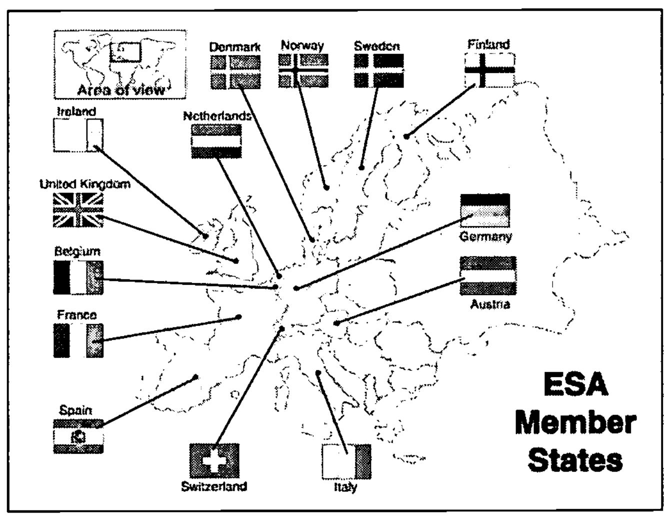


Figure 8 *Diagram of the ESA member states.*

Canadian Space Agency (CSA)
CSA was founded in 1989. Canada also participates in the international space program as an associate member of ESA and as a member of the International Space Station Program. CSA headquarters is located in Ottawa, Canada. The Canadian space life sciences program has participated in a series of Spacelab missions with experiments that examine how humans adapt to space flight.

Centre National d'Etudes Spatiales (CNES) of France
CNES, created in 1961, has five locations: headquarters in Paris; rocket activities in Evry; technical activities in Toulouse; launch site in Kourou; and stratosphere balloon activities in Aire sur l'Adour. The CNES space life sciences program was established in 1970 to investigate five areas: neuroscience; cardiovascular science; musculoskeletal physiology; gravitational biology; and exobiology.

Deutsches Zentium fur Luf-Und Raumfahrt (DLR) of Germany
The German life sciences research program began in 1972 with experiments on radiation biology. This program now focuses on the responses of biological systems to space elements, the exploration of Earth's ecosystem, and the acquisition of medical and technological knowledge to maintain human presence in space. DLR's human physiology program focuses on the cardiovascular, nervous, musculoskeletal, and endocrine systems.

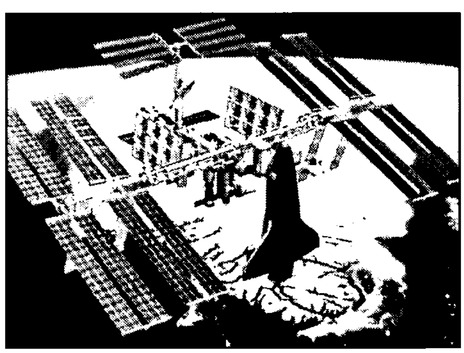


Figure 9 Illustration of the International Space Station.

The National Space Development Agency (NASDA) of Japan
Established in 1969, NASDA oversees development of, and practical space applications for, Japan. It is responsible for developing and launching space vehicles and for overseeing space experiments and involvement with the International Space Station. Japan has a long history of collaboration with other space agencies, and is developing the Japanese Experiment Module (JEM) that will be attached to the International Space Station.

The Russian Space Agency was not a partner on Neurolab. However, the Russian Space Station, Mir, has provided invaluable opportunities for studying physiological and psychosocial issues that will play a role in the success of future long-duration International Space Station missions.

THE INTERNATIONAL SPACE STATION

At present, each Shuttle mission must take all that is needed for survival and for conducting science in space. By constructing a permanent space station, it becomes possible to assemble equipment and materials for longer-duration experiments and resupply without disrupting the scientific experiments. The International Space Station (Figure 9) will allow scientists from around the world to conduct such experiments. Scientists will be able to leave a critical amount of equipment on the Space Station—certain equipment will be "stockpiled" so that the astronauts will not have to return to Earth for material.

Neurolab: A Special Space Mission to Study the Nervous System

President George Bush and the United States Congress declared the 1990s to be the "Decade of the Brain." This declaration recognized the spectacular advances that have taken place in neuroscience research over the past twenty-five years and encouraged further research. Aptly called "the last frontier of human biology," neuroscience research holds infinite possibilities for greater understanding of how the nervous system works and for preventing and treating nervous system ailments.

In response to the President's declaration, NASA dedicated a Spacelab Shuttle mission to conduct research on the nervous system and behavior in space. This 17-day mission, called Neurolab, was scheduled for launch in April of 1998. Its main objectives were the study of basic neuroscience research questions and the exploration of mechanisms responsible for neurological and behavioral changes in space.

In keeping with its history of collaboration with other space agencies, and in order to take advantage of the talents of the neuroscience research community, NASA planned the Neurolab Shuttle mission as a collaborative effort among NASA, other national research agencies, such as the National Institutes of Health (NIH): Division of Research Grants, National Institute on Aging, National Institute on Deafness and Other Communication Disorders, National Heart, Lung, and Blood Institute, National Institute on Neurological Disorders and Stroke, the National Institute on Child Health and Human Development, National Science Foundation (NSF), the Office of Naval Research (ONR), and international space agencies interested in how microgravity affects the nervous system.

Accordingly, in July 1993, NASA issued an Announcement of Opportunity, soliciting proposals for experiments to be conducted on the Neurolab mission. The announcement was followed by a series of pre-proposal meetings held in Tokyo, Japan; Chicago, USA; and Glasgow, Scotland. These meetings provided information to assist prospective applicants in preparing their proposals for experiments on the Neurolab mission. NASA received 172 responses in its call for research proposals—98 from scientists in the US and 74 from other investigators around the world.

In March 1994, all proposals were reviewed for their scientific merit by United States and international scientists. The review was managed by the NIH. The proposals considered most meritorious were later reviewed for their engineering feasibility and appropriateness for the Space Shuttle environment. Thirty-two proposals that met these criteria were selected, and the investigators were assigned to Investigator Teams based on shared subjects, shared hardware, or common research themes. The teams were given ten months, called a Science Definition Period, to develop integrated research plans and procedures that met their original scientific objectives while maximizing the use of scarce Shuttle resources. At the end of this period, the proposals were subjected to a second round of reviews managed by NIH to ensure that the scientific value of the experiments remained intact. Twenty-six proposals were assigned to the Neurolab Spacelab mission and six were designated as small payloads to be flown on other missions because they could be conducted in the mid-deck area on other Space Shuttle flights. However, all 32 investigations were designated as the Neurolab Program.

NEUROLAB PARTNERS

The Neurolab mission was remarkable for its national and international participation. The Neurolab mission demonstrated how scientists from around the world are able to work together to pursue scientific information that will benefit all people. The experience from Neurolab will become increasingly important as space life scientists spend longer periods of time conducting experiments on the International Space Station.

International partners provided some major pieces of equipment for Neurolab and funding for investigations from their respective national research teams. National partners provided funding for the ground-based portions of Neurolab investigations that are relevant to their respective missions. The Neurolab Investigators came together at regularly scheduled meetings, called Investigators Working Group (IWG) meetings, to discuss Neurolab experiments, to coordinate and integrate their experiments, and to decide how their ground-based experiments would best be replicated in space. NASA engineers and technicians had primary responsibility for ensuring that all scientific and engineering elements of the mission worked together for a successful launch.

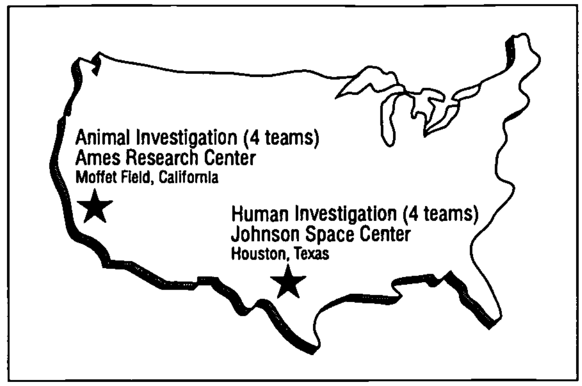


Figure 10 *Diagram of locations of the NASA centers that manage the Neurolab teams.*

SCIENCE TEAMS

Conducting scientific research onboard the Space Shuttle is very different from doing research on Earth. All resources, such as electrical power, experimental supplies and space to store them, work space, and crew time, are valuable and limited commodities that must be judiciously allocated and shared by the investigations.

Four Neurolab science teams (Figure 10) carried out human investigations, and four conducted investigations on other animals. The human investigation teams were managed by the Johnson Space Center (JSC), located in Houston, Texas. Scientists on these teams examined four areas of neuroscience: the autonomic nervous system (part of the nervous system that handles automatic functions like breathing), circadian rhythms and sleep, vestibular function (balance), and sensory/motor function and performance. The animal investigation teams, managed by the Ames Research Center (ARC), located in Moffet Field, California, included an adult neuronal plasticity (ability of mature nerve cells to adapt) team, mammalian development, and aquatic and insect neurobiology teams.

USING ANIMALS IN RESEARCH

Physical space on the Space Shuttle was very limited so all experiments were designed so they could be accommodated in the Spacelab. Neurolab carried a variety of species, including rats, mice, swordtail fish, toadfish, crickets, and snails, into space. The study of these animals helped explain the role of gravity in development and other aspects of the nervous system. Some of the experiments complemented studies conducted on the human crew; all were based on important information from ground-based experiments.

Experiences with animals in space laid the foundation for human space exploration and for advancing understanding of changes that occur in cells and body systems in microgravity. Space life scientists increasingly use cell cultures and computer models to understand these changes and to ask new questions about living systems in space. Animal models are used to examine changes brought about by space flight on the brain, bones, muscles, heart, and other areas of the body and to study developmental biology when there are no other viable alternatives. Much significant information about responses of the body to microgravity also has come from detailed studies of astronauts themselves, both during and after space flight.

NASA, in consultation with a panel of ethicists from the animal protection and regulatory communities, has developed and adopted a strict set of guidelines for animal care and use. All research procedures involving animals must meet these regulations, which require that the fewest number and simplest animals possible be involved. The NASA Principles for the Ethical Care and Use of Animals were developed around the belief that the use of animals in research involves responsibility, not only for the care and protection of the animals, but for the scientific community and society as well.


Figure 11A
Commander
Richard A. Searfoss


Figure 11B
Pilot
Scott D. Altman


Figure 11C
Mission Specialist
Kathryn P. Hire


Figure 11D
Mission Specialist
Richard Linnehan

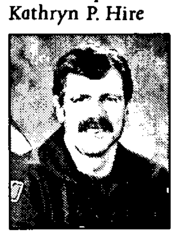


Figure 11E
Mission Specialist
Dave R. Williams


Figure 11F
Payload Specialist
James A. Pawelczyk


Figure 11G
Payload Specialist
Jay Buckey


Figure 11H
Alternate
Payload Specialist
Chiaki Mukai


Figure 11I
Alternate
Payload Specialist
Alexander Dunlap

THE CREW CONDUCTS SCIENCE IN SPACE

All space missions require years of dedication and hard work from experts in a variety of disciplines, and the Neurolab Shuttle mission was no exception. While we often hear about the incredible feats achieved by astronauts in space, we learn less about the role of thousands of dedicated space engineers, technicians, technologists, and administrators who make the launches possible. The Neurolab crew consisted of nine astronauts and scientists (Figure 11):

- One Commander
- One Pilot
- One Mission Specialist trained and designated Flight Engineer
- Two Mission Specialists (astronauts), members of the Payload Crew and one of whom was Payload Commander.
- Two Payload Specialists recommended by the IWG and selected by NASA, who had specific qualifications appropriate to the mission. They were not career astronauts and returned to their respective careers after the mission.
- Two Alternate Payload Specialists, recommended by the IWG and selected by NASA, who received training as Payload Specialists and were prepared to become payload specialists if necessary. They also had special roles during the mission.

The Nervous System

OVERVIEW OF THE NERVOUS SYSTEM

Before studying the brain in space, it is helpful to know something about the normal nervous system as it functions on Earth. What is the nervous system? What does it do? How does it do it? Of these three seemingly simple questions, the first two are reasonably straightforward, but the third is much more difficult to answer. Neuroscientists have some ideas about what the nervous system does, but because there are so many levels of understanding, and because neuroscience research is unfolding information so rapidly, our ability to describe how the nervous system processes information is constantly changing. Aptly described as the final frontier of biology, neuroscience research is beginning to reveal some of the mysteries of the brain, the spinal cord, the specialized sense organs and the complicated network of nerves that together make up the nervous system.

The nervous system keeps us aware of our environment and allows us to react appropriately to external conditions. For example, if threatened, we use our senses—e.g., sight, smell, and hearing—to assess the level of danger and to avoid, hide from, or confront the source of danger. But the nervous system does much more than enable us to interact with our environment by sensing and responding to it. After all, we think, compose music, express love, experience sadness, do mathematics, and even study the brain. These are all nervous system activities that help to make us what we are. How we are able to perform these activities remains one of the deeper mysteries of the nervous system. The best computers pale in comparison to the human brain. Through the actions of our nervous system, we can carry out, sometimes with little effort, a wide variety of tasks that thus far have proven difficult, if not impossible, for machines.

Over the past thirty years, neuroscientists have made tremendous inroads into the investigation of the nervous system and have begun to answer some of our more complex questions about it.

Neurons

The basic signaling unit of the nervous system is the nerve cell, or **neuron** (Figure 12), which comes in many different shapes, sizes and chemical contents.

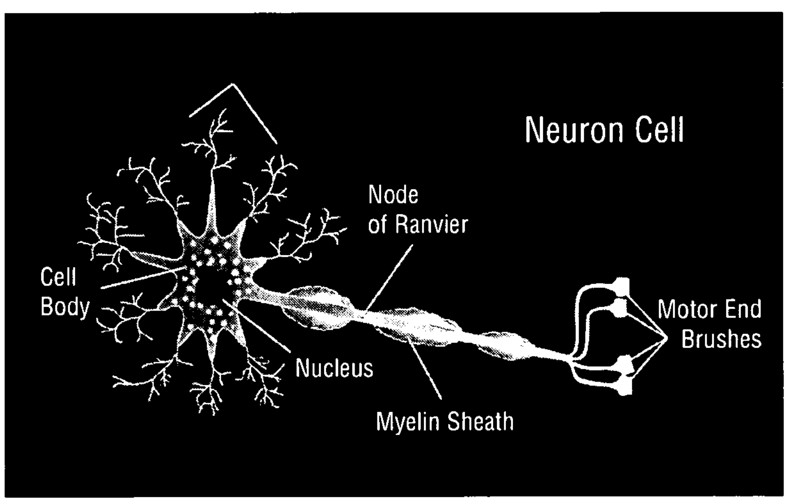


Figure 12 *Diagram of a neuron.* *Adapted by permission* (Purves, 1997)

Information about the environment is garnered through sensory cells that are specialized to respond to a particular external stimulus. In all sensory systems, the sensory cell generates an electrical signal in response to the stimulus via a process called sensory transduction. The electrical signals are forwarded to the spinal cord or brain, where they are processed and sometimes transmitted to effector organs, such as muscles or glands, to produce the appropriate response.

The general layout of neurons is fairly constant. Information is received on structures known as **dendrites**, transmitted to the cell body and passed on via an **axon** which typically ends on a dendrite of the next cell in line. The place where an axon contacts a dendrite or effector organ, such as a muscle or gland, is called a **synapse** (Figure 13).

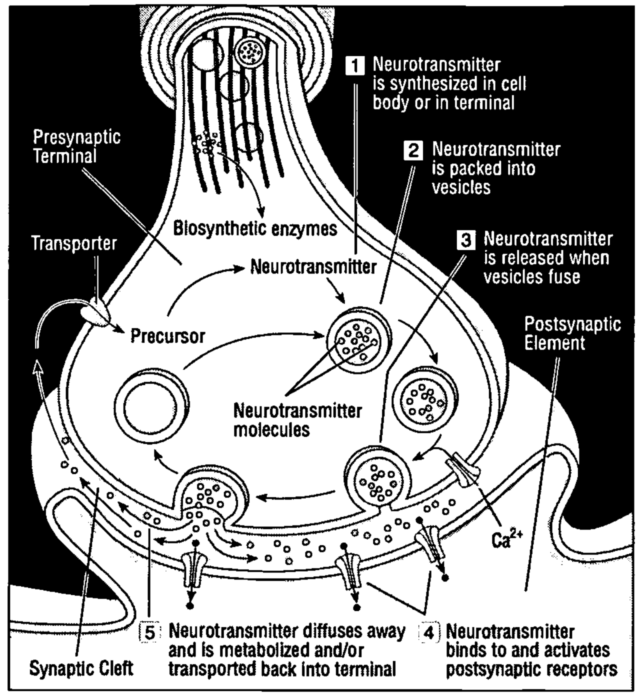


Figure 13 *Diagram of a Synapse.* *Adapted by permission (Purves, 1997)*

The electrical signal in axons is a brief voltage change called an **action potential** (Figure 14), or **nerve impulse**, which can travel long distances, sometimes at high speeds, without changing amplitude or duration. When an action potential arrives at the end of the axon, it causes the release of a stored chemical substance called a **chemical neurotransmitter** into the synapse. The neurotransmitter can either increase or decrease the probability that the next cell will fire an action potential. When it increases the likelihood that the next cell will fire an action potential, the process is called **excitation**, the transmitter is called an excitatory transmitter and the synapse is an excitatory synapse. When it decreases the likelihood that the next cell in line will fire an action potential, the process is **inhibition** and the transmitter and synapse are called inhibitory.

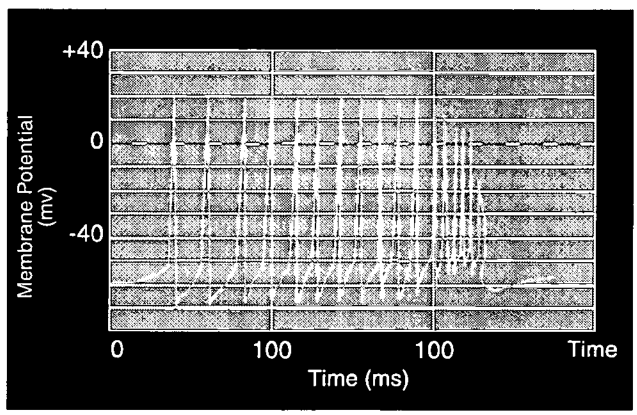


Figure 14 *Diagram of Action Potential recorded from the cell body of a Purkinje neuron in the cerebellum.*

The number of synapses that a given neuron makes on another neuron or the effectiveness of a particular synapse in causing excitation or inhibition—synaptic efficacy—is not constant. In several cases, particularly during development, both the number of synapses and synaptic efficacy are altered. Scientists agree that one important factor in determining number and strength of synapses is the level of use of the system. The effect of use can be particularly strong during a short window of time during development called the "critical period." The time at which the critical period occurs differs from system to system. These use-dependent changes come under the heading of "synaptic plasticity." Some plastic changes last a short time—seconds to minutes—while others last a long time—hours, days and even years. Our ability to learn and remember is a manifestation of synaptic plasticity.

In certain systems, the nervous system responds to changes that take place in such a manner as to keep the system working more or less the same. For example, if the amount of neurotransmitter substance released at a synapse is decreased, then the number of sensing molecules or neurotransmitter receptors at the synapse might increase to produce about the same size response as before. The molecular mechanisms that are used to detect the changes and to make the appropriate alterations are not well understood. Space neuroscientists have learned from past experiments that cells adapt at the molecular and anatomical levels to the microgravity environment of space. Neurolab scientists conducted a series of experiments to further understand the molecular and anatomical bases of plasticity in neurons.

ANATOMY OF THE NERVOUS SYSTEM

Neuroscientists divide the nervous system into two components— the central nervous system and the peripheral nervous system. The central nervous system is comprised of the brain and the spinal cord. The peripheral nervous system includes the sensory neurons that link the brain and spinal cord to sensory receptors and efferent neurons connected to the muscles, glands, and organs.

The Brain

The brain is the most complex organ in the human body. It is comprised of the cerebrum, the brainstem, and the cerebellum (Figure 15). It is surrounded by three protective layers of tissue called the **meninges**, and bathed in liquid called the **cerebrospinal fluid**. This fluid also protects the brain from injury and provides nourishment to its surrounding tissues.

The **brainstem** is a funnel-shaped structure consisting of three components—the **medulla**, the **pons,** and the **midbrain**. These three structures contain motor and sensory nerve cells that receive information from the skin and muscles of the head, and from the special sense organs of hearing, balance, and taste. Groups of nerve cells in the brainstem control many of the automatic functions of our bodies, such as heartbeat, breathing, and digestion, as well as our overall alertness.

The **cerebellum** is divided into symmetrical hemispheres, right and left. The core of the cerebellum is made up of white matter, and the exterior is covered by grey matter called the **cortex**. The white matter gets its name from its whitish appearance in fresh tissue and is due to the presence of an insulating material called **myelin**. Grey matter is devoid of myelin and is mainly comprised of cell bodies of neurons and glial (non-neuronal) cells. The **cerebellum** is divided into three parts, the **cerebrocerebellum,** which receives signals from the cerebrum, the **vestibulocerebellum**, which receives input from the brainstem, and the **spinocerebellum,** which receives electrical signals from the spinal cord (Figure 16). The surface of the cerebellum is shaped by thin folds, called **folia**.

The cerebellum coordinates motor activity, posture, and balance, and helps us store information about motor skills such as the blink reflex and the **vestibulo-ocular reflex** (VOR). VOR helps us keep our eyes fixed on a visual target while we move our head.

The **cerebrum** (Figure 15) represents 85% of the total weight of the human brain. It has a highly convoluted surface, with ridges called **gyri** and valleys called **sulci**. Neuroscientists and neurologists have mapped out the different areas of the cerebral cortex that control the various sensory and motor activities of the human body.

Like the cerebellum, the cerebrum is divided into symmetrical hemispheres. Each hemisphere is divided into four "lobes," the frontal, parietal, temporal, and occipital lobes. These lobes have special functions. The **frontal lobe** is involved with planning and movement; the **parietal lobe** with sensation; the **occipital lobe** with vision; and the **temporal lobe** with learning, memory, and emotion.

The cerebral hemispheres surround an area called the **diencephalon**, which consists of the **thalamus** and the **hypothalamus**. The thalamus is a key structure of the cerebrum. It acts as a gateway for sensory information coming from the major systems—vision, hearing and balance, taste and smell—to the corresponding sensory area of the cerebral **cortex**.

The hypothalamus regulates the autonomic nervous system, reproduction and **homeostasis**. Homeostasis is the process by which our bodies maintain a stable internal environment in the face of changing conditions. Many systems of

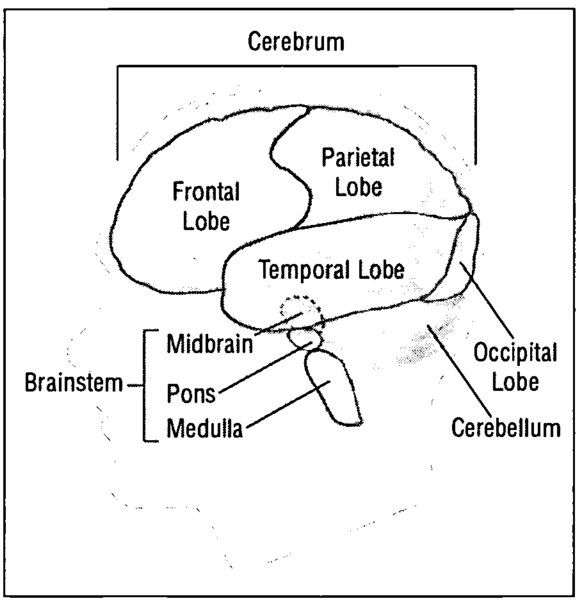


Figure 15 *Diagram of the brain (sideview).*

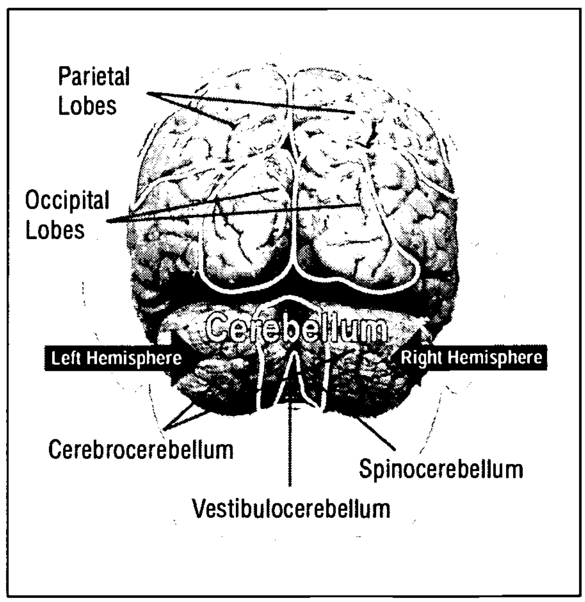


Figure 16 *Diagram of the brain (rearview).*

the body show rhythmic changes within a period of approximately one day—circadian rhythms. The **suprachiasmatic nucleus** is thought to function as the body's master biological clock and is located in the hypothalamus, which is a major part of the diencephalon.

The Spinal Cord

The spinal cord lies in the vertebral canal and is protected by the bony spinal column. In the spinal cord, the positions of grey and white matter are reversed within the brain. The grey matter is on the inside, while the **myelinated nerve tracts**, that make up the white matter, are on the outside.

Thirty-one pairs of peripheral nerves originate from the spinal cord and spread throughout the body. Sensory information carried by the **afferent** (incoming) axons in the peripheral nerves enters the spinal cord through the **dorsal** roots. Motor commands, carried by the **efferent** (outgoing) axons, leave the spinal cord through the **ventral** roots.

NEUROLAB SCIENCE AND THE NERVOUS SYSTEM

The Neurolab Shuttle carried twenty-six experiments that studied the effects of microgravity on the following five aspects of the nervous system: developmental neurobiology; vestibular function; spatial orientation and visuo-motor performance; autonomic nervous system regulation; and sleep and circadian rhythms.

Developmental Neurobiology

The human brain and spinal cord are formed from dividing cells in the fertilized egg. In order to form a fully developed brain and spinal cord, cells from the fertilized egg must undergo mitosis, migration and differentiation. **Mitosis** is the process by which cells divide. Cell **migration** refers to the movement of cells from their birthplace to their final destination. Cell **differentiation** is the process by which developing cells mature into their final specialized form.

Scientists believe that proper development of the nervous system depends upon precise timing of mitosis, migration, and differentiation. In addition, neural populations must form appropriate connections to each other early in development or risk undergoing programmed cell death. The period in which neural populations establish connections with each other starts during early **embryogenesis** and can continue well into the postnatal ages. Embryogenesis is a phase of prenatal developmental stages. Thus, early and postnatal developmental stages are critical for normal spinal cord and brain maturation.

The developing nervous system may interact with gravity in ways scientists do not yet completely understand. Neurolab scientists designed several experiments using a variety of animals to study the effects of space environment conditions on the development of the nervous system. For example, one such experiment looked at the changes in size and neuronal connectivity of the gravity sensing organs in snail and swordtail fish. Another set of experiments studied spatial learning acquisition in the rodent hippocampus, a specialized brain structure involved in learning and memory.

Vestibular Function

Most living organisms have sensory receptors for sensing gravity and transmitting information about head and body orientation and motion. In vertebrates, including humans, this system is called the **vestibular system**. The vestibular system is made up of three **semicircular canals** and the **otolith organs** of the **utricle** and **saccule** which are located in the inner ear.

The semicircular canals are primarily responsible for sensing head rotation. They contain fluid and receptor hair cells that are encased in a delicate membrane called the **cupula** (Figure 18). Head movements cause the fluid to shift, thereby triggering the hair cells to send sensory impulses along the vestibular nerve to the higher centers in the brain. The three canals are situated roughly at right angles to one another in the three planes of space. This allows the canals to act separately and in combination to detect different types of 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 motion (**yaw**).

The otolith organs are responsible for detecting **linear acceleration** (Figure 17), movement of the head in a straight line (side to side, up and down, back and forth). The utricle and saccule are membranous sacs. On the inside walls of both the utricle and saccule, there is a bed of several thousand hair cells, whose hair bundles are covered by small, flat crystals. These crystals are called **otoliths**, a word which means "ear stones." The utricle and the saccule are often referred to as "the otolith organs." When you hold your head in the normal erect position, the hair cells in the utricle lie in a horizontal position. When you tilt your head to either side, the hairs bend, thereby stimulating the hair cells to send a signal to the brain about the amount of head tilt.

In the weightless environment of space, tilting the head does not stimulate the otoliths. Signals from the otolith organs conflict with the semicircular canals and the visual signals that are being sent to the brain. The microgravity environment of space affects astronauts in significant ways. They may experience dizziness, get space motion sickness, and be unable to differ-

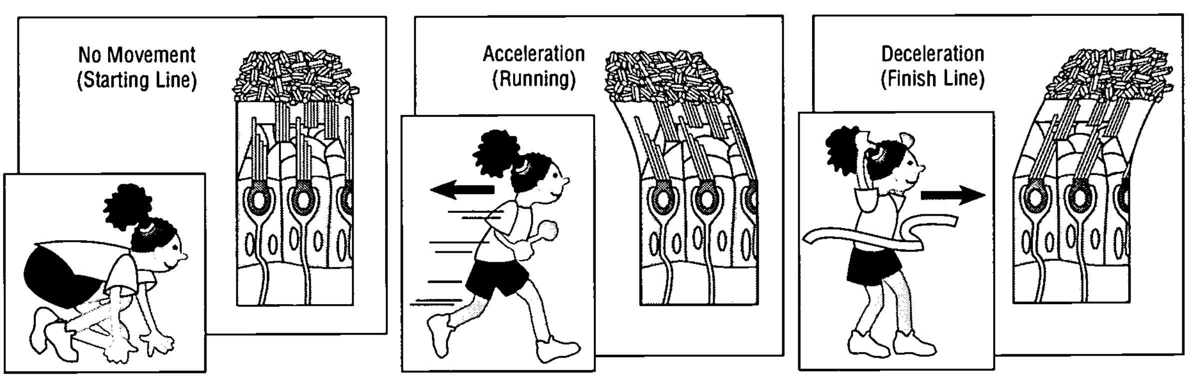


Figure 17 *Diagram of how the otoliths sense linear acceleration.*

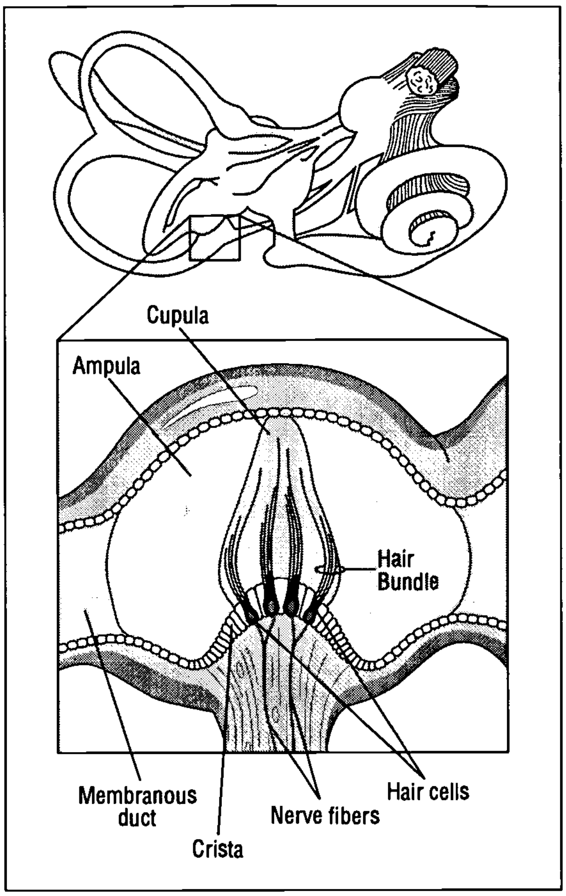


Figure 18 *Diagram of a receptor hair cell.*

entiate up from down. They sometimes become disoriented because they cannot fully perceive where their limbs are located.

The Neurolab scientists developed several experiments to study why astronauts feel unsteady on their feet and experience difficulty with balance upon return to Earth. One experiment correlated spatial orientation with the axis of eye movement using an off-axis rotating chair capable of providing accelerations and decelerations. By using the measurements of astronauts' eye movements, scientists were able to determine how spatial orientation of astronauts changed and how the vestibular system works in space. Studies on Earth have shown that movements of the eyes accurately reveal what happens in the inner ear.

Luckily for astronauts, the vestibular system is very adaptable. After a few days in space, the astronauts float without discomfort. When they return to Earth's gravitational environment, their vestibular system readapts over several days to its normal functions.

Spatial Orientation

The process by which we align, or position, our bodies in relation to objects or reference points in a three-dimensional space is called **spatial orientation.** To maintain this sense of "where we are," our **somatic sensory system** processes signals from our vestibular, visual, tactile, and proprioceptive (a sense of the movements and positions of the limbs) systems.

In space, astronauts must maintain their spatial orientation without the "down" direction signal which gravity provides on Earth. Astronauts have to adapt to the sensory disturbances produced by microgravity. Some depend heavily on vision, while others orient their bodies in relation to external references, such as equipment racks or the floor of the spacecraft.

The Neurolab scientists designed a variety of novel technologies and tests to show how this change takes place. The astronauts performed several experiments to determine how spatial orientation and movement is altered in space. These included a ball-catching test to see how the perception of moving objects changes in microgravity; the use of a virtual environment system to study body orientation; and the study of the effects of microgravity on pointing and reaching tasks. The information collected from these experiments provided insights into how the nervous system creates balance between information it gathers from the eyes, inner ears, and joints.

The Autonomic Nervous System

The autonomic nervous system has two major divisions—the **sympathetic** and **parasympathetic** (Figure 73). The main control center in the brain for the autonomic system is the hypothalamus. The sympathetic system organizes and regulates the body's response to stress. For example, sympathetic neurons enable blood vessels to constrict, speed up heartbeat, dilate our pupils, stimulate secretion by our sweat glands, and prepare us to respond to emergencies— the so-called "flight or fight" reaction. The parasympathetic system organizes the body's responses that save energy and balances the body's various systems. It slows the heartbeat, constricts the pupils in our eyes, dilates or expands blood vessels, stimulates digestion, and generally prepares the body for relaxation and rest.

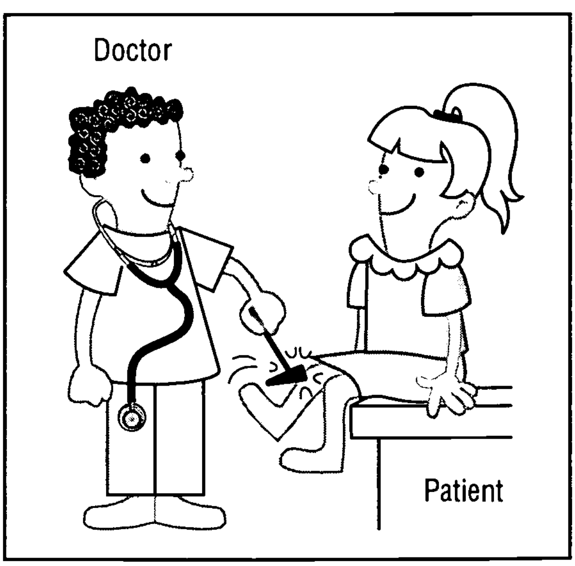


Figure 19 *Diagram of involuntary or reflex action.*

These **responses** are called involuntary or reflex actions (Figure 19) because they occur automatically to integrate and coordinate the autonomic system's responses. The microgravity environment changes these responses, which may cause problems for the astronauts. One problem is feeling faint and light-headed shortly after flight because of low blood pressure. Since the autonomic control of circulation changes in a microgravity environment, the Neurolab scientists studied how the regulation of functions, such as blood pressure and blood flow to the brain is changed in space.

Sleep and Circadian Rhythms

There are daily rhythms to many of our bodily functions. Many of these rhythms run on an appropriate 24-hour cycle that is called "circadian rhythm." These rhythms persist, even if one lives in a dark place and does not know the time of day. Circadian rhythms are closely linked with sleep, and their disruption can easily disturb sleep.

Scientists agree that the "master clock" for circadian rhythms is located in the suprachiasmatic nucleus, which forms part of the hypothalamus. The suprachiasmatic nucleus receives information from our eyes, and this information is used to synchronize our circadian rhythms with sunlight.

Astronauts sometimes have trouble sleeping on Shuttle Missions. The Neurolab scientists studied the astronauts' circadian rhythms to learn why sleep is disrupted in space. They also examined the effectiveness of the hormone melatonin (which is involved with sleep) as a sleep aid, and studied how changes in breathing caused by microgravity, affected the astronauts' sleep.

Neurolab Lessons & Activities

The Scientific Method

Lessons and Activities

GRADES 5–12

Part II

The Scientific Method

Scientists aim to gain knowledge and reach an understanding of the world around us. To achieve this goal, scientists must be curious, make observations, ask questions, and try to solve problems. Early scientists tended to draw conclusions from observations that were largely speculative (e.g., the Earth was flat or that the sun circled the Earth). By the mid-sixteenth century, some scientists began to realize that far more knowledge could be obtained by using a systematic approach to obtaining information and solving problems.

One ground-breaking scientist was Andreas Vesalius (1514–1564), the first physician to write an extensive text about human anatomy based on meticulous dissections of human bodies. In 1620, Sir Francis Bacon published his *Novum Organum* in which he attempted to provide a complete method for studying science. From these early beginnings, the Scientific Method evolved as an orderly, systematic process for solving problems.

By the mid-nineteenth century, Charles Darwin and other scientists were following what has become the modern scientific method. According to this method, the first step is to speculate or create a hypothesis. The second step consists of carrying out experiments and/or making comparative observations to test the hypothesis.

Steps of the Scientific Method

1. Identify the problem
2. Collect information about the problem
3. Propose a hypothesis
4. Test the hypothesis by conducting experiments, making comparative observations, and collecting data
5. Evaluate the data collected through investigation
6. Draw conclusions based on data and determine whether to accept or reject the hypothesis
7. Communicate results and ask new questions

The **problem** is a statement of the question to be investigated. Observations and curiosity help to define exactly what problem should be investigated and what question(s) answered. Once a problem is defined, a scientist should collect as much information as possible about it by searching journals, books and electronic information sources. This information will provide a basis for forming the hypothesis.

A **hypothesis** is often considered to be an "educated guess." The word "guess" is inappropriate, however, because a hypothesis should be based on information gathered. A hypothesis can be defined more accurately as a "proposed answer to the problem." The hypothesis is then tested through experimentation and observation. The results of experimentation provide evidence that may or may not support the hypothesis.

To be effective, experiments must be properly planned. The plan is called the **procedure**, which describes the things that actually will be done to perform the investigation. This is where decisions are made about which variables will be tested and which will be kept constant, what to use as a control, how many samples to use, how large the sample sizes should be, safety precautions needed, and how many times to run the experiment. Many scientists investigate questions that cannot be answered directly through controlled experiments in laboratories. For example, scientists studying global warming, the AIDS epidemic and losses of biodiversity must use comparative methods to examine differences that occur in the natural world.

When developing the procedure for an experiment, consider the following:

1. Test only one variable at a time.

A scientist wanting to find out "why trees shed their leaves in the fall" would have to consider the factors that affect trees, such as the type of tree, the amount of water they receive, the temperature, the length of daylight to which they are exposed, and the type of soil in which they are growing. These are the variables which can cause changes to occur in an experiment. To obtain reliable results, only one variable should be tested at a time. All others should be kept constant, whenever possible.

If the scientist's hypothesis states that shorter daylight hours cause trees to shed their leaves in the fall, trees of the same age should be tested. They should be placed in the same size pots with the same type of soil, given the same amount of water, and kept at the same temperature. The only thing changed should be the number of hours of light to which different groups of trees are exposed. Any variable that the experimenter chooses to change, such as the hours exposed to light, is referred to as the **independent variable**. The change in the experiment that happens as a result of the independent variable, such as the length of time that it takes for the leaves to fall, is referred to as the **dependent variable**.

2. Use controls.

The **control** is used for comparing the changes that occur when the variables are tested. If a number of young oak trees are placed in a greenhouse and exposed to 10 hours of light to simulate fall conditions, how will the scientist know if a loss of leaves is due to the amount of light? It could be due to the temperature that he/she chose, or the amount of carbon dioxide in the air. To avoid such uncertainty, two identical experiments must be set up: one in which the trees are exposed to 10 hours of light and the other, the control, in which they are exposed to light for a longer period of time to simulate summer conditions. All factors for the control are exactly the same as for the test, except for the variable being tested, the amount of light given to each tree.

3. Use several samples.

Using a number of samples prevents errors due to differences among individuals being tested. Some trees are more hearty than others. If only a few trees are tested, some may lose leaves for reasons that are not related to the amount of light. This will produce misleading results. Larger numbers of samples will provide more accurate results.

4. Always use appropriate safety measures.

Safety measures to be followed vary according to the type of experiment being performed. For example, laboratory-based experiments frequently require that participants wear protective clothing and safety goggles, and that dangerous volatile chemicals be used only under a vented fume hood.

5. Repeat the experiment several times.

To make valid conclusions, the scientist must have reproducible results. Ideally, comparable results should be obtained every time the experiment is run.

After the plan, or procedure, is complete, the experiment is run. It is essential that careful and accurate records be kept of all observations during an experiment. The recorded observations and the measurements comprise the **data**. It is always useful to present data in the form of charts, tables, or graphs, as these provide a visual way to analyze and interpret the results (Figure 20). When drawing graphs, the independent variable is conventionally plotted on the horizontal axis, and the dependent variable is plotted on the vertical axis.

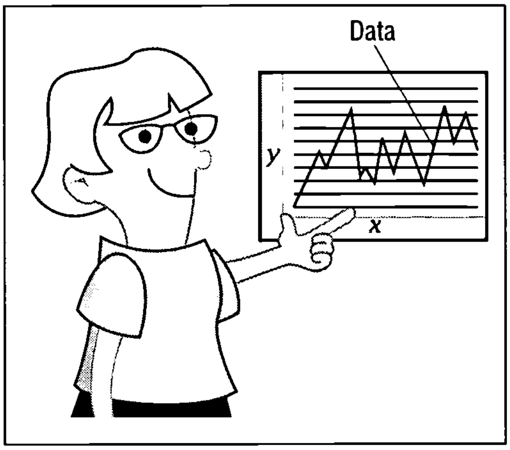


Figure 20 *Diagram of teacher using graph representing data.*

Analysis of data from the experiment allows the scientist to reach a **conclusion**. The scientist determines whether or not the data support the hypothesis and decides whether to accept or reject the hypothesis. The conclusion should provide an answer to the question asked in the problem. Even if the hypothesis is rejected, much information has been gained by performing the experiment. This information can be used to help develop a new hypothesis if the results repeatedly show that the original hypotheses is inappropriate.

After performing many investigations on a particular problem over a period of time, a scientist may come up with an explanation for the problem, based on all the observations and conclusions made. This is called a **theory**. A Scientific Theory is an explanation, supported by data, of how or why some event took place in nature.

Students should be encouraged to understand that the scientific method can be applied to solving everyday problems, such as "Under what conditions do I study best?" or "What type of lunch box will keep my lunch coldest?" The activities in this manual allow students to understand and experience many of the problems addressed, and hypotheses proposed, by Neurolab scientists. Activities, such as the Escher Staircase (Pages 95 – 99), simulate actual experiments that were performed on board Neurolab. It will be exciting for students to compare the results of the control experiments performed on Earth with the results of tests performed in space.

LEARNING ACTIVITY I:
Introduction to the Scientific Method

OVERVIEW

Students will learn to make observations, formulate hypotheses and design a controlled experiment, based on the reaction of carbon dioxide with calcium hydroxide.

SCIENCE & MATHEMATICS SKILLS

Making and recording qualitative observations, drawing conclusions

PREPARATION TIME

10 minutes to gather equipment; 30 minutes to prepare calcium hydroxide solution

Preparation of one liter of lime water (Teacher should prepare a day ahead of time):

MATERIALS

- 10 grams calcium hydroxide powder
- One liter of water
- Filter paper
- Filter funnel
- Large bottle (2 liters)
- Flasks or small bottles

1. Add 10 grams calcium hydroxide $Ca(OH)_2$ powder to one liter of water.
2. Cover and shake well. Calcium hydroxide is very slightly soluble in water and 10 grams will provide more solid than will dissolve.
3. Allow the suspension formed to settle for a few minutes.
4. To separate the lime water from the suspension, use a filter paper and filter funnel apparatus to filter the suspension.
5. If the lime water filtrate is still slightly cloudy, filter for a second time, using a new filter paper.

$Ca(OH)_2$	=	Calcium Hydroxide
CO_2	=	Carbon Dioxide
$CaCO_3$	=	Calcium Carbonate
H_2O	=	Water
H_2CO_3	=	Carbonic Acid Gas
Ca^{++}	=	Calcium

MAJOR CONCEPTS

- Our exhaled breath contains carbon dioxide gas.
- The carbon dioxide we exhale reacts with calcium hydroxide in solution to form insoluble calcium carbonate and water.*
- Formation of calcium carbonate precipitate can be used as a test for the presence of carbon dioxide.
- If carbon dioxide continues to be bubbled into lime water (calcium hydroxide solution) after a period of time, the white precipitate disappears. The excess carbon dioxide forms carbonic acid in the water and the calcium carbonate reacts with the carbonic acid to form calcium ions and bicarbonate ions, which are soluble in water.†

* $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

† $CaCO_3 + H_2CO_3 \rightarrow Ca^{++} + 2HCO_3$

6. Keep the lime water tightly closed when not in use, as it will react with carbon dioxide from the air and become cloudy.
7. The calcium hydroxide and water suspension can be stored in a large bottle, and lime water filtered off when needed.
8. The filtered lime water can be stored in smaller bottles or flasks, 500 milliliters in volume, for use in class. One (1) liter will be sufficient for one class of 24 students for days one and two.

CLASS TIME

Two or three periods of 40 – 45 minutes

MATERIALS
Day 1: Per student

- 1 plastic test tube, 50 milliliters (ml) in volume
- 1 straw
- 10 – 15 ml lime water solution (calcium hydroxide solution)
- Goggles

MATERIALS
Day 2 and Day 3: Per student

The materials will vary depending on the design of the students' experiments. All students will require test tubes, lime water, foil, and straws.

BACKGROUND

Carbon dioxide comprises only 0.033 percent of Earth's atmosphere, yet it is the principle inorganic source of carbon for living organisms. Carbon dioxide and water are the raw materials required by plants for the synthesis of sugars through photosynthesis. Organisms release carbon dioxide back into the atmosphere as a waste product of respiration and other cellular processes.

This activity allows students to test for the presence of carbon dioxide in exhaled air. On Day 1, each student will blow through a straw into a solution of calcium hydroxide. The carbon dioxide in the air will combine with the calcium hydroxide to produce a white precipitate of calcium carbonate. Students will compare their solutions to those of the teacher, in which a precipitate will not be visible. (Students will not immediately be able to observe that if they continue to blow into the calcium hydroxide solution, the white precipitate will disappear.) Students will then generate hypotheses to explain the divergent results.

The second part of this activity (Day 2) involves designing an experiment to test the hypotheses determined in the class discussion on Day 1. It may be handled in different ways depending on the age of the students.

GRADES 10–12

For homework, have each student (or team of students) formulate a hypothesis to explain why they had a precipitate and the teacher did not. They should design a simple controlled experiment to test the hypothesis. On Day 2, review students' procedures and allow them to perform their experiments, record their observations and draw conclusions. Grades 10 – 12 should be able to complete the activity in two days, grades 5 – 9 in three days.

GRADES 7–9

Have students work in groups of three to four to formulate a hypothesis about the disappearance of the precipitate and design an experiment to test the hypothesis. Encourage each group to investigate a different variable. The hypothesis and procedure proposed by each group should be presented to the class and discussed, based on the questions on pages 41 – 42 under Day 2. The students will then run the experiments they designed on Day 3.

FOR GRADES 5–6

Before proceeding, have the whole class participate in a teacher-directed discussion to determine possible hypotheses about the precipitate and how to design experiments to test each hypothesis. This will help to prepare them to conduct their experiments the next day.

Note to Teacher: *The students' answers to the discussion questions will vary, depending on the hypothesis tested and the design of the experiment. The questions are intended to be a check list to help students determine whether or not they have designed a valid experiment.*

DAY 1

PROCEDURE

1. Explain to students that it is important for scientists to make careful observations, and inform them that they will practice making observations.

2. Direct each student to fill a test tube with 15 ml of the calcium hydroxide solution that you have prepared in advance and to use a straw to bubble their breath into the liquid slowly. (Make sure that the solution is clear.) Caution them against blowing into the liquid too vigorously.

   Note to Teacher: *For grades 5 and 6, the test tubes of liquid could be set up ahead of time. Students should wear goggles while bubbling into the solution.*

3. Have the students observe the solution after blowing through the straws for approximately 1 – 2 minutes. Students should record their observations in their notebooks. Explain that these observations will make up students' data.

   Note to Teacher: *Most students will get a white precipitate and stop bubbling. Those in higher grades may know exactly what happened.*

4. Use the following questions as a basis for a class discussion.
   - **What gases are present in exhaled air?**
     Carbon dioxide gas (nitrogen, water vapor and small amounts of oxygen are also present).
   - **What is the clear liquid?**
     Lime water
   - **How can we test for the presence of carbon dioxide?**
     Bubble the gas into the lime water.
   - **What is a positive test for carbon dioxide?**
     Carbon dioxide turns clear lime water cloudy.
   - **Why is a precipitate formed?**
     Lime water is a solution of calcium hydroxide. It chemically reacts with carbon dioxide to form solid calcium carbonate (chalk).

5. When the students are convinced that they know exactly what happened, bring out the "teacher's results." Explain that you did the exact same experiment, but got very different results! Your test tube has no white precipitate—it is clear. The class now has a problem to solve: **How can there be no white precipitate when the teacher performed the same experiment?**

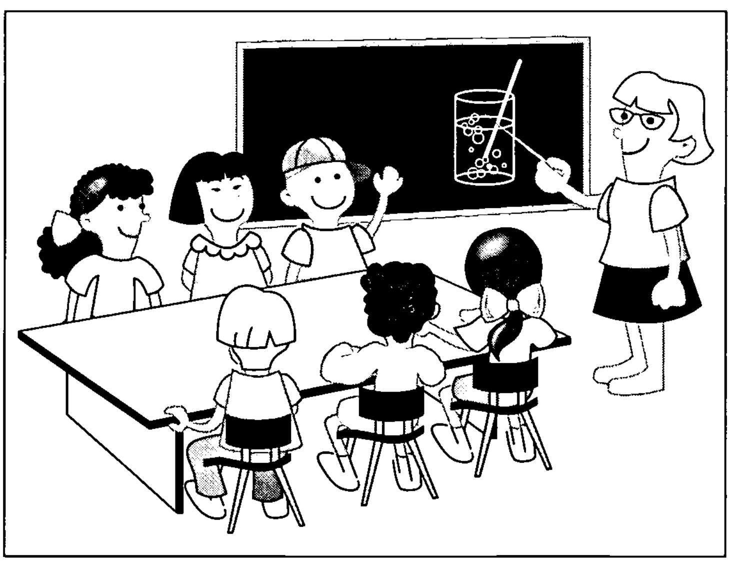


Figure 21 *Diagram of teacher-directed discussion with class.*

6. Discuss with students what factors might affect the production of a precipitate. (DO NOT tell the students how you obtained your results.)

   Possible answers might be:
   - Time—how long exhaled air was bubbled into the solution.
   - Adults vs. teenagers.
   - Rate of bubbling.
   - Light vs. dark.
   - Temperature of the liquid.
   - Any other conditions at time of breathing.

7. Explain that all of the factors identified by students are known as **variables**.

DAY 2

PROCEDURE

1. Use the following questions to guide students or groups of students in the development of their hypotheses and experimental designs.

- **Does the hypothesis offer an answer to the problem?**
  Yes it does. The problem was, "Why was there no white precipitate when the teacher performed the experiment?" The hypothesis states that the teacher may have exhaled into the solution for a longer time than the students.

- **Does the experiment have a control?**
  Yes. The control is the average length of time that the students exhaled into the solution of lime water (possibly about one minute).

- **Which materials are needed? Are the materials readily available?**

- **What conditions are being kept constant?**
  The conditions kept constant are the temperature of the liquid, the size of the straws, the rate of bubbling into the liquid and the amount of lime water used for each test.

Exhale Time (observations)	Amount of Precipitate
0.25 min.	+
0.5 min.	++
1.0 min.	+++
1.5 min.	+++
2.0 min.	+++
2.5 min.	+++
3.0 min.	++
3.5 min.	++
4.0 min.	+

Figure 22 *Sample of data sheet for recording precipitate.*

- **What is the independent variable being tested?**
  This is the variable that the experimenter chooses to change. In the example given, it is the increased length of time that the students choose to exhale into the lime water.

- **What is the dependent variable being measured?**
  The dependent variable is the amount of precipitate present after exhaling into the tube of lime water.

- **How will each group present its data?**
  The data may be presented in the form of a chart (Figure 22).
  This can be indicated by using + to represent the density of the precipitate.

DAY 3

1. Allow individuals or teams of students to perform their experiments, collect data and draw conclusions. A post-experiment discussion is recommended to review the conclusions made by each group. Each group's experiment should be evaluated based on the appropriateness of the experimental design to test the group's hypothesis (not whether the group actually found the "correct" solution).

2. For a typical experiment to test the hypothesis that "the length of time that air was blown into the solution" caused the teacher's results to be different, each student in a group of four should use the same size tube, the same amount of lime water, run the experiment at the same temperature, use the same size straws and attempt to bubble at the same rate. Students could estimate how long they exhaled into their liquid the first day. This could be the control time. One student in each group could blow into his/her tube for the control time. Each following student in the group could increase his or her time by two to four minutes.

POST-LAB DISCUSSION

3. Compare the experiments performed by each group of students. For each experiment designed, discuss the variable tested, the control, the factors kept constant, and the results obtained. Note that the amount of lime water used, and the size of the straws and test tubes should be the same for each experiment. A chart, such as the one below, can be developed on an overhead projector.

Independent Variable Tested	Control	Constants	Observations
1. Length of time breath was bubbled into the solution (from .25 mins. to 4 mins.)	2 mins.	Room temperature Bubble slowly Keep tube in the light	The precipitate formed, increased, then decreased
2. Temperature of the water (warm/cold)	Room temperature	Bubble for 2 mins. Bubble slowly Keep tube in the light	Precipitate formed, did not decrease
3. Rate of bubbling (slowly/quickly)	Bubble slowly	Room temperature Bubble for 2 mins. Keep tube in the light	Precipitate formed, did not decrease
4. Amount of light (light/ dark)*	Keep tube in the light	Room temperature Bubble for 2 mins. Bubble slowly	Precipitate formed, did not decrease

Figure 23 *Example of chart comparing experiments.*

* *Cover test tube with foil to create darkness.*

4. From the class observations, it can be seen that only the length of time affects the amount of precipitate formed. At this point, explain that excess carbon dioxide bubbled into lime water forms carbonic acid which dissolves the precipitate of calcium carbonate.

The use of the scientific method to systematically test different hypotheses will enable the students to determine which hypothesis is correct in answering a problem.

Developmental and Cellular Neurobiology

Lessons and Activities

GRADES 5–12

Section I

Developmental and Cellular Neurobiology

TOPIC

Recent studies have shown that microgravity has an effect upon normal development and function of nerves and muscle.

How will prolonged space flight alter development and normal function of the human neuromuscular system?

INTRODUCTION

The human body is composed of three muscle types: skeletal, smooth, and cardiac muscles (Figure 24). **Skeletal muscle** controls all voluntary movement, such as walking, sitting, or throwing a ball. **Smooth muscles** perform unconscious or involuntary motions, such as moving food through the digestive system. **Cardiac muscle** is heart muscle which is responsible for pumping blood through the body. All three muscle types differ from each other in how the nervous system transmits signals to them and in the types of molecules present within the muscle cells.

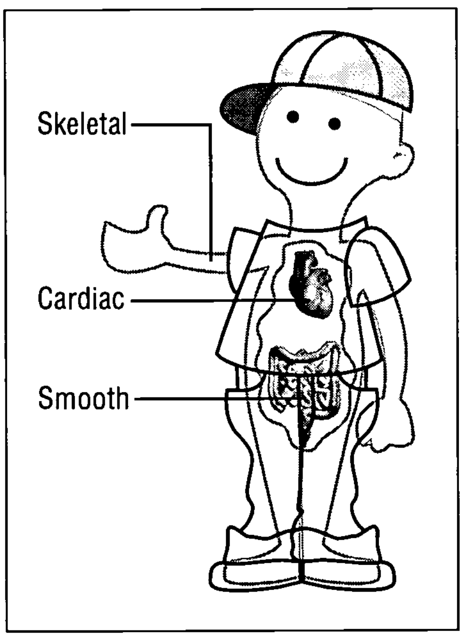


Figure 24 Diagram of three muscle types.

Skeletal muscles that are involved in standing and walking are referred to as weight-bearing muscles. Scientists believe **weight-bearing muscles** are profoundly affected by exposure to microgravity. Weight-bearing muscles also consist of two different fiber types known as **slow (or red)** and **fast (or white) twitch muscles.** The two different muscle types are involved in specialized types of movement and activity of neurons of the central nervous system are believed to influence which type of fiber the muscle will become.

The capacity to perform detailed experiments on both human and animal subjects in space provides fascinating opportunities to investigate functional changes in the absence of gravity's effects. Is gravity necessary for normal development and function of skeletal muscle? Does the nervous system require gravity to make functional contact with weight-bearing skeletal muscle correctly? Does gravity alter the manner in which the nervous system communicates with muscle? Experimental research can provide invaluable information about the underlying mechanisms of gravity's effect upon human physiology. The Neurolab team investigated how space flight and microgravity affect the nervous system and its interaction with skeletal muscle.

Things to Know

OVERVIEW OF THE SKELETAL NEUROMUSCULAR SYSTEM

Weight-bearing muscles are attached to the bones of the body by tendons. Both slow twitch (red) and fast twitch (white) weight-bearing muscles control body movement by contraction (becoming shorter). The muscles contract as a result of signals from neurons that are connected to the muscle fiber.

Neurons are the basic unit of the nervous system (Figure 25). Each neuron consists of a cell body with extensions that either send information (axon) or receive information (dendrite). Neurons that send contraction signals to the muscle are known as **motor neurons** and are located in the spinal cord. The motor neuron's axon reaches skeletal muscle early in development and

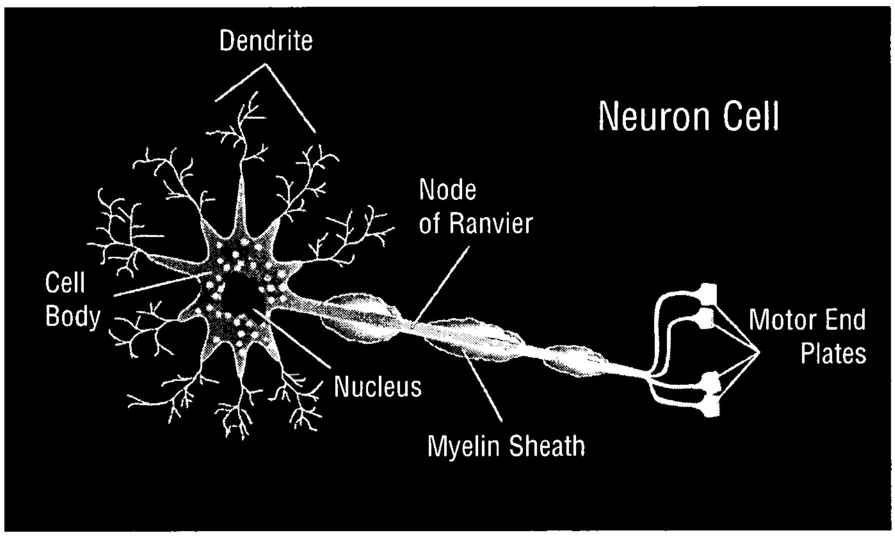


Figure 25 Diagram of a neuron cell.

forms a specialized connection known as the **motor end plate** (Figure 25). Scientists believe that axonal signals transmitted from motor neurons to the muscle fiber will determine whether the muscle fiber will become either a slow twitch or fast twitch type. Slow and fast twitch muscles manage different types of motion necessary to function in gravitational fields.

Slow twitch (red) muscles have a rich blood supply and are capable of endurance activities, such as marathon running or standing for prolonged periods. In contrast, fast twitch (white) muscles have a more limited blood supply and are specialized for very fast contractions and forceful movements like lifting heavy weights. In addition, fast twitch muscles fatigue easily. Exposure to microgravity will cause both slow and fast twitch weight-bearing skeletal muscles to shrink. However, slow twitch weight-bearing muscles appear to be more vulnerable to microgravity.

DEVELOPMENT OF THE NEUROMUSCULAR SYSTEM

Motor neurons make connections with muscles early in development. The ability of the neuron to find the muscle and make a connection (synapse) is highly controlled by signals present during the developmental period. When the neuron first contacts its target muscle, it will make more synapses than it requires. Once the muscle matures, the extra synapses are eliminated and the muscle will become either a slow or fast twitch fiber. Maturation into either a slow or fast twitch fiber will determine whether the muscle can perform such functions as standing for prolonged periods in a normal gravitational field or briefly lifting a very heavy weight.

How does microgravity affect neuronal function?

Scientists are studying how microgravity will affect developmental signals from the neuron to the muscle. It is possible that gravity is required for the neuron to form functional motor end plates and behave normally.

DEVELOPMENT OF MOTOR SKILLS

The development of motor skills, such as walking, requires maturation of the neuromuscular system. As these systems develop and become more coordinated, the ability to walk develops over a definite sequence of milestones: the baby lifts its head, then successively supports its body with its arms, turns over, sits up, crawls then walks with assistance (Figures 26A, 26B and 26C). Finally, the baby learns to walk alone. This sequence occurs as muscle and bone strength increase and the nervous system becomes calibrated to control the timing and strength of muscle activity and interpret the incoming sensory signals. Just as one must practice baseball or the piano to play well, it is also necessary to practice to learn how to stand up, walk, jump, and run.

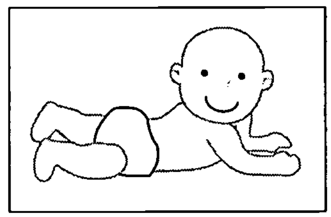


Figure 26A Diagram of baby supporting body with arms.

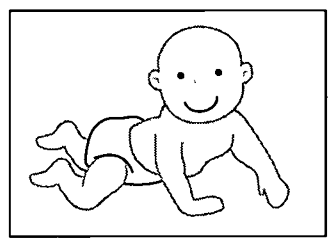


Figure 26B Diagram of baby crawling.

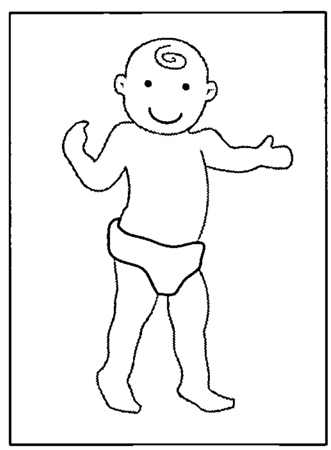


Figure 26C Diagram of baby walking alone.

At each step in the process of learning to move in a coordinated fashion, the baby is developing in the presence of Earth's gravity. In microgravity, important developmental signals from the neuron to the muscle may be altered during the critical developmental period making it difficult for this motor system to develop. Experimental studies in microgravity will help scientists determine what role gravity plays in the normal development of human neuromuscular systems.

LEARNING ACTIVITY I:
What Cells Can I See in Muscle and Spinal Cord Tissues?

OVERVIEW
Students will observe, on a prepared slide, cells of muscle and spinal cord tissues.

SCIENCE & MATHEMATICS SKILLS
Observing, comparing, describing, drawing conclusions

PREPARATION TIME
10 minutes

CLASS TIME
50 minutes

MATERIALS
Each student or group of students will need:

- A compound light microscope
- Prepared slides of skeletal muscle and spinal cord tissues (preferably a cross section and longitudinal section)

MAJOR CONCEPTS

- To distinguish between cell types that make up spinal cord and muscle tissues.
- To observe and distinguish the nuclei of cell types and how nuclei differ between muscle cells and motor neurons.

BACKGROUND

The body's motor systems require specialized cells to perform coordinated movement. Skeletal muscle cells fuse during development, forming cylindrical fibers. As a result, muscle fibers are multinucleated (more than one nucleus). The motor neuron sends an axon out of the spinal cord through the nerve and attaches to the muscle to form a motor end plate.

The Neurolab scientists attempted to identify the primary changes that occur in motorneurons and muscle fibers in the microgravity environment. They conducted experiments with frozen, stained muscle fibers and spinal cord tissue from rats that were flown into space. To conduct these experiments, the microscope was used to examine histological sections of muscle fibers and spinal cord tissues. Analysis determined whether the fibers were smaller or whether the neuronal cell body was altered.

This activity will allow you and your students to observe cells in muscle and spinal cord tissues under the microscope.

PROCEDURE

1. Students should be familiar with using the microscope (Figure 27) before carrying out this activity.

2. Divide class into groups of 2 – 4 students. Each student group should have one microscope, which they should check to make sure is clean and working properly.

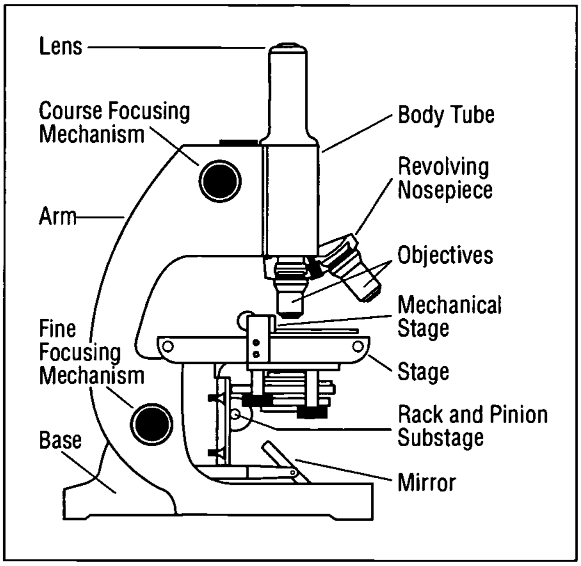


Figure 27 Diagram of a microscope.

3. Give each group five prepared slides. Each group should have one slide of rat muscle tissue and four slides of rat spinal cord tissue regions.

4. Instruct the students to use two different magnifications and sketch the cells they observe on a copy of the Student Activity Sheet at the end of this activity. Students should record the magnification used for each sketch.

5. Have students find and label the nuclei and the cytoplasm for each tissue. Also have them identify and label all other parts of the cells.

6. Make overhead transparencies or photocopies of the photographs (Figures 28 and 29) and allow students to compare their sketches to the photographs. Ask students to describe as many differences and similarities between the cells in the two tissues as possible. Have them report the number of cells that were observed of each tissue type.

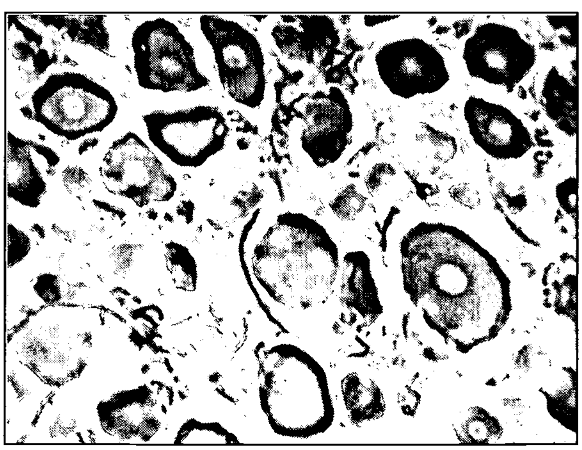


Figure 28 Photograph of a magnified spinal cord cell (x200).

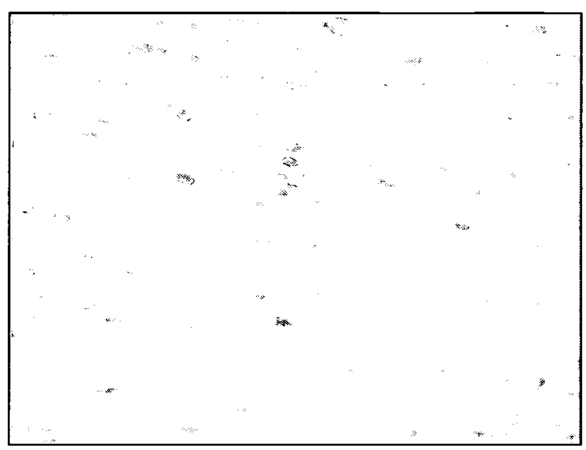


Figure 29 Photograph of a magnified smooth muscle cell (x248).

Evaluation

REVIEW QUESTIONS

1. **Describe the shapes of muscle cells.**
   Muscle cells are elongated in shape. The nuclei are fairly uniform.

2. **Do muscle cells look different from spinal cord cells? How do they differ?**
   Yes. The muscle cells are elongated cylinders and the spinal cells are somewhat circular.

THINKING CRITICALLY

1. **If the Neurolab scientists found differences in shapes and/or sizes of these types of cells during their mission, what might this mean about microgravity?**
   If the Neurolab scientists found differences in shapes and/or sizes, it may indicate that microgravity had affected the development or maturation of these cells.

2. **How do you think microgravity may affect human muscle and spinal cord cells?**
   Microgravity may affect human muscle and spinal cord cells by changing the number of cells during the cell division stage of development or by altering the shape and size during change in development.

SKILL BUILDING

1. Obtain slides of human skeletal muscle and human spinal cord tissues and have students compare these to rat tissue.

2. Obtain slides of cardiac and smooth muscles for students to observe. Have them compare these to the slides of skeletal muscle.

Note to teacher: Prestained slides may be obtained from:

Science Kit & Boreal Laboratories Phone: 1-800-828-7777 Fax: 1-800-828-3299 www.sciencekit.com	**Muscle tissue**, cat. #69178-05 (price: approximately $6.00 ea.) **Spinal cord tissue**, cat. # 69242-03 (price: approximately $5.00 ea.)
Wards Natural Science Phone: 1-800-962-2660 Fax: 1-800-635-8439 www.wardsci.com	**Muscle tissue**, cat. #33W3542 (price: approximately $6.00 ea.) **Spinal cord tissue**, cat. # 93W3699 (price: approximately $5.00 ea.)

STUDENT ACTIVITY SHEET
What Cells Can I See?

Name ______________________________ Date ____________

OBJECTIVE To compare and contrast the cells of smooth muscle and spinal cord tissues.

DIRECTIONS Obtain a group of prepared slides from your teacher. The teacher will give your group a microscope (Figure 30) for you to observe the cells on the prepared slides.

PROCEDURES

1. Your group should have one microscope. Check to make sure that the microscope is clean and working properly.
2. You should have five prepared slides. One slide of rat smooth muscle tissue and four slides of four regions of rat spinal cord tissue.
3. Use two different magnifications and sketch the cells you observe. Record the magnification used for each sketch. (First use the lowest magnification lens, then rotate to the next magnification.)
4. Find and label the nuclei and the cytoplasm for each tissue. Also identify and label all other parts of the cells.
5. Compare your sketches to the photographs or transparencies provided. Describe as many differences and similarities between the cells in the two tissues as possible. Report the number of cells that you observe of each tissue type.
6. After you have completed the muscle tissue, repeat procedures 3 through 5 using the four regions of the spinal cord tissue slides.

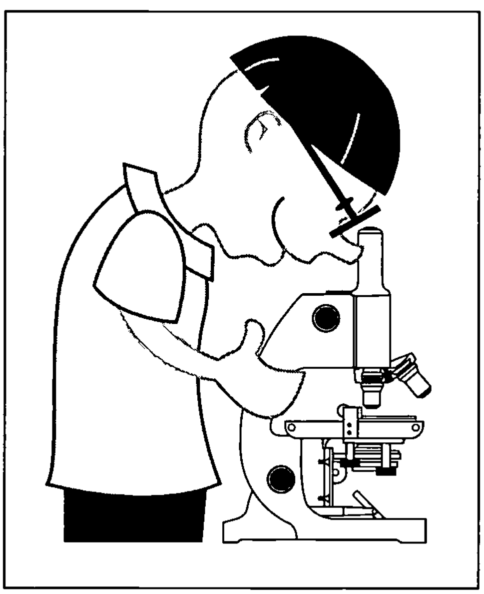


Figure 30 Diagram of student looking through a microscope.

Page 2

Name ______________________________ Date ______________

Muscle Tissue

MAGNIFICATION 1: ______________ **MAGNIFICATION 2:** ______________

Diagram of muscle (sketch) Diagram of muscle (sketch)

Descriptions of number, shape, and size of cells: ______________________________

Page 3

Name ______________________________ Date ______________

Spinal Cord Tissue Region 1

MAGNIFICATION 1: ______________ **MAGNIFICATION 2:** ______________

Spinal Cord Tissue Region 2

MAGNIFICATION 1: ______________ **MAGNIFICATION 2:** ______________

Descriptions of number, shape, and size of cells: ______________________________

Page 4

Name ______________________________ Date ____________

Spinal Cord Tissue Region 3

MAGNIFICATION 1: ____________ **MAGNIFICATION 2:** ____________

Spinal Cord Tissue Region 4

MAGNIFICATION 1: ____________ **MAGNIFICATION 2:** ____________

Descriptions of number, shape, and size of cells: ______________________________

LEARNING ACTIVITY II:
Target Recognition and Synapse Formation During Development

OVERVIEW

Students will learn that growing axons make more connections than they require during development and will maintain only those connections necessary for correct neuromuscular functioning.

SCIENCE & MATHEMATICS SKILLS

Inferring, problem-solving, observing, drawing conclusions

PREPARATION TIME

10 minutes

CLASS TIME

50 minutes

MATERIALS

Each team or group of 10 – 16 students will need:

- Five – eight sections of colored string (each a different color and cut 10 – 20 feet long)—one piece for every two students on the team.

MAJOR CONCEPTS

- Axons must be able to form permanent connections (synapses) with their targets.
- Growing axons must be able to find and identify proper target cells during development.

BACKGROUND

This lesson focuses on neuron/target muscle recognition in neural development. The axon is the long filamentous part of a neuron leading away from the neuronal cell body. The end of the axon is subdivided into many filaments, which form the motor end plate (Figure 25). When messages are transmitted, an impulse flows from the neuron to the target muscle. Only those synapses which are utilized continuously to perform mature motor functions are maintained.

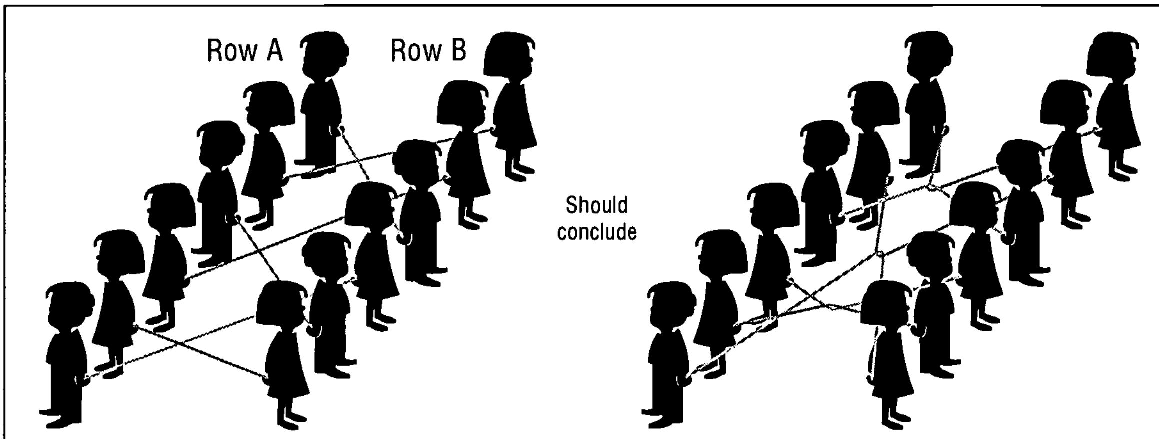
The importance and relevance of gravity's influence on target recognition and synapse formation can be determined through investigations of target selection in space.

PROCEDURE

1. Arrange students in two rows (row A and row B), facing away from each other, with equal numbers in each row. Make sure that the students use string long enough to account for tangling in the middle, as shown in Figure 31. Students in row A will represent axonal growth cones. Students in row B will be target muscles. The appropriate target of each student in row A will be the row B student directly behind him/her.

2. Give each student in row A an end of one of the cut strings.

3. Give the other end of each string to a student in row B. Make sure that none of the strings go straight across to the "proper" student. No correct connections should exist at first, and the strings should be crossed at the outset (Figure 31).



Note: Strings can be tangled in the middle as long as students directly across from each other end up holding the same color.

Figure 31 *Diagram of students demonstrating proper axonal/target connections.*

4. To begin, have the first student in row A (the axonal growth cone) tug on his/her string to simulate the axon searching for its target cells. The student in row B with the other end (an improper target) will not know whether the person tugging is the proper neuron or not.

5. You or another student will act as an observer and provide information about whether the string is connected to the proper target by answering either "yes" or "no," when the row A person tugs on a string. (A proper connection is made when the students across from each other are holding the same colored strings.) If the feedback is "no," ask the student in row B to switch strings with the student next to him/her.

6. Have the first student repeat his/her tug until enough switches have been made to find the "proper" target and elicit the "yes" feedback from you (or the observer).

7. Direct the next student in row A to tug, and repeat the process.

Note to Teacher: The strings in between the student rows will become tangled. This is fine. In reality, neurons are arranged in bundles called nerves. Crossing will inevitably occur, but since the same colored strings eventually will be held by the students across from each other, students will understand that despite their potentially confusing path, the proper connections are made.

8. Have the students try the same procedure, but without saying "yes" or "no." (This exercise will prove that the correct connections cannot be made without proper recognition.)

Evaluation

REVIEW QUESTIONS

1. **What is required for axons to properly connect to their targets?**
   Axonal growth cones are required to specifically recognize the appropriate target.

2. **What happens when any part of the system breaks down?**
   If a part of the system breaks down, improper functioning of the sensory system may occur.

THINKING CRITICALLY

1. **How might microgravity affect the connections made?**
   Microgravity may cause binding at improper sites.

2. **Is there point-for-point correspondence between neurons originating in a certain area and their target areas?**
   Yes. There is point-for-point correspondence because the neurons give rise to the axonal growth cones that specifically form connections to target sites.

3. **How are the specific connections made and maintained?**
   Specific connections are made by forming stable connections through target binding.

SKILL BUILDING

1. Have each student in row A record the number of attempts before connecting with the appropriate student in row B. Have students share their data and compute a class average of the number of attempts necessary.

2. Have students create another signaling system for guiding the connection process in the model.

LEARNING ACTIVITY III:
Motor Skills Development

OVERVIEW

Students will construct a timeline of the development of motor skills in humans by pooling observations of children of different ages. They also will construct an autobiographical account of their own development.

SCIENCE & MATHEMATICS SKILLS

Making and recording qualitative and quantitative observations, creating charts and tables, drawing conclusions

PREPARATION TIME

None

CLASS TIME

30 minutes to explain the activity, which requires one week of observation

MATERIALS

Each student will need:

- Note pad
- Pencil or pen
- Tape recorder (optional)

BACKGROUND

Neurolab experiments tested the hypothesis that gravitational fields are necessary during critical periods of mammalian postnatal development (development after birth) for the normal sequence of motor system development to occur. This hypothesis suggested that space rats (and people) would turn out differently than Earth rats (and people) if they were weightless during certain critical times during their development. Neurolab scientists also used information about normal motor system development to make comparisons with development of motor skills of rats under microgravity conditions.

MAJOR CONCEPTS

- Critical periods exist during the development process in which we must interact with our environments for development to progress normally.
- There is a sequential development of motor skills that takes place over time (e.g., from a baby lifting his/her head, to supporting his/her body with his/her arms, to turning over, to sitting up, to crawling, to walking with assistance, and finally, to walking alone).
- The nervous system accounts for the effects of gravity during the "programming" of the motor system.

Reflexes in Babies

The first steps of the investigation will be to find out the ages of babies and children in each student's family and, if possible, in neighboring families. Based on information available to different class members, the group should be able to choose children of different ages to observe. Using the pooled observations made by students, each student or the class as a whole should be able to apply their observations and make a chart, or "timeline" of normal human development.

Should be elicited by a parent and observed by the student.

GRASP REFLEX The grasp reflex is the easiest baby reflex to observe. If pressure is placed on the baby's hand or foot, the fingers or toes will curl up. The baby will hold tightly onto a finger (Figure 32).

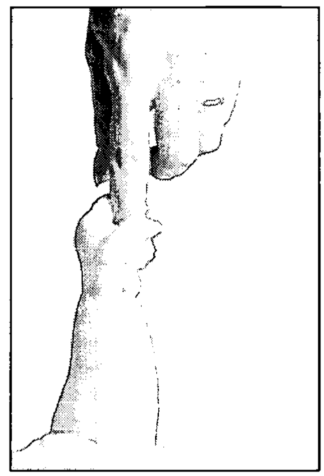


Figure 32 Photograph of grasp reflex.

RIGHTING REFLEX This is a good example of the nervous system developing before muscles do. When a baby is placed in a sitting position, he/she will try to keep his/her head straight. If the neck muscles are not strong enough, the baby will need some help. When the neck muscles develop, the baby will be able to hold his/her head up.

STARTLE REFLEX This reflex can be elicited by an unexpected noise. After hearing a loud noise, a baby's arms and legs move together, then out, then up, then in. At the same time, the hands and legs open and close.

STEPPING REFLEX If a baby is held under the arms while his/her feet are touching a solid surface, the baby will lift one foot up and put it down, followed by lifting the other foot (Figure 33). The same reflex can be observed if the baby's feet are pressed against a couch. This reflex is seen from birth to about six to eight weeks of age, and again between eight and twelve months.

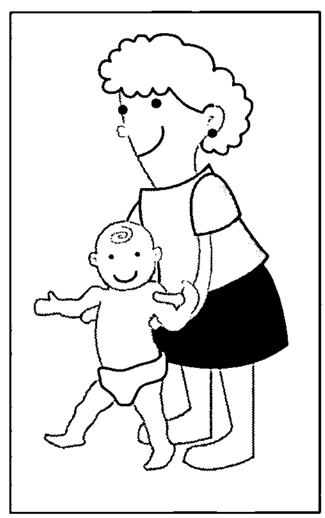


Figure 33 Diagram of stepping reflex.

TONIC NECK REFLEX

If the baby is lying on his/her back and not crying and his/her head is turned to one side, often the arm on the same side will extend while the leg on the other side will flex (Figure 34). This is the same position you see when a right-handed baseball player extends his/her arm up to catch a ball. His/her head will be turned to the right, the right leg will be extended, and the left arm and leg will be bent.

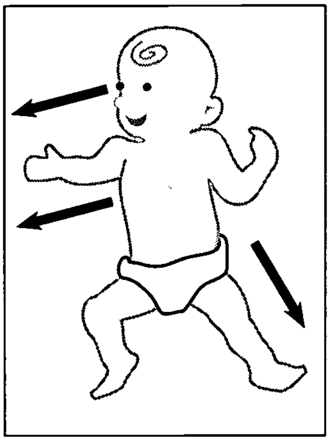


Figure 34 Diagram of tonic neck reflex.

For older students, this activity can be extended to include the study of the development of language among children of different ages. The main objective of the activity is to gather information by observation and to learn that there is a time-related course of human development. Students also will learn whether the development of certain skills depends on strength, the nervous system, or both, and if development progresses in a front-to-back, head-to-tail, or other sequence. Over the course of the activity, students will observe human development, take a "family history" from their parents, and write an autobiography. They will then compare the accuracy of what they learned about human motor development by direct observation, "hear-say" information, and memory.

Note to Teacher: *It is important to emphasize that growth and development is a continuous process and that milestones are not reached at a particular age, but over a range of ages.*

PROCEDURE

Part One: Observing Development

1. Survey the students in the class to determine the numbers and ages of each student's siblings (and younger friends and neighbors). From the list provided, choose babies, toddlers, and children (up to about seven – eight years of age) to include in the activity and to be observed by different members of the class. ***Suggest to the students that their parent(s) or guardian(s) provide this information.***

2. Assign students or groups of students to observe babies, toddlers and young children from the list during the course of the following week.

3. Tell the students to observe their subject(s) carefully, take notes and fill out the class survey sheet, listing development skills and reflexes (see Student Activity Sheet on page 50).

4. If this activity is extended to language development (which may be the most interesting for high school students), tape recorders may be used to document sounds.

5. Based on the class data, have each student or group of students describe the timeline of the acquisition of motor (and language, if applicable) skills in children.

STUDENT ACTIVITY SHEET
Observing Development of Younger Subjects

Name ______________________________ Date ______________

1. What are the "vital statistics" of your subject?

_______ weight
_______ height
_______ weight and length at birth
_______ gender
_______ number of siblings
_______ position in family (what number child?)
_______ twin

2. Can your subject do the following? ***Place a check next to each action your subject can perform.***

Movement

_______ lift head
_______ hold head up and look around
_______ support body with arms
_______ roll over
_______ grab something, hold onto it
_______ sit up with support
_______ sit up without support
_______ reach and pick up a toy
_______ crawl
_______ crawl up stairs

Awareness of Self and Others

_______ follow family members with eyes
_______ smile
_______ laugh
_______ recognize self in mirror
_______ recognize hands
_______ recognize feet
_______ recognize own name
_______ point at things
_______ wave good-bye
_______ copy sounds
_______ say first words

Walking

_______ stand up from sitting or crawling position
_______ stand without falling, if holding onto something
_______ stand alone
_______ walk while holding onto something
_______ walk alone
_______ stand on one foot
_______ jump on one foot
_______ hop
_______ skip
_______ jump
_______ run
_______ walk up stairs

Skilled Movement

_______ eat with a spoon
_______ drink from a cup
_______ drink from a glass
_______ use a knife and fork
_______ throw a ball straight
_______ draw a straight line
_______ make a circle around a drawing of a house
_______ copy a circle, triangle or drawing of a house
_______ catch a ball (if so, what size ball?)

3. How many different kinds of controlled movements can your subject make? __________
Add from above.

Part Two: Autobiographies

1. Have students fill out developmental surveys (as before) about their own development with their parent(s)' or guardian(s)' help (pediatricians often have this type of information from "well child" exams). See Student Activity Sheet on page 53.

2. Student should identify the sources of their information (e.g., self, parent, doctor, document, etc.).

3. Have each student use his or her own developmental surveys to create an autobiographical description of his or her own development from birth until age six.

Evaluation

REVIEW QUESTIONS

1. **Are motor skills acquired in a particular sequence during development?** The acquisition of motor skills follows the development of the nervous system. The nervous system, as well as motor skills, develops from the head down. Babies can control their arms before their legs. This is because the motor cortex, which controls fine movements, develops over a roughly three-month period from 4 – 7 months. The development of sensory ability, such as improved vision is due to development of the connections between the retina and the brain.

2. **What determines the sequence? Is it influenced by age, weight or gender?**
   The sequence is determined by the growth of the nervous system. Since strength is also important, developments of the muscular system also plays an important role.

   For the purposes of this discussion, the sequence is not influenced by gender (although girls and boys develop particular skills at different rates). Weight only plays a role in the case of underweight babies—malnutrition can delay development.

3. **Is there a difference between what one observes and what one remembers? Why?**
   Yes. Relying on memory can be worse than not remembering at all because memory can be selective—we only remember some aspects of our experiences. Also, memory can be incorrect or inaccurate because it is influenced by emotion, by what we expect, or by what we want to remember.

THINKING CRITICALLY

1. If available, have students bring in pictures of themselves between the ages of 0 – 2 years and put the photos on a board. Have students use their data bases (Student Activity Sheet: Observing Your Own Development) to try to guess the ages of their classmates in each of the pictures (Figure 35).

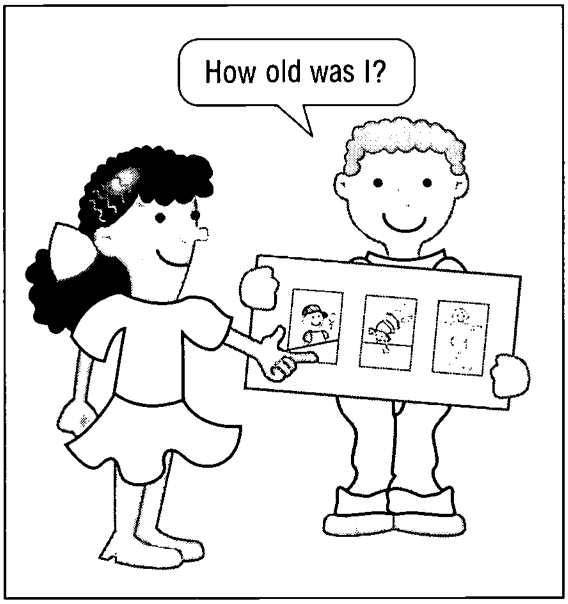


Figure 35 Diagram of student observing development of another student.

2. Is knowledge of the subject's age useful developmental information? Does this requirement vary according to the overall age of the subject (e.g., each hour, day, week, month, or year)?

3. What might happen to a person that developed under microgravity if he/she were exposed to conditions of increased gravity, such as Earth?

   The purpose of the Neurolab experiments was to gather data that would help us answer this question. However, there were some hints from other experiments—it was thought that the motor control and strength of animals that developed under conditions of reduced gravity would be different from those of animals that developed on Earth. As animals learn to walk, the nervous system is fine tuned to the conditions they experience. The fact that babies are born with very little motor control means that what they experience as they gain particular motor skills may influence their development.

   An animal from the Moon visiting Earth for the first time would feel very heavy and would find it hard to move. This is because postural muscles needed to support its body against the force of gravity would be very weak. The circulatory system would also have problems because it would be harder for the heart to pump blood up to the head. The animal might feel faint.

SKILL BUILDING

1. What are the advantages and disadvantages of each source of information used in this activity? What is the accuracy of each source? For example, ask each student about jumping rope.

   - Can your sister, brother, neighbor jump rope?
   - When did the parent of your subject say he/she could first jump rope?
   - Do you remember when you could first jump rope?

STUDENT ACTIVITY SHEET

Observing Your Own Development

(from birth to age six)

Name ______________________________ Date ______________

1. What are your "vital statistics"?

_______ weight
_______ height
_______ weight and length at birth
_______ gender
_______ number of siblings
_______ position in family (what number child?)
_______ twin

2. At what age could you do the following?

Movement

_______ lift head
_______ hold head up and look around
_______ support body with arms
_______ roll over
_______ grab something, hold onto it
_______ sit up with support
_______ sit up without support
_______ reach and pick up a toy
_______ crawl
_______ crawl up stairs

Awareness of Self and Others

_______ follow family members with eyes
_______ smile
_______ laugh
_______ recognize self in mirror
_______ recognize hands
_______ recognize feet
_______ recognize own name
_______ point at things
_______ wave good-bye
_______ copy sounds
_______ say first words

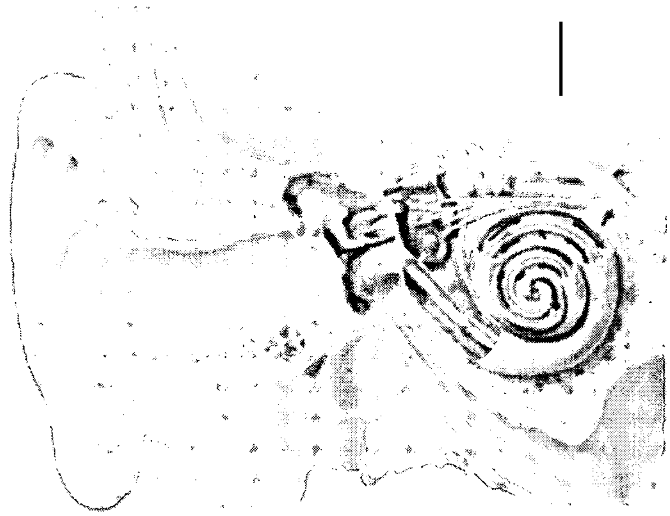
Walking

_______ stand up from sitting or crawling position
_______ stand without falling, if holding onto something
_______ stand alone
_______ walk while holding onto something
_______ walk alone
_______ stand on one foot
_______ jump on one foot
_______ hop
_______ skip
_______ jump
_______ run
_______ walk up stairs

Skilled Movement

_______ eat with a spoon
_______ drink from a cup
_______ drink from a glass
_______ use a knife and fork
_______ throw a ball straight
_______ draw a straight line
_______ make a circle around a drawing of a house
_______ copy a circle, triangle or drawing of a house
_______ catch a ball (if so, what size ball?)

3. How many different kinds of controlled movements could you make? _____________
Add from above.



Vestibular Function

Lessons and Activities

GRADES 5–12

Section II

Vestibular Function

TOPIC

How will the body maintain a sense of balance in space?

The vestibular system is the part of the nervous system that controls balance.

INTRODUCTION

The human body has a remarkable system for maintaining a sense of orientation and equilibrium. Human beings can keep their balance while walking on a tight rope (Figure 36) 100 feet above the ground, doing repeated pirouettes in a ballet performance, and dodging in and out of traffic on a busy street. How does the body calculate and control its movement so precisely?

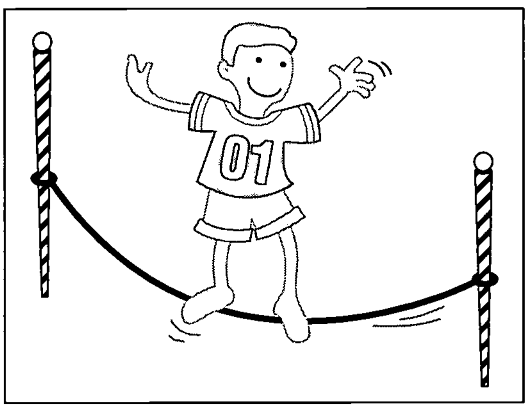


Figure 36 *Diagram of student maintaining balance while walking a tightrope.*

Balance and equilibrium involve constant interpretation by the brain of sensory information coming from all over the body. This information includes visual cues, touch sensations, and signals from the inner ear. Normal movements and stimuli encountered in the every day environment do not upset our equilibrium. However, we all have experienced dizziness and difficulty walking after spinning around in a circle. What causes this disorientation, and how does the body return to equilibrium? Astronauts experience similar sensations of dizziness and disorientation during their first few days in the weightless environment of space. Upon returning to Earth's gravity, they must re-adapt and frequently have difficulty standing upright, stabilizing their gaze, walking, and turning corners. How do different environmental conditions and stimuli affect astronauts' orientation, movement, and equilibrium? The Neurolab team studied these issues to gain a better understanding of the intricate functions of the human balance and sensory systems.

Things to Know

THE VESTIBULAR SYSTEM

One of the most important components in the control of balance is the **vestibular system**. Part of the neuro-sensory system ("neuro" refers to nerves, "sensory" to the senses), the vestibular system processes information about motion (acceleration, movement, and orientation) and helps the body to maintain or restore equilibrium. This system is key to our senses of balance and self-motion and to our ability to distinguish between motion of the body itself and motion of things outside the body.

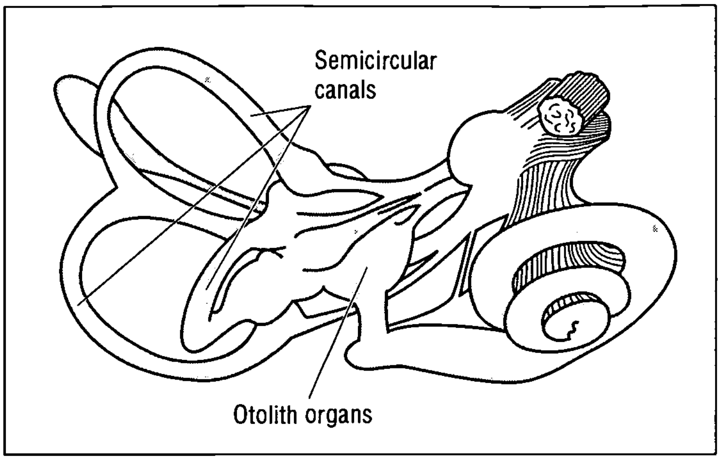


Figure 37 Diagram of the vestibular system.

The vestibular system (Figure 37) is comprised of three semicircular canals, two membranous sacs called **otolith organs** in the inner ear, and areas of the brain that process information from these organs. Within the inner ear, the three **semicircular canals** are shaped like inner tubes of tires. They contain fluid and hair cells. Hair cells have a small organ called the "hair bundler," which is formed by dozens of small hairs. These small hairs extend into the semicircular canals. When the fluid in the canals shifts or moves, the hair cells also bend and signal the brain about the direction in which they are being moved. The brain uses this information to determine the direction and speed in which the body is accelerating or decelerating.

The **semicircular canals** help the body maintain balance and equilibrium and are oriented along three axes. Semicircular canals also help us to maintain our fixed gaze, even in the presence of complex body movements (Figure 38A). One canal is horizontal. Its hair cells are maximally bent when the head is turned in the yaw axis (shaking from side-to-side to communicate "no") (Figure 38B). Another canal is perpendicular to the horizontal axis. It is oriented like the wheels of a bicycle headed straight. The hair cells in this vestibule respond maximally to pitching motions of the head (when the head moves up and down to communicate "yes") (Figure 38C). The third canal is perpendicular to both of the others, and its hair cells are bent most when the head rolls from one side in a "maybe" shrug (Figure 38D).

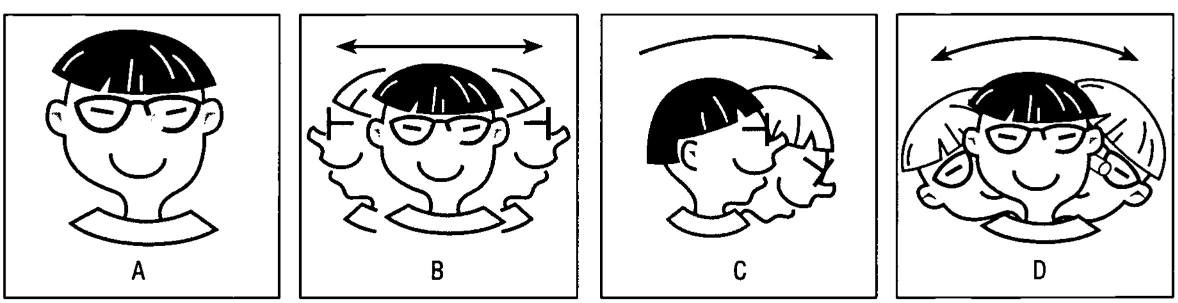


Figure 38 Diagram of how the semicircular canals help the body maintain balance and equilibrium.

Figure 38A Diagram of no movement.

Figure 38B Diagram of yaw axis movement.

Figure 38C Diagram of pitching motion.

Figure 38D Diagram of rolling motion.

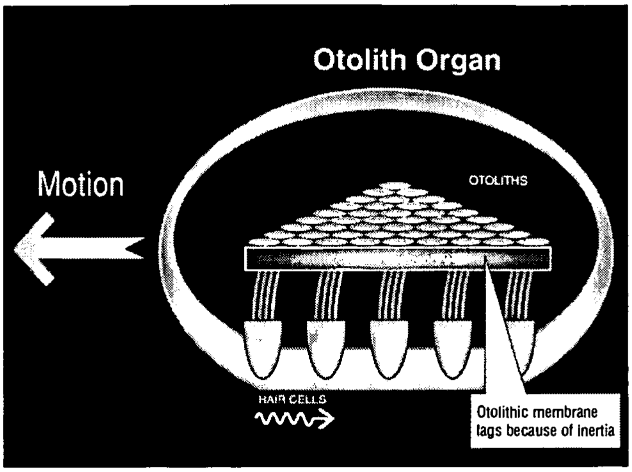


Figure 39 Diagram of a hair cell.

Within the otoliths, the hair cells are stuck into a gelatine-like membrane called the **otolithic membrane**. When the body moves, the otolithic sac moves with it. However, because the otolithic membrane is loaded with rocks (otoliths), inertia causes it to lag (Figure 39). This lag causes the hairs to bend, stimulating the hair cells. When the head tilts, the sac also tilts and the weight of the rocks causes the hairs to bend. This way the otolith sack detects linear motion and tilt.

In addition to the vestibular system, the eyes also play an important role in balance. Visual signals that are sent to the brain provide information about body position and motion relative to one's surroundings. These signals work in concert with those from the vestibular, tactile (touch), and motor (muscles, joints) systems to tell the brain what is happening. The eyes also automatically move in a direction opposite of the head to maintain a stable visual image. This coordination of eye and head movement is called the **vestibular-ocular reflex** and can take various forms. For example, one type of vestibular-ocular reflex, known as **nystagmus**, occurs when a person is spun around and then suddenly stops. The eyes respond by moving in the direction opposite to the direction of spin in an attempt to stabilize the field of vision until equilibrium is restored.

MOTION AND PERCEPTION

The perception of our body's position, known as **proprioception**, is determined through sensors in our joints, skin, and muscles. These sensors detect touch, pressure, movement, and the contraction of muscles. The input from these sensors allows us to determine, or establish, the exact position of most parts of our body and coordinate our movements.

The **coriolis effect** occurs when the head is in motion and constantly changing direction. For example, coriolis effects occur when one is on a boat that is rocking and rolling, or is in an airplane experiencing turbulence, or in a car with soft suspension going around a lot of curves. In these situations, acceleration information is bombarding each of the semicircular canals at the same time. The vestibular organs make connections with many centers, such as the cerebellum (to coordinate motion), and to the eyes (to coordinate head-eye movements). The vestibular organs also make connections with the hypothalamus, which controls many autonomic functions. This connection is responsible for nausea and dizziness when the vestibular system is over-stimulated.

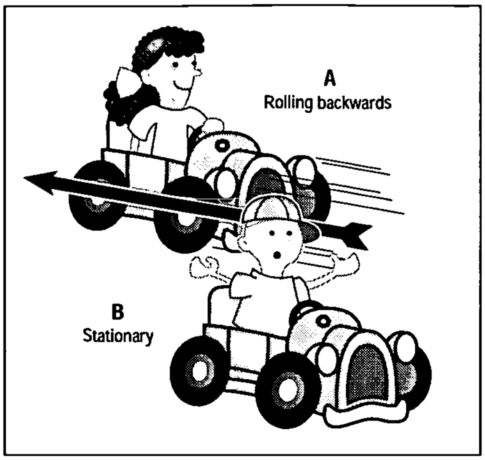


Figure 40 *Diagram of vection.*

Vection is 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. For example, vection occurs while we are sitting in a parked car, reading, or looking ahead. We sometimes "feel" as though the car is rolling, when, in reality, the vehicle next to the car has started moving (Figure 40). Visual cues, especially those located in the periphery of one's vision (things a person can see out of the corner of his or her eye) strongly affect sense of movement, even without any sensations in the inner ear vestibular system, and without any actual movement of the body.

LEARNING ACTIVITY I:
Visualizing How the Vestibular System Works

OVERVIEW

In this activity, students will learn about the effects of different types of motion on the hairs suspended in fluid in the inner ear.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, measuring angles of rotation, calculating averages, creating charts, creating models, drawing conclusions

PREPARATION TIME

15 minutes (at least one day before the activity)

CLASS TIME

50 minutes

MATERIALS

Each group of 3 – 4 students will need:

- One tube of super glue (should be water resistant and adhere to glass and hair-like fibers) OR a hot glue gun and glue sticks
- Automatic turntable (such as for pottery class), centrifuge, or other rotating device (such as a Lazy Susan or old record player)

MAJOR CONCEPTS

- Hair cells within the vestibular system are affected by movement of the head in different directions.
- Movement causes fluid in the inner ear to shift, bending the hairs attached to the hair cells.
- Hair cells send messages to the brain indicating the direction of movement.
- Hair cells specifically are sensitive to changes in the speed or direction of motion.

MATERIALS (cont.)

- 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

BACKGROUND

In this activity, students create a model that permits them to visualize the movement of fluid and bending of hairs in the inner ear in response to motion. It also demonstrates how the vestibular system maintains or restores equilibrium despite movement.

The vestibular system is key to our senses of balance and self-motion.

Located in the inner ear, the vestibular apparatus is comprised of three canals containing fluid and receptor cells, called hair cells. Long hairs extend from the hair cells into the canals and are embedded in the cupula. Motion of the head causes the fluid in the canals to shift or move, which in turn, causes the hairs to bend. The direction of the movement determines the direction in which the hairs are bent. When motion ceases, the vestibular system reacts in the opposite direction until equilibrium is reached again and the hairs are motionless.

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 be bent 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.

PROCEDURE

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 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 41B).
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 the straight position. Have students record the time (Figure 41D).
7. Direct the students to repeat this procedure, with each student taking a turn rotating the cylinder, observing the watch, and recording the time. 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.

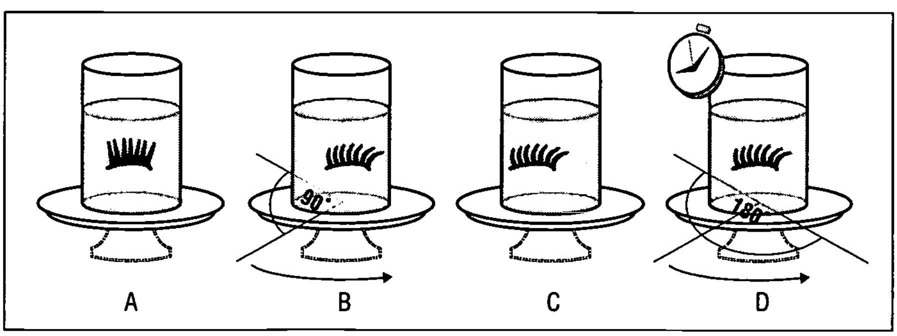


Figure 41 Diagram of furry or wispy material or false eyelash in motion.

Figure 41A at rest. Figure 41B 90° rotation. Figure 41C motionless. Figure 41D 180° rotation.

Figure 42 *Diagram of students observing fuzzy material in action.*

10. Have students present their data from steps 7, 8 and 9 in tabular format (Figure 43).

11. If a rotating device or turntable is available, have students place the cylinder on the device and rotate slowly (so as not to splash or dislodge the eyelashes) at an even rate for one minute (Figure 42). 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.

Understanding the Vestibular System

90 degrees (observations)	180 degrees (time)	90/180 degrees (time)	1 minute rotation (observations)	Person rotating	Person w/stopwatch

Figure 43 *Example of chart to record motion observations.*

EVALUATION

At this point, students should understand how rotation of varying direction and magnitude affects the motion of hairs suspended in fluid.

REVIEW QUESTIONS

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

2. **Was there a difference in the time required for the hairs to stop moving after the 90 degree and 180 degree rotations? How do you explain this?**
   Students' answers will vary. There should be no difference in the time because both stops were sudden and the movement was not continuous.

3. **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 fall forward and if we try to stand up we experience dizziness.

THINKING CRITICALLY

1. **In step 7, each student took a turn at each task. Were the times measured the same or different for each student? What might account for the differences in time?**

2. **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. If they were placed in a vacuum, there would be no movement of the hairs.

3. **Why do patients who are bed-ridden for long periods of time often experience dizziness and difficulty standing upright?**
   These patients experience dizziness because their vestibular systems have not been required to function. Due to the lack of movement, when the patients stand, the vestibular systems are activated and their bodies have to adjust.

SKILL BUILDING

Have students pool their measurements from the different trials and calculate class averages. How much did the individual measurements vary from the class averages? What does this tell us about incorporating several trials into the design of an experiment?

STUDENT ACTIVITY SHEET

Visualizing How the Vestibular System Works

Name ______________________________ Date ____________

OBJECTIVE

To learn about the effects of different types of motion on the hairs suspended in fluid in the inner ear.

MATERIALS

- Tube of super glue
- Rotating device
- Fuzzy or wispy material
- Clear glass jar or cylinder with lid
- Water
- Watch
- Note pad
- Pen or pencil

DIRECTIONS

Work in groups of four, maximum. Your group will need all of the materials.

PROCEDURES

1. At least one day before actually performing the activity, glue the fuzzy material to the inside of the beaker or glass cylinder. Attach the fuzzy material to the side of the beaker or cylinder (not the bottom).
2. Have one member from your group fill the cylinder with water. The water should settle until it is motionless.
3. Rotate the cylinder quickly 90 degrees to the right (maintaining the vertical position of the cylinder) and observe what happens to the fuzzy material (Figure 44B).

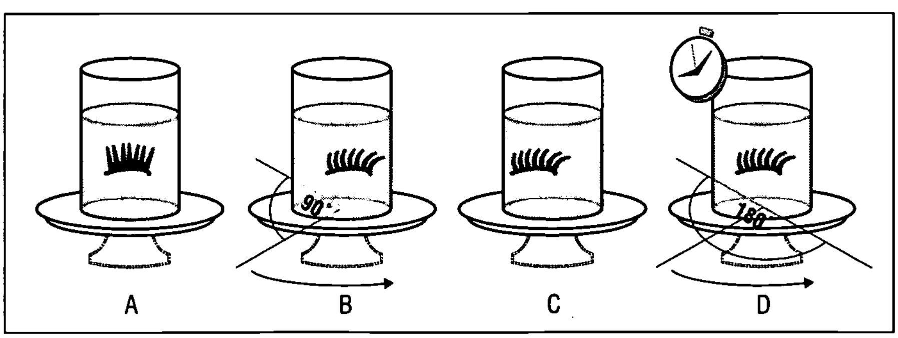


Figure 44A at rest. Figure 44B 90° rotation. Figure 44C motionless. Figure 44D 180° rotation.

Page 2

Name ______________________________ Date ______________

4. Rotate the cylinder 90 degrees in the other direction and record observations.

5. After the motion stops, 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 the straight position (Figure 44D). Record the time.

6. Repeat the procedures, with each student in your group taking a turn rotating the cylinder, observing the watch, and recording the time. Using the chart, record the name of the person who rotated the cylinder and the person who operated the watch beside the measured time.

7. Calculate the average time required for the hairs to come to rest after rotating the cylinder, and record your calculations.

8. 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. Record your observations.

9. Present your data from steps 6, 7, and 8 in tabular format (Figure 45).

10. If a rotating device is available, place the cylinder on the device and rotate slowly (do not splash or dislodge the fuzzy material) at an even rate for one minute. (Use the watch to time one minute.) Observe what happens to the hairs as they continue to spin, and after rotation is stopped. Record your observations.

Understanding the Vestibular System

90 degrees (observations)	180 degrees (time)	90/180 degrees (time)	1 minute rotation (observations)	Person rotating	Person w/watch

Figure 45 Example of chart to record motion observations.

Page 3

Name ______________________ Date ____________

Understanding the Vestibular System

90 degrees (observations)	180 degrees (time)	90/180 degrees (time)	1 minute rotating (observations)	Person rotating	Person w/watch

LEARNING ACTIVITY II:
Vestibular-Ocular Reflex

OVERVIEW

In this activity, students will perform various investigations to understand the vestibular-ocular reflex and learn about the importance of visual cues in maintaining balance.

SCIENCE & MATHEMATICS SKILLS

Observing, communicating, collecting quantitative data, calculating frequencies, drawing conclusions.

PREPARATION TIME

10 minutes

CLASS TIME

50 minutes

MATERIALS

For IIA of the activity, each pair or group of students will need the following items:

- Pen or pencil
- Note pad
- Book

IIB of the activity will require the following:

- Chair that rotates smoothly—preferably with back and arms, such as a desk chair
- Watch or clock with second hand
- Note pad
- One blindfold (optional)
- Protractor
- Chalk
- String or yarn (3 feet)
- Push pin
- Yard stick for drawing lines
- Pen or pencil

MAJOR CONCEPTS

- The vestibular system helps to maintain balance and equilibrium.
- Vestibular-ocular reflexes coordinate eye movement relative to head movement.
- The nystagmus (one type of vestibular-ocular reflex) helps the eye to stabilize the field of vision after movement. The eyes usually move in the direction opposite the initial movement.

BACKGROUND

This lesson is similar to some of the exercises the Neurolab team conducted as they studied the vestibular function in space. It helps to demonstrate the importance of gravity and visual cues to the human balance and sensory systems. Gravity provides a continual downward force, which the vestibular system (particularly the otolith organs) uses to process information about motion and orientation. To understand the effects of space travel on the vestibular system, Neurolab scientists studied how the vestibular system reacts to certain stimuli, within Earth's gravitational field and under microgravity conditions.

The following activities will demonstrate the **vestibular-ocular reflex,** which is the body's way of coordinating signals from the visual field with signals from the vestibular organs of the inner ear. This reflex is extremely important for stabilizing vision when we are moving. When the head rotates or tilts in any direction, the eyes move in the opposite direction to compensate, maintaining a stable visual image. Therefore, movements of the eyes can provide clues about what is happening in the vestibular system. The eyes respond similarly to movement of objects outside the body. However, the vestibular-ocular reflex occurs only when the vestibular system is stimulated (in other words, when the head moves).

During these activities, students will observe eye movements and monitor the stability of the visual field during different types of movements: **saccadic**, the fast movement of the eye and **smooth pursuit**, the slow movement of the eye during the vestibular-occular reflex. In IIA, students will compare stability of a moving image under two conditions: (1) when the object of vision is moving but the head is stationary; and (2) when the head is moving but the object is stationary. When the head is stationary, the vestibular system is not activated, and the image blurs more quickly. When the head is moving, the vestibular system is stimulated and works together with visual and proprioceptive sensory systems to maintain a stable image.

In IIB, students will compare the effects of rotation on the sensation of spinning under varying conditions: (1) when the visual system is activated; (2) when the visual system is not activated; and (3) when the otolith organs are activated by a downward movement.

PROCEDURE

IIA: Stability of Moving Images

1. Assign each student a partner.
2. Have the partners stand about five feet away from each other. One student will be the subject, the other will be the recorder.

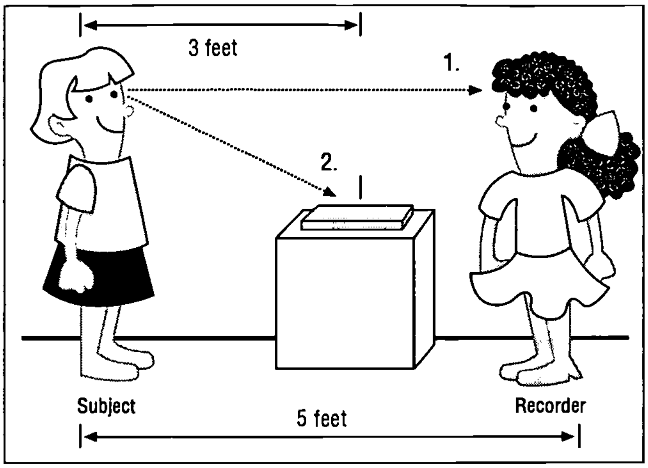


Figure 46 Diagram of student observing saccadic eye movement.

3. Tell the subject to look at his or her partner, and then to look away to a book placed about three feet away. The recorder should look at the subject's eyes and determine the type of eye movement he or she is exhibiting. The recorder should record the type of eye movement, saccadic or smooth pursuit.

4. Have the students reverse roles and repeat steps one through three.

5. Next, have each subject focus on the end of a pen or pencil held by the recorder about one foot in front of the subject's face. Tell the subject to hold his or her head still while the recorder moves the pen or pencil back and forth slowly in front of the subject's eyes. Instruct the recorder to move the pen or pencil from one side to the other as though he or she were trying to hypnotize the subject (Figure 47A).

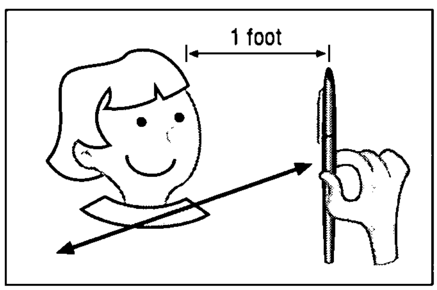


Figure 47A Diagram of techniques for testing saccadic (fast eye movement).

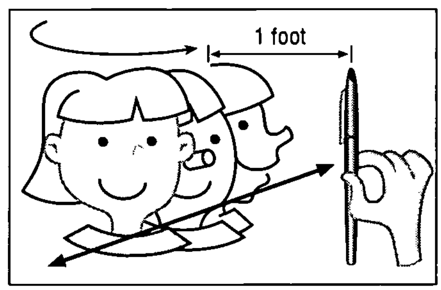


Figure 47B Diagram of techniques for testing smooth pursuit (slow eye movement).

6. Each partner should record the types of eye movement that are exhibited by the other: saccadic or smooth pursuit.

7. Let the team members switch roles and repeat the exercise.

8. Finally, have one student from each team hold a pen or pencil about a foot in front of his or her partner's face while the partner keeps his or her eyes on the pen or pencil. Both of the students should move their heads around while observing (Figure 47B).

9. Have the students record their observations of each other's eye movements.

10. Discuss these observations with the students. Ask if the eye movements were the same in each trial. Have students compare and contrast their observations.

IIB: Effects of Rotation on Vision

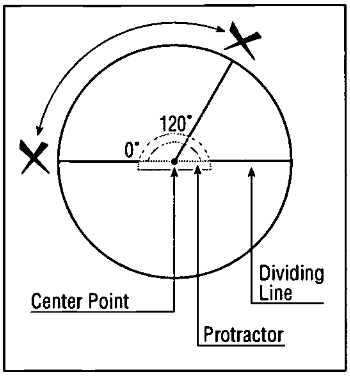


Figure 48 Diagram of 120 degree floor drawing.

1. Instruct students to draw a circle on the floor by attaching a three-foot string to a piece of chalk and attach the other end to a push pin. Have the students establish a dividing line by drawing a line through the center of the circle. They should then align the center point of the protractor with the center of the dividing line of the circle. Direct the students to place a mark outside of the circle at the dividing line (0°). They should place another mark outside of the circle at 120°. The students should make sure that the marks are visible to the person rotating the chair (Figure 48).

2. Select one rotating chair with arms for this activity and place the chair at the center of the circle. Since students will be spinning in the chair, caution them to exercise care. Students sitting in the chair should hold the arms of the chair during the rotation.

3. Before beginning, demonstrate to students how to turn the chair carefully, so that the student sitting in the chair does not tumble out. If necessary, review the procedure with the students to make sure that they understand what they are supposed to do.

4. Have students conduct the activity in groups. One student will be the subject, a second student will spin the chair and the remaining students will be recorders and time keepers.

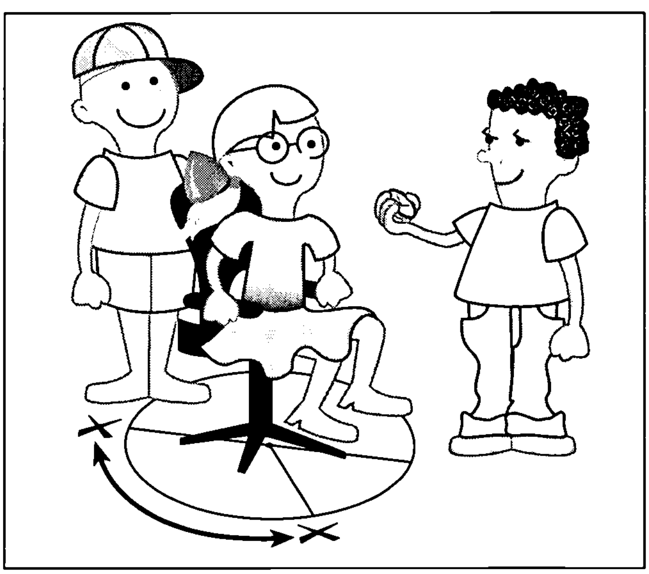


Figure 49 Diagram of student rotating student 120 degrees per second.

5. Have each subject sit erect in a rotating chair. Another team member should turn the student in the chair for a full minute at 120 degrees per second, then suddenly bring the student to a full stop (Figure 49).

6. The other members of the team should observe the eyes of the student sitting in the chair after it has been stopped. Using the watch, they should time how long it takes for the effect of spinning on the student's eyes to stop and record their observations.

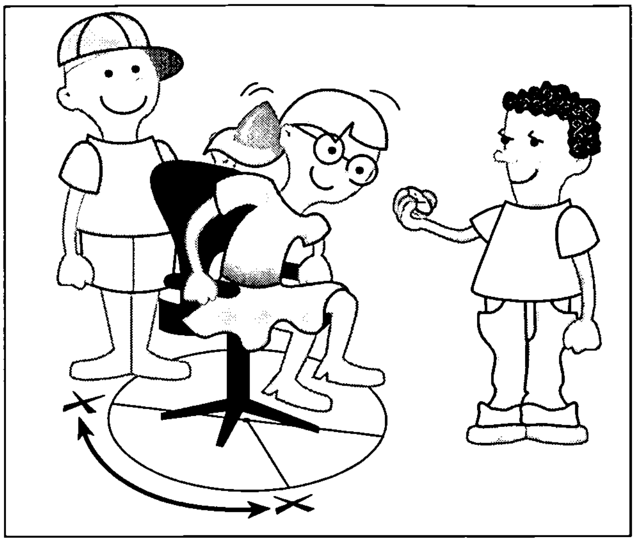


Figure 50 *Diagram of student rotating student 120 degrees per second while head is in pitched position.*

7. Have the students repeat step 3, but instruct the student in the chair to hold his or her head forward during spinning. The other partners should observe how long this student's eye movement lasts after the chair has stopped and then record these observations (Figure 50).
8. Have students within the groups switch roles so that they all will have an opportunity to participate in the various roles of this activity.
9. Have the students in each group summarize their data and present a group average of time required to stabilize eye movement after the spinning, both in step 3 and step 5.

Evaluation

REVIEW QUESTIONS

1. **What does the vestibular-ocular reflex do?**
   The vestibular-ocular reflex coordinates eye movement relative to head movement.
2. **What 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. **What is the difference between "saccadic" and "smooth pursuit"?**
   There are two components of eye movement during the vestibular-ocular reflex. The fast movement of the eye is called "saccadic" and the slower movement is called "smooth pursuit."
4. **Why is the vestibular system important to movement?**
   It helps the body to maintain balance and to adjust to movements of the body as well as movements outside of the body.
5. **What is motion sickness?**
   The symptoms of dizziness, drowsiness, and nausea that are caused by the coriolis effect or pseudo-coriolis effect.

THINKING CRITICALLY

1. **Why do people who have problems with their vestibular systems suffer from motion sickness?**
   If the vestibular system is damaged, the signals going to the brain are inappropriate or missing, causing motion sickness.

2. **How is motion sickness related to visual cues?**
   The symptoms of motion sickness may be triggered by visual stimuli. The pseudo-coriolis effect is inducted by visual illusions of self-motion.

3. **What would happen if the vestibular system were destroyed? Explain how one would act and feel.**
   A person would have problems adjusting to movement and maintaining balance. The person may experience some motion sickness.

4. **Why might a person experience motion sickness when not moving or in an IMAX theater?**
   The visual illusions would overload the vestibular system producing the pseudo-coriolis effect.

5. **Will 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 vestibular system would respond and adapt to microgravity. Without gravity, the vestibular system would have to make adjustments to the constant movement of the body just as it does when astronauts are in space.

SKILL BUILDING

Have students use the Internet to locate resources related to disorders of the vestibular system (Figure 51). How might Neurolab research provide insight into these disorders?

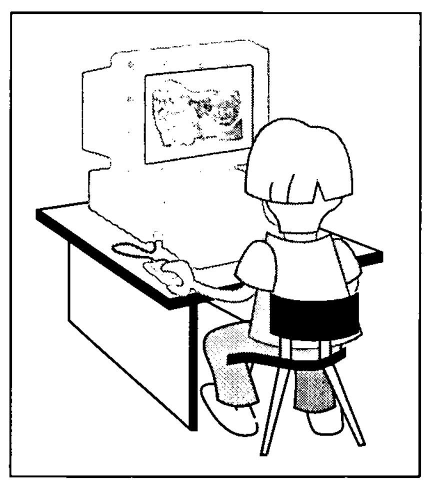


Figure 51 Diagram of student using the Internet.

STUDENT ACTIVITY SHEET

IIA. Stability of Moving Images

Name ______________________________ Date ______________

Head Position (stationary or side-to-side)	Description of eye movement (smooth or saccadic)	Subject	Recorder

STUDENT ACTIVITY SHEET
IIB. Effects of Rotation on Vision

Name ______________________________ Date ______________

Head Position	Description of eye movement	Length of time for eyes to stop moving	Person in chair (subject)	Person spinning (observer)

Spatial Orientation and Visuo-motor Performance

Lessons and Activities

GRADES 5–12

Section III

Spatial Orientation and Visuo-motor Performance

TOPIC

Gravity is an important component that enables organisms to establish frames of reference and maintain a sense of orientation with respect to objects in the environment.

How did the Neurolab astronauts maintain their sense of spatial orientation in a microgravity environment?

INTRODUCTION

Perception of where one is located with respect to certain landmarks in the environment (**self-orientation**), and where specific objects are located with respect to each other (**object-orientation**), are interdependent. Our abilities to recognize and interact with objects in the environment depend on proper perception of self-orientation as well as object-orientation.

Our perception of self-orientation depends on input from our external sensory organs (**exteroceptors**), such as our eyes, ears, and nose. It also depends on input from our internal sensory systems (**interoceptors**). These include **proprioception**, which is a system of specialized receptors and nerves in our bodies that monitor the positions of our muscles and joints. Another example is the **vestibular system** located inside the head near each ear. This system responds to rotations and accelerations of the head as well as to gravity. Under ordinary conditions, the input to the brain from all of these sensory systems are consistent with one another. However, in microgravity conditions, the vestibular information that the brain receives changes, and this sometimes leads to motion sickness, as well as to illusory perceptions.

Things to Know

RELATIVE POSITION AND PATH ANALYSIS

The term **frame of reference** refers to a coordinated system for specifying the locations and movements of objects. For example, map makers use the North and South poles, and the equator, to establish a frame of reference for the Earth. This allows us to specify locations in terms of their latitude and longitude.

Similarly, the brain uses its sensory organs to establish and maintain a frame of reference to specify locations of objects with respect to the body.

For example, in the Northern Hemisphere, vision can be used to establish "East," the direction from which the sun is seen to rise in the morning, and "West," the direction where the sun sets in the evening. Locations and movements of the body and other objects can then be specified within this frame of reference. For example, one may think, "To go home, I must travel eastward."

Vision can also potentially provide a frame of reference for "up." For example, we know that to see the sky we look "up," or that to determine the direction of the ground on which our feet rest we look "down." Information about "up" and "down" is also provided independently by the **otolith organs**, a component of the vestibular system that responds directly to gravity.

NAVIGATION

When you travel from a location in the environment to which you later want to return, your brain is confronted with the problem of how to navigate back home. One way your brain might accomplish this task is to use some form of **Path Integration.** This is an automatic process performed by the brain to try to continuously keep track of how far you have traveled, and in what direction, over each segment of your path, and then use this information to compute your current position relative to your starting point. Many animal species, even those with very simple nervous systems, are able to utilize some form of path integration to navigate. For example, ants can navigate their way back home after foraging in search of food (Figure 52).

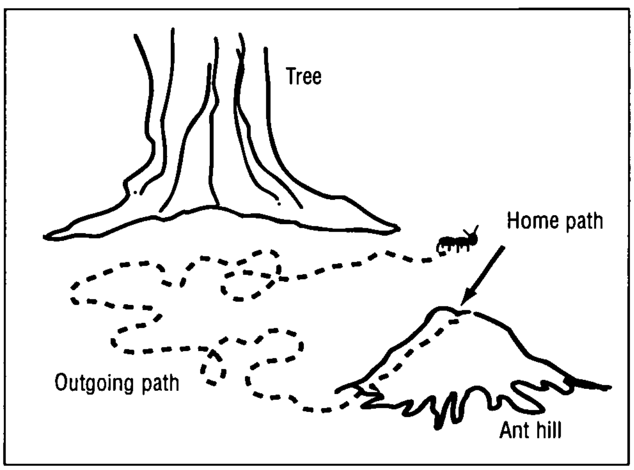


Figure 52 *Diagram of path integration.*

Our brains are able to construct and store spatial maps that specify our current location with respect to important landmarks. These maps are formed by combining information from interoceptors with **corollary discharge**. A corollary discharge is a copy of the motor commands that the brain sends to the muscles. For example, if the brain is trying to figure out how far the body has walked since leaving home, it has two obvious sources of information. One is to examine the corollary discharge of the signals that were sent to the leg muscles. In other words, the brain knows how many steps you have walked because it was the brain itself that sent the commands to the leg muscles that caused you to walk.

An independent source of this same information comes from proprioception which supplies the brain with detailed information about positions and movements of the muscles and joints in the legs. Similarly, the vestibular system sends information to the brain every time you accelerate or decelerate in speed, or rotate to turn a corner.

Finally, this information about your current location is augmented by vision, olfaction, and audition. For example, through **vision,** you can tell that you are in your classroom by looking around, through **olfaction**, you can tell that you are near the cafeteria by the way it smells, and through **audition,** you can know that you are near your classroom because you can hear the sound of your students talking.

Under ordinary circumstances, the information supplied to the brain from these various sources is consistent and thus the spatial maps that are formed by the brain are accurate. In mammals, there is a specialized structure called the **hippocampus** that appears to play a major role in storing these maps (Figure 53). The hippocampus is a seahorse-shaped structure located deep in each hemisphere of the brain. Self-orientation is coded in the hippocampus in the neural firing patterns of specialized neurons called **place cells.** These place cells buzz with electrical activity whenever an animal knows it is located in a certain place. Different place cells are active in different locations. By recording the activity from many place cells at the same time, scientists essentially can read an animal's mind and tell where the animal thinks it is located.

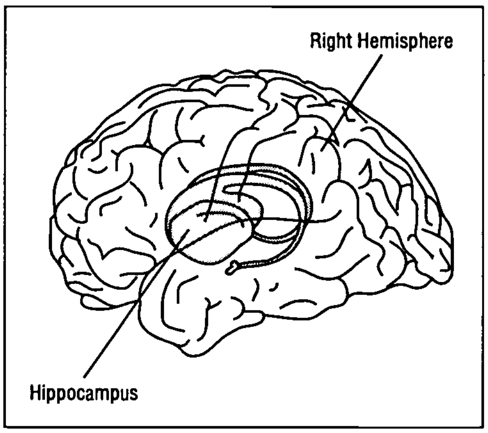


Figure 53 *Diagram of the hippocampus within the brain.*

SPATIAL ORIENTATION IN MICROGRAVITY

In microgravity conditions, the vestibular information that the brain receives is changed. In order to understand why this is so, we need to understand how the vestibular system operates. The vestibular system is composed of two subsystems called the **semicircular canals** and the **otolith organs.** There are three semicircular canals and they signal to the brain whenever the head is rotated. One responds to **yaw** motions (motion that occurs when you shake your head side-to-side), a second to **pitch** motions (motion that occurs when you do a back flip), and a third to roll motions (motion that occurs when you turn cartwheels). The otolith organs send two kinds of information to the brain. First, they signal whenever you accelerate or decelerate (the feeling of being sucked into the back of the car seat when you press on the gas pedal to pass another car). Second, they respond to gravity to tell you which end of your body is "up," and which is "down."

Imagine that you are performing a cartwheel to your left. As you first start the motion, your semicircular canal signals that your head is starting to rotate to the left, and simultaneously your otolith organs are signaling that the "up" direction is shifting from the top of your head towards your right ear. Halfway into the cartwheel, your semicircular canal continues to signal that your head is rotating to the left, and now your otolith organs signal that the top of your head is in the "down" position. If you have your eyes open, the input to your brain will be consistent with the input from your vestibular system because the world will look "upside-down."

Similarly, the proprioceptive inputs from your muscles will indicate that the force from the floor shifted from your feet to your hands. If you were to turn the same cartwheel under the condition of microgravity, the input from your semicircular canals and from vision would be identical, but the input from the otolith organs would be inconsistent because it would not signal that the direction "up" shifted during your cartwheel. Also the force exhibited by the floor on your muscles would be less in microgravity.

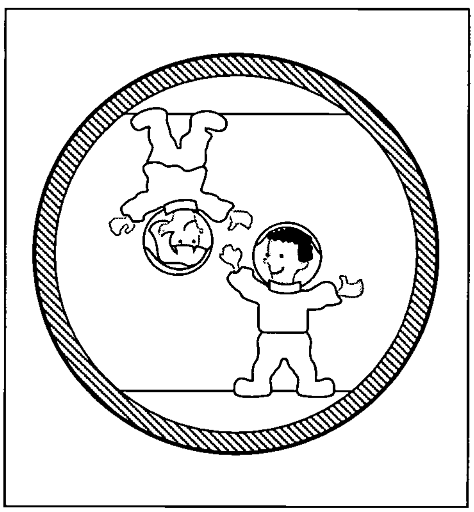


Figure 54 Diagram of free floating.

This kind of inconsistent input is a regular occurrence in the brains of astronauts during a space flight. Astronauts experience the spacecraft and Earth from their bodily attitudes. Because the "down cue" that Earth's gravity provides to the otolith organs, as well as to the proprioceptive receptors in the muscles and joints are not present in microgravity, the crew must rely on vision to become oriented and figure out where they are located in relation to the space they occupy. In daily life on Earth, the "floor" is always beneath our feet and people are upright. However, in weightlessness, free floating crews view the cabin interior, and each other, from many orientations. For example, when floating in symmetrical cabin interiors, the surface beneath their feet feels like "the floor," even if they are floating upside-down with their feet touching the ceiling (Figure 54). As a result, space flight often causes altered spatial orientation, illusions of body orientation, changes in visuo-motor performance, and space motion sickness.

TRICK MAZE EXPERIMENTS ON NEUROLAB

One Neurolab animal experiment tried to determine whether or not spatial maps in the hippocampus are disrupted by the inconsistent information provided to the brain under conditions of microgravity. Neurolab scientists used a unique set of trick mazes designed to fool the animals into thinking they were in one place, based on corollary discharge and proprioception (where the animals thought their legs should have taken them), when in reality they were in another place (which they were able

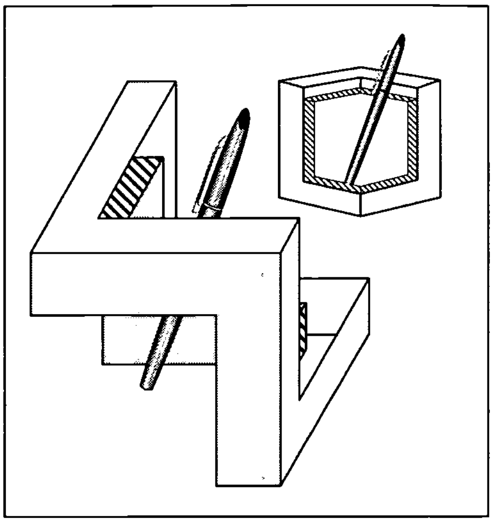


Figure 55 Diagram of an Escher Staircase.

to see from what their eyes told them). One maze was called the Escher Staircase (Figure 55) and another was called the Magic Carpet (Figure 56). Scientists wanted to see whether the animals' hippocampi were telling them they were "home" or not by measuring the activity of the place cells in the hippocampi.

In the **Escher Staircase**, there was a route around three inner walls of a corner of a cube. In the presence of gravity, you could not walk around the staircase because you cannot walk along the sides of walls. However, in the absence of gravity's effect, it was possible to follow a route that combined three 90 degree "yaw" turns with three 90 degree "pitches" and end up back home at the starting point. The animal did not have any input from its otolith organs informing it that it had been walking on the wall instead of the floor during part of the route. It had been predicted that even though the animal was back to where it started, it would be confused. The visual system would tell the brain that all the visual landmark cues indicated that the animal was back where it started the maze, but the path analysis performed by the brain would probably think the animal needed to turn one more corner to return home (as would be the case if the animal had not been able to walk on the walls).

The **Magic Carpet** maze played a similar trick that was possible only in the absence of gravity's effect. It was a plus-shaped maze that could pitch and roll the animal so they ended up facing 180 degrees in the opposite direction to where it had started without ever turning around. Again, the visual cues told the animal it had turned around, but path analysis would not. It was believed that the hippocampal place cells would put more emphasis on path analysis computations than on visual information. Thus, the prediction was that when the animal returned to its starting position, the hippocampus would underestimate the animal's true position by 90 degrees on the Escher Staircase and by 180 degrees on the Magic Carpet.

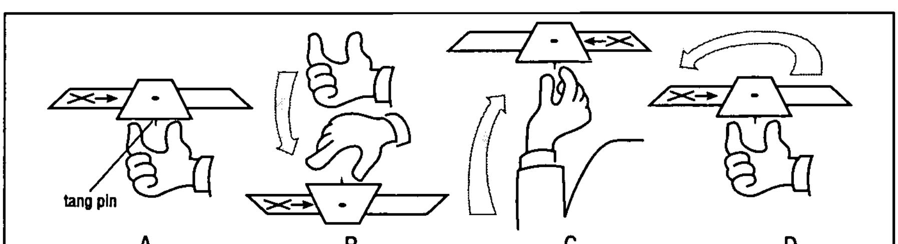


Figure 56 Diagram of the Magic Carpet.

LEARNING ACTIVITY I:
Finding Your Way Around Without Visual or Sound Cues

OVERVIEW

In this activity, students will play a series of simple games to investigate navigation without visual and sound cues.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting quantitative data, creating graphs, interpreting data, drawing conclusions, communicating

PREPARATION TIME

15 minutes

CLASS TIME

45 minutes

MATERIALS

- Access to an open area
- Measuring tape
- Timer (watch or clock with second hand)
- Graph paper, one sheet per student
- Pencil (pen or chalk is acceptable), one per student
- Bell
- Blindfold, one per student
- Candy to reward for foraging
- Statistical calculator

BACKGROUND

The brain is able to interpret information from several different body systems to estimate position. Visual cues, information from the otolith organs in the inner ear, sound cues, and information from the motor system are used to determine spatial orientation.

MAJOR CONCEPTS

- The brain combines information from several different sources to estimate position.
- Inertial navigation (navigation based on motion-related cues) can provide direction without visual or auditory cues.
- The environment can be navigated with some success by solely using feedback received by the brain from self-motion sensors in the body.

This activity allows students to investigate how well the central nervous system is able to estimate position based on information other than visual and sound cues.

PROCEDURE 1

Navigating Without Visual or Sound Cues

1. Have each student take a partner and a blindfold to an open area.

2. Designate an area as "home" base by placing a piece of paper on the ground where the students are, or mark the spot with tape forming an "X" on the ground or on the floor.

3. Have one member (subject) of each student team tie the blindfold over his/her eyes so he/she cannot see anything. This is a test to see if the student can navigate without visual cues. Encourage the students not to cheat.

4. Once blindfolded, each subject should walk around continuously for 30 seconds, like an ant foraging for food, and then try to return to the same spot where he/she started (Figure 57). Have the students make at least four turns as part of the path. They may go anywhere, as long as they try to end up at the starting place after 30 seconds. Each student's partner should let him/her know how much time has elapsed every 10 seconds. Have the partners move around so that the subjects cannot use the sound of their partners' voices as the cues for "home."

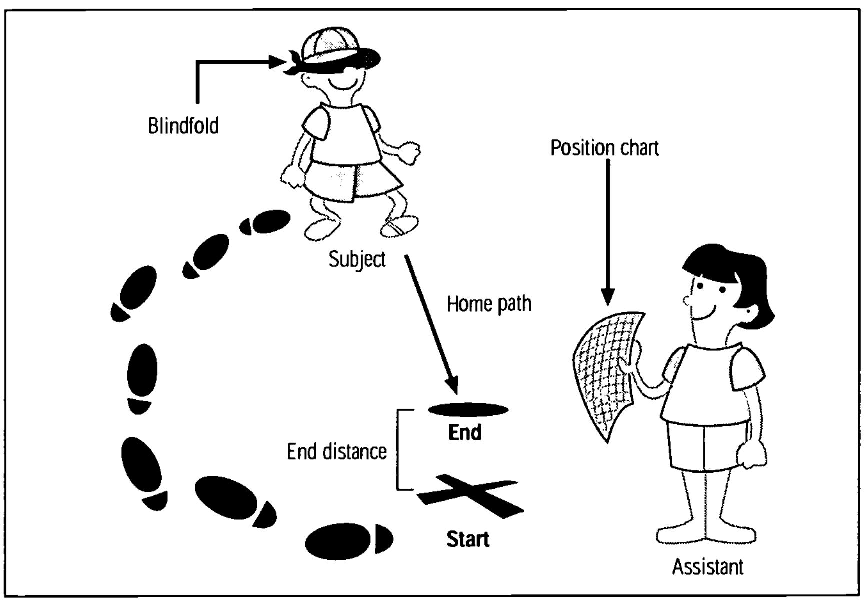


Figure 57 *Diagram of student walking blindfolded to show how inertial navigation can provide direction without sight or sound.*

5. Make sure that the partners do not give the blindfolded students any hints. The environment should be as quiet as possible so that students receive no sound cues. Once each blindfolded student believes he/she has returned to home base (or, after the 30 second time limit is

reached), instruct him/her to remove the blindfold and measure how far he/she is from the starting mark. This distance should be recorded. Instruct the students not to worry if they end up far away from "home" after their first try.

6. To add excitement, distribute little packets of candy at random and have the students forage on hands and knees blindfolded, starting from a location called home, marking the floor (or pavement, if you are outdoors) with something they cannot feel, such as chalk. Then ring a bell and have them try to get back to home base within five seconds. The students might pretend that they are foraging ants and that the bell is a danger signal. Thus, they would try to get back "home" quickly.

Each student should have the opportunity to try this experiment at least once.

PROCEDURE 2

Using Quantitative Information to Assist Navigation Without Visual or Sound Cues

Note to Teacher: *Encourage students not to make any audible clues that might alter results. The environment should be quiet.*

1. Have your students repeat the previous activity, again blindfolded. But this time, instead of having the blindfolded students wander around randomly, have them count the number of steps they take in each direction.

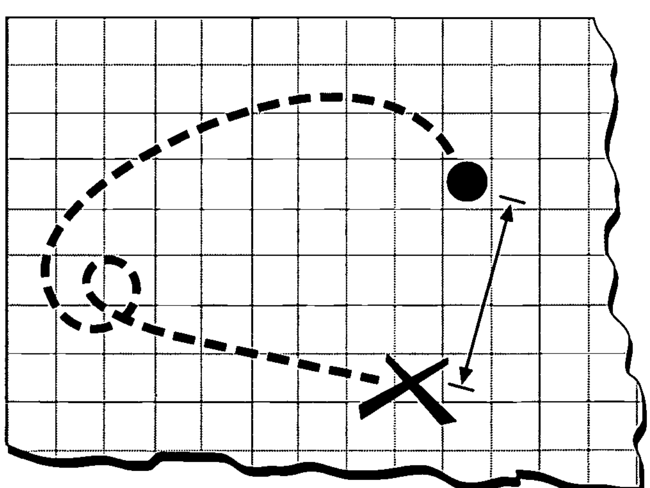


Figure 58 *Diagram of a position chart.*

2. The partner should help the blindfolded student by writing down the number and direction of steps taken by the blindfolded student. Partners can try to chart the student's course by drawing the student's position at each step on a sheet of graph paper (Figure 58).

3. At 30 seconds, the blindfolded students should try to find their way "home" by guessing where they are, using how far they have gone in each direction as a cue. Direct each blindfolded student to tell his/her partner how far, and in which

direction(s) he/she thinks he/she needs to travel in order to reach home. (It is acceptable if the partner looks at the chart to see if the blindfolded student is correct, but the partner should not give any hints.)

4. The student should now try to find home. Once the blindfolded students reach the place they believe to be "home," have their partners measure the distance from where the students ended to the actual starting place, or "home." Have students compare their estimates of the distance to home with the actual measurements. Each student should try the experiment.

PROCEDURE 3

Using a Pre-established Pattern to Navigate Without Sound or Visual Cues

1. All students should be blindfolded for this exercise. As many students can participate at one time as available space will allow.

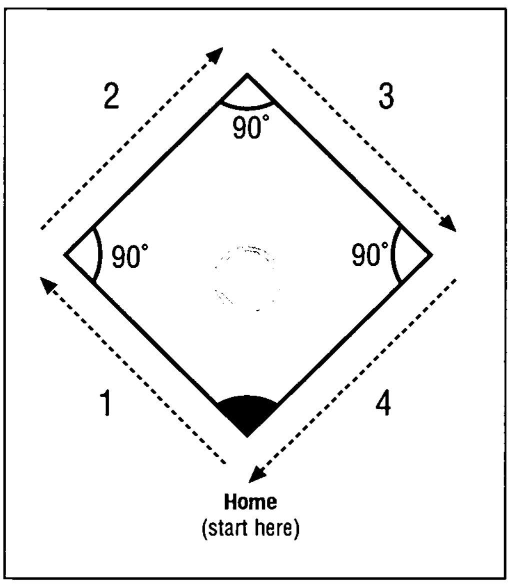


Figure 59 *Diagram of a pre-established pattern.*

2. Students should blindfold themselves and try taking 10 steps forward from their "home" mark. They should then turn 90° to the right, take 10 more steps, turn 90° to the right again, take 10 more steps, and stop (Figure 59). Ask the students if they think they are back to where they started yet.

3. Have the blindfolded students turn 90° to the right and take 10 more steps. Have the students add all their 90 degree turns to determine how many degrees they have rotated in total.

4. Ask the students where their brains tell them they are. Direct them to lift their blindfolds and see if they are "home." The students should measure how far they are from their mark and record the measurement. If the students counted accurately, they should be close to the place where they started.

5. Have students compare measurements from the three trials. Have them identify the trial in which they navigated most accurately and the trial in which they were least accurate in returning to home. Why do they think the results varied from one trial to another?

Evaluation

REVIEW QUESTIONS

1. **What types of information does the brain use for navigation and determining position?**
   The brain receives and utilizes sensory information from the eyes, ear, and nose to determine position.

2. **Is it possible to estimate position using information from only one or two sources?**
   Yes. It is possible.

THINKING CRITICALLY

1. **What is the minimum amount of sensory information needed for navigation?**
   A minimum of two sensory information is needed for navigation.

2. **Was navigation successful without visual cues?**

3. **How much error occurred when using each of the tactics?**

4. **Which tactic produced the least error? Why?**

5. **How much more or less difficult would the task have been if one could walk up and down walls?**

SKILL BUILDING

1. Have students pool the class data from each of the trials, compute the mean distance from "home" for each trial and, using a statistical calculator, find the standard deviations (averages) of each of the trials. Have them use this information to decide whether the results of each trial are different or not.

2. Have student teams devise their own experiments to further investigate navigation without visual cues.

STUDENT ACTIVITY SHEET

Finding Your Way Around Without Visual or Sound Cues

Name ______________________________ Date ______________

Student Name	Procedure 1	Procedure 2	Procedure 3
Total			
Average			

LEARNING ACTIVITY II:
Pitch, Roll and Yaw: The Three Axes of Rotation

OVERVIEW

This exercise will help students understand how the visual and vestibular systems work with the hippocampus to determine location and direction.

SCIENCE & MATHEMATICS SKILLS

Observing, measuring, visualizing objects in three dimensions, drawing conclusions

PREPARATION TIME

None

CLASS TIME

45 minutes

MATERIALS

No materials needed

BACKGROUND

The body is capable of rotating in three different ways (roll, pitch, and yaw). This activity will help students understand the three axes of rotation.

MAJOR CONCEPTS

- Without gravity's effect as a reference, it is difficult to detect the body's orientation.
- In microgravity, astronauts' brains will rely on place cells within the hippocampus for information about position.
- Place cells are more strongly influenced by computations based on path integration than by visual cues.

Body in Rolling Motion

The sideways motion of a body doing a cartwheel (Figure 60) is called a **roll**.

Body and Head Pitching

The motions of the body when somersaulting (Figure 61) are called a head over heels **pitch**. The head is up, then down, then up, then down. Throwing a football or a baseball is also a pitch motion.

Yaw

When you stand up and turn left and right, the motion you have made is called a **yaw** axis motion (Figure 62). One "yaws" when spinning around in a rotating chair, or when doing a pirouette.

HEAD DIRECTION CELLS

There are cells deep within the brain that tell the hippocampus in which direction the head is facing in the yaw axis. These are called **head-direction cells**. The head direction cells always specify direction relative to some important landmark. In the classroom, the front of the classroom might provide a landmark to form a frame of reference labeled by the brain as "forward" (facing the front of the classroom) and "backward" (facing the back of the classroom). When facing the front of the classroom, the head-direction cells tell the hippocampus that the head is facing forward.

When the head is turned to face the back of the room, another set of head-direction cells becomes active and tells the hippocampus that the head is facing backward. Yaw motions are sensed by the vestibular system even if the eyes are closed. They are not influenced by gravity and can be sensed even when upside-down. Unlike yaw motions, the pitch and roll motions usually have gravity for a reference. This is because the otolith organs that respond to gravity are activated along with the semicircular canals during these motions. Thus, the responses of the vestibular system to "pitch" and "roll" will be altered in microgravity conditions compared to these responses in Earth's gravity.

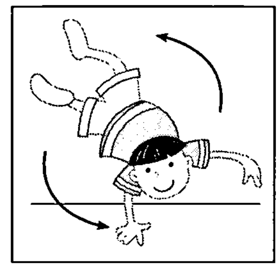


Figure 60 *Diagram of rolling motion.*

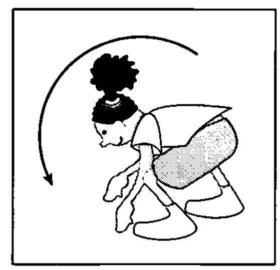


Figure 61 *Diagram of body pitching.*

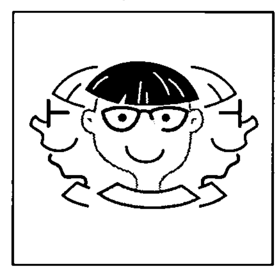


Figure 62 *Diagram of yaw axis motion.*

PROCEDURE

1. The roll, pitch and yaw motion diagrams to the right can be emulated by your students outdoors or in a large area such as a hallway.
2. Demonstrate each of the movements or show the figures on an over-head chart. Then let all of the students attempt each of the different rotations.
3. To begin the rolling cartwheel motion (Figure 60), have the students lead with their right hands, with their left ears facing up to the sky. As they roll along or rotate in the correct direction, their right ears will face upward, while their left ears are down, and so on.
4. For pitch (Figure 61), have students attempt both a head-over-heels pitch (summersault) and a pitching motion with the arm. Students can also shake their heads "yes."
5. For yaw (Figure 62), have students stand and turn left, then right. Students also should try spinning in a pirouette. They can also shake their heads side-to-side as if gesturing "no."

6. Explain to students that the body has different systems to sense yaw, pitch, and roll movements. Introduce the concept of **head direction cells**, which tell the hippocampus whether the head is facing forward or turned toward the back. Ask them to identify which type of rotation the head direction cells would be detecting. Mention that the head direction cells are not influenced by gravity, whereas the pitch and roll motions usually have gravity for a reference.

LEARNING ACTIVITY III:
Building a Magic Carpet

OVERVIEW

Students will compare and contrast pitch and roll motions by using a Magic Carpet maze similar to one that was used for Neurolab investigations.

SCIENCE & MATHEMATICS SKILLS

Observing, measuring, visualizing objects in three dimensions, drawing conclusions

PREPARATION TIME

None

CLASS TIME

45 minutes

MATERIALS

Each student or team of students will need:

- Scissors
- Two strips of cardboard or posterboard (2.5 inches wide and 18 inches long)
- Metal paper fasteners (tang pins)

MAJOR CONCEPTS

- Roll is a sideways motion.
- Pitch is a head-over-heels movement.

BACKGROUND

The Neurolab Magic Carpet experiment was designed to investigate "pitch" and "roll" in microgravity. The Magic Carpet is a maze shaped like a plus symbol that can work only in a weightless environment. This maze allowed the astronauts to pitch and roll animals in space, so that without making any yaw turns, the animals ended up facing the opposite direction from where they started.

Neurolab scientists used this trick maze to fool animals into thinking they were in one place based on their self-motion cues, while their visual systems gave them conflicting information about their locations. The scientists wanted to know whether rats' hippocampi told them they were "home," or not, by measuring the activity of place cells.

PROCEDURE

1. Tell students they will be creating another puzzle that was used by Neurolab scientists to investigate navigation and spatial orientation in space.
2. Have the students follow the four steps for building a Magic Carpet.

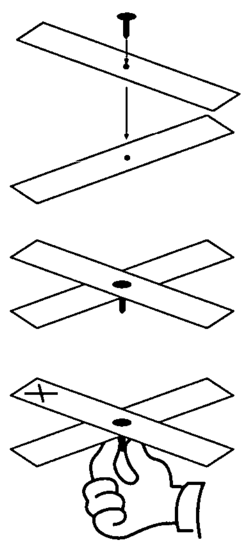


Figure 63 Diagram of construction of a Magic Carpet.

How to Build a Magic Carpet

I. Cut two strips of cardboard 2.5 inches wide and 18 inches long.

II. Put a hole in the center of each strip and fix the two together, perpendicular to one another, with a bent tan pin. Do not split the tangs of the pin when attaching the strips.

III. Hold the tang pin in the hand (palm up), with the head of the tang pin pointing up and the tangs pointing down.

IV. Mark the end of the Magic Carpet that is farthest away from you with an "X" to represent an animal, as if the animal were facing you.

3. The Magic Carpet will allow the students to perform the following roll and pitch maneuvers, as shown in Figures 64A and 64B.
4. To perform roll maneuvers, the Magic Carpet should be turned so the head of the tang is pointing down and the student's hand is on top. Explain to the students that if an animal were on Earth, it would have fallen to the ground. When this experiment is performed in space, the animal will remain on the Magic Carpet, even when it is turned upside down, because there is little gravity.

5. To examine pitch maneuvers, have the students turn their wrists and elbows upward so the head of the tang is on top again. Ask them if they see how the "X" is now on the end of the maze closest to them, as if the animal were facing away from them. The students should note that the animal did not have to make any yaw axis motion, yet it ended up facing 180° away from where it started (Figures 64C & 64D).

6. Now rotate the Magic Carpet 180° in a yaw motion so that the "X" ends up where it started as if the animal were facing you.

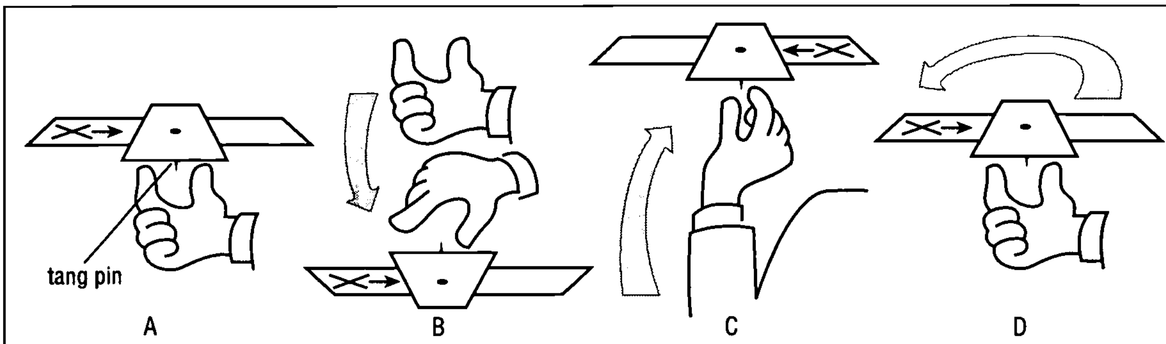


Figure 64 Diagram of the Magic Carpet.

Evaluation

REVIEW QUESTIONS

1. **Which two types of rotation does the Magic Carpet use?**
   Pitch and roll.

2. **How does the brain track movements and position?**
   The hippocampus gets information from many different parts of the brain, and integrates it to assess where the animal is in space. The hippocampus uses self-motion cues (vestibular, muscular, body position senses), visual (sight) and auditory (sound) cues.

THINKING CRITICALLY

1. **If the animal's brain is not properly encoding pitch and roll motions, what will its hippocampus tell it about where it is?**
   If the animal has not moved, except for a 180° roll, then the hippocampus will not indicate that the animal has moved, and the hippocampal map should indicate that the animal is in the same place.

2. **Will its vestibular system indicate that it has moved at all?**
The vestibular system should indicate some disturbance, but it cannot give the hippocampus accurate pitch and roll information without gravity.

3. **What will its visual cues tell it?**
No visual cues have been removed, therefore, the animal will receive accurate information regarding its position.

4. **What will its place cells do?**
If the hippocampus has not yet learned how to use this new set of visual cues, then it will rely on the self-motion cues from the vestibular system and we think it will tell the animal that it has not moved.

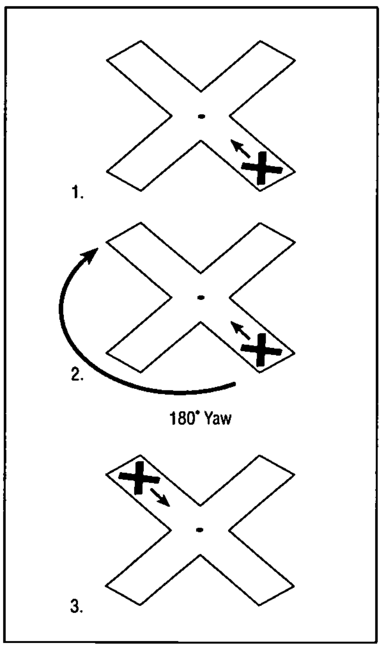


Figure 65 *Diagram of a helicopter blade movement.*

5. **What if the animal was turned 180 degrees in the yaw axis (a movement like helicopter blades)? Have the students demonstrate (Figure 65).**
Since the yaw movements don't depend on gravity, the vestibular system should accurately inform the hippocampus that the animal has moved 180° and is now facing in the opposite direction.

6. **Where does the "X" end up?**
Where it started.

Note to teacher: *If the animal is sensing motion with its vestibular system, it will not accurately sense that it has motion. It will only detect that it has undergone a 180 degree "yaw," and this would indicate that it is 180 degrees from where it started. Vision will indicate that the animal is back where it started. It is predicted that the animal will think it has rotated 180 degrees because the place cells are influenced more by the vestibular system than by the inertial navigation system.*

STUDENT ACTIVITY SHEET
How to Build a Magic Carpet

Name ______________________ Date __________

OBJECTIVE To compare and contrast pitch and roll motions by using a Magic Carpet similar to one that was used for Neurolab investigations.

MATERIALS
- Scissors
- Two strips of cardboard or poster board (2.5 inches wide and 18 inches long)
- Metal paper fasteners (tang pin)

DIRECTIONS You will be creating another puzzle that was used by Neurolab scientists to investigate navigation and spatial orientation in space. Follow the four steps to building a Magic Carpet (Figure 66).

PROCEDURES

1. Cut two strips of cardboard 2.5 inches wide and 18 inches long.
2. Put a hole in the center of each strip and fix the two together, perpendicular to one another, with a bent tang pin. Do not split the tangs of the pin when attaching the strips.
3. Hold the tang pin in the hand (palm up), with the head of the tang pin pointing up and the tangs pointing down.
4. Mark the end of the Magic Carpet that is farthest from you with an "X" to represent an animal, as if the animal were facing you.

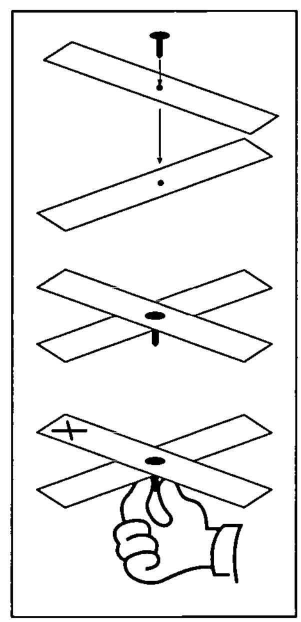


Figure 66 Diagram of construction of a Magic Carpet.

Name ______________________ Date ____________

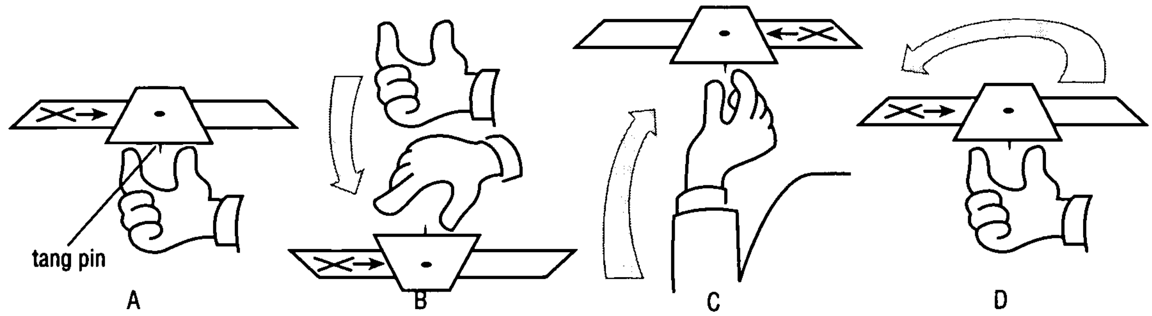


Figure 67A *In hand* Figure 67B *After roll* Figure 67C *After roll and pitch* Figure 67D *Starting position*

Figure 67 *Diagram of the Magic Carpet.*

5. The Magic Carpet will allow you to perform the following roll and pitch maneuvers, as shown above.
6. To perform roll maneuvers, the Magic Carpet should be turned so the head of the tang is pointing down and your hand is on top (Figure 67B).
7. To examine pitch maneuvers, turn your wrists and elbows upward so the head of the tang is on top again (Figure 67C).

LEARNING ACTIVITY IV:
Building a 3-D Space Maze: Escher Staircase

OVERVIEW

Students will create Escher Staircase models similar to those that were used by the Spatial Orientation Team to investigate the processing of information about pitch, roll, and yaw.

SCIENCE & MATHEMATICS SKILLS

Observing, measuring, visualizing objects in three dimensions, drawing conclusions

PREPARATION TIME

None

CLASS TIME

45 minutes

MATERIALS

Each student or team of students will need:

- Scissors
- Three strips of cardboard or posterboard (two inches wide and two feet long)
- Three metal paper fasteners (tang pins)
- Light-weight ball (ping-pong)
- Magic marker

BACKGROUND

The Neurolab Escher Staircase experiment was designed to investigate whether, within microgravity, the hippocampus received inaccurate information about pitch and roll motions, but still had a fully functional yaw motion detection system. On board Neurolab, investigators used the weightless environment to pit the vestibular and proprioceptive (which is hampered by the microgravity environment) against the visual cues of position.

The Escher Staircase is a maze that can be run only in microgravity, because it requires movement up and down and sideways along three of the walls that make up the inside of the cube. There is no distinction between horizontal and lateral movements in a microgravity environment. Rats running

MAJOR CONCEPTS

- Without gravity as a reference, the information provided to the brain about "pitch" and "roll" motions will be distorted.
- In microgravity, astronauts' brains will rely on place cells in the hippocampus for information about position.
- Place cells are more strongly influenced by vestibular and proprioceptive systems visual cues.

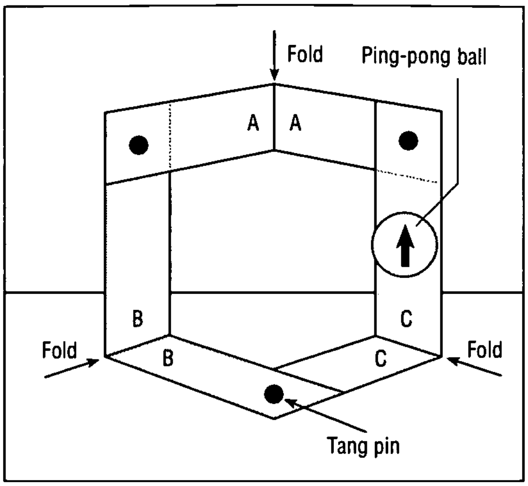


Figure 68 Diagram of a student model of an Escher Staircase.

the maze in microgravity made three 90° pitches and three 90° yaws to end up where they started. The maze is named after the artwork created by **M.C. Escher**. Escher, an artist, incorporated optical illusions into his work.

PROCEDURE

1. Discuss the trick maze experiment that the astronauts conducted during the Neurolab mission (this experiment is described in the "Things to Know" section). Tell students that they will be constructing an Escher Staircase similar to the one that was used for the experiment.

2. Have each student or pair of students follow the five steps below to build an Escher Staircase.

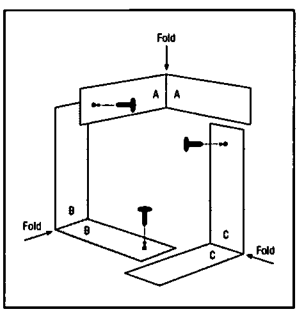


Figure 69 Diagram of the construction of an Escher Staircase.

How to Build an Escher Staircase

I. Cut cardboard into three strips (A, B and C) that are two inches wide and two feet long.

II. Punch holes near the top and bottom of each strip.

III. Bend the center of each strip to a 90 degree angle.

IV. Use the tang pins to connect strip A to strip B, and strip B to strip C at the holes.

V. Orient the strips at the tang joints so that they are 90 degrees relative to each other, and then connect strip C to strip A.

VI. Draw an arrow on the ping-pong ball.

3. After students have built the Escher Staircase model, have them move the light weight ball along the maze for one full circuit with the arrow pointing in the direction of travel (Figure 68). Have them think about whether it would be possible to walk along the maze in the presence of gravity. What about in space? What types of information would the brain need to remain oriented while walking along the staircase?

Evaluation

REVIEW QUESTIONS

1. **Describe yaw, pitch, and roll.**
   Yaw motions are in the horizontal plane relative to your body, for example, shaking your head "no."

   Pitches are turns in the vertical plane, for example, bending over forward to touch your toes.

   Rolls are turns along the long axis of your body, for example, when you accidentally roll off the bed when you are sleeping.

2. **For which of these rotational movements does the brain depend on gravity to process information about the movement?**
   Pitches and rolls.

THINKING CRITICALLY

1. **How many yaw axis turns did the students' hands make?**
   Three 90° yaw axis turns complete one full circuit on the Escher Staircase.

2. **How many pitches? If an animal has no way of encoding the pitch turns, what will the inertial navigation tell the animal's hippocampus after it has made one full circuit? What will the visual cues tell it?**
   Three 90° pitches complete one full circuit on the Escher Staircase. Inertial navigation calculations should tell the animal that it has only made 270° worth of turns and it needs to move forward and make one more 90° yaw turn before completing the circuit. Visual cues are accurate. If the animal uses the visual cues quickly, it would accurately indicate that animal's true position in the environment.

3. **Which system will the hippocampus rely on the first time the animal is exposed to the maze, having not yet learned the visual relationships between landmarks?**
   Scientists hypothesize that the animal will rely on selfmotion cues (inertial navigation) at first, because it has not spent enough time in the environment to have learned how the visual cues map out.

4. **What about the second day it runs the maze?**
   The animal will have spent enough time looking at the environment to be able to rely on its placement to tell where it is.

5. **Can you make only three 90 degree turns in the yaw axis in space, yet end up right back where you started?**
   Not if you are also moving forward.

6. **Without gravity as a reference for sensing the pitch and roll motions, how can you tell if you are back where you started?**
   Using yaw and translational movement cues along, you can keep fairly good track of where you are relative to where you started, only if you have not moved up or down. Without gravity to help your vestibular system keep track of pitches and rolls, if you make translational movements after a pitch, your map calculation of your position will be inaccurate.

SKILL BUILDING

1. The artist M.C. Escher created a number of paintings that present gravity-defying optical illusions. Have students find more examples of his work using resources at the library or on the internet.

2. Have students create their own artworks that present paradoxes or illusions in their design.

STUDENT ACTIVITY SHEET

How to Build an Escher Staircase

Name ______________________________ Date ______________

OBJECTIVE

To understand how the brain processes information about pitch, roll, and yaw.

MATERIALS

- Scissors
- Three strips of cardboard or poster board (two inches wide and two feet long)
- Three metal paper fasteners (tang pins)
- Light-weight ball (ping-pong)

DIRECTIONS

You will be constructing an Escher Staircase similar to the ones that were used for the experiment. Follow the five steps below to build an Escher Staircase.

PROCEDURES

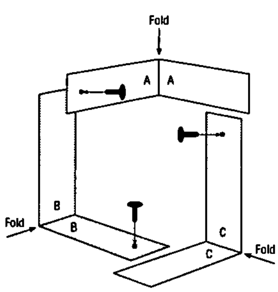


Figure 70 *Diagram of construction of an Escher Staircase.*

1. Cut cardboard into three strips (A, B, and C) that are two inches wide and two feet long.
2. Punch holes near the top and bottom of each strip.
3. Bend the center of each strip to a 90 degree angle.
4. Use the tang pins to connect strip A to strip B, and strip B to strip C at the holes.
5. Orient the strips at the tang joints so that they are 90 degrees relative to each other, and then connect strip C to strip A.

After you have built the Escher Staircase (Figure 71), move your hands or a light weight ball along the maze for one full circuit. Think about whether it would be possible to walk along the maze in the presence of gravity. What about in space? What types of information would the brain need to remain oriented while walking along the staircase?

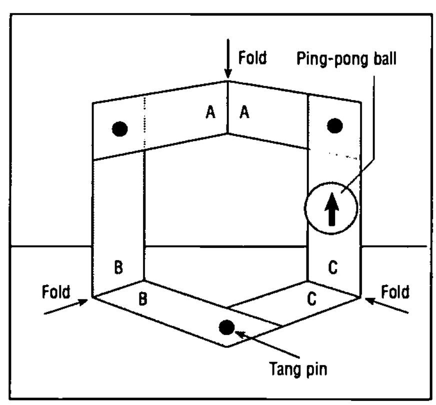
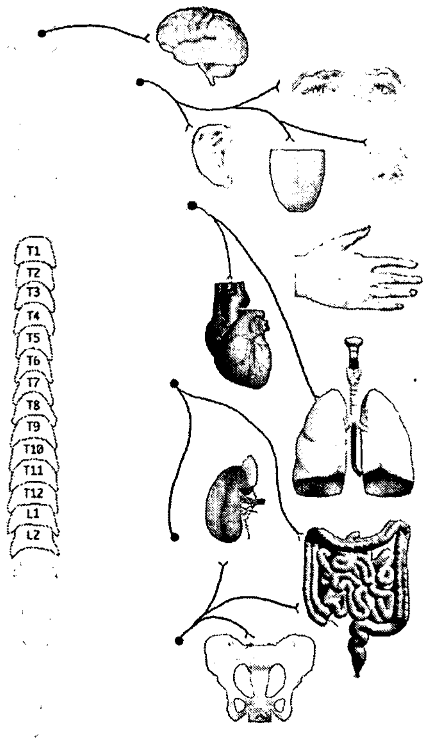


Figure 71 *Diagram of an Escher Staircase.*



Autonomic Nervous System Regulation

Lessons and Activities

GRADES 5–12

Section IV

Autonomic Nervous System Regulation

TOPIC

How did the bodies of Neurolab astronauts function in space?

The autonomic nervous system is the control center of automatic body functions.

INTRODUCTION

In the course of daily living, we seldom think about the many processes that are occurring automatically within our bodies. Fortunately, we don't have to remember to direct our process of digestion; to maintain our body temperature at 37°celsius; or to control blood pressure and the flow of blood within our circulatory system. All of these processes (and many more) are governed by a component of the nervous system known as the autonomic nervous system—the body's automatic control center.

One of the many questions that the Neurolab team asked concerns what happens to blood pressure regulation in a weightless environment. The circulatory system functions to distribute blood throughout the body under conditions created by Earth's gravity. For example, when you stand, the pull of gravity draws blood away from your head and toward your feet. However, you do not faint from lack of oxygen-carrying blood to the brain. Why not? The answer lies in the body's ability to regulate blood pressure. In spite of standing rapidly, the pressure is adjusted in order to maintain a constant flow of blood to the brain. The level of blood pressure—the pressure within your arteries—is determined by the pumping of blood into the vessels by the heart and the resistance to blood flow by those blood vessels. Your blood flow to the brain does not change because your autonomic nervous system responds to the challenge of gravity on blood flow by modulating the blood pressure.

This section contains three activities that will help you and your students explore the autonomic nervous system's regulation of blood pressure.

Things to Know

THE HEART AND BLOOD FLOW

The heart and blood vessels called arteries are responsible for carrying oxygen, nutrients, and other substances to all parts of the body. Metabolic waste products are removed from the tissues by the blood and carried to specific organs designed to remove them from the body by capillaries and veins. Blood moves through the heart and body because of a very simple principle: blood (or for that matter, any fluid) flows according to pressure difference—from where pressure is higher to where pressure is lower. The heart, which acts as a pump, is responsible for creating pressure within the closed confines of the circulatory system.

Blood pressure within a blood vessel is defined as the force exerted by the blood against the walls of the vessels. Blood pressure within the arteries rises and falls with the cycles of the heart, or stages by which blood is pumped through the four chambers of the heart and out to the circulation. Blood passes through the heart in a fixed sequence. The heart has four valves—the tricuspid, pulmonary, mitral, and aortic—which regulate blood flow between chambers and between the heart, the pulmonary vessels, and the systemic vessels (Figure 72). First, blood enters the right atrium from very large veins (the superior and inferior vena cavae). The right atrium squeezes, the tricuspid valve opens, and blood flows to the right ventricle. Next, the right ventricle squeezes, the tricuspid valve closes, the pulmonary valve opens, and blood is injected into the pulmonary artery. Blood then travels through the lungs, where it takes on oxygen and discharges carbon dioxide, and enters the left atrium through the pulmonary veins. The left atrium squeezes, the mitral valve opens, and blood flows into the left ventricle. Finally, the very muscular left ventricle squeezes, the mitral valve closes, the aortic valve opens, and blood is ejected into the aorta, the largest artery of the body. From there, the oxygen-rich blood is carried to other parts of the body by a branching system of vessels.

The walls of the blood vessels contain concentric layers of smooth muscle. These muscles and the muscles of the heart are controlled by autonomic nervous system nerves that regulate blood vessel size. A decrease in the diameters of the blood vessels makes it more difficult for blood to flow through the vessels. When this decrease in size occurs, greater pressure is required to force the blood through the vessels. This increased pressure is exerted by the heart as it forces blood into the aorta. In contrast, when the smooth muscles of the blood vessels relax, increasing the diameters of the vessels, resistance to blood flow is reduced and less blood pressure is required to maintain a given flow rate. Not only does the autonomic nervous system control the diameter of blood vessels, it also modulates the rate at which the heart pumps—either by speeding it up, or slowing it down. Through these functions, the autonomic nervous system regulates blood pressure.

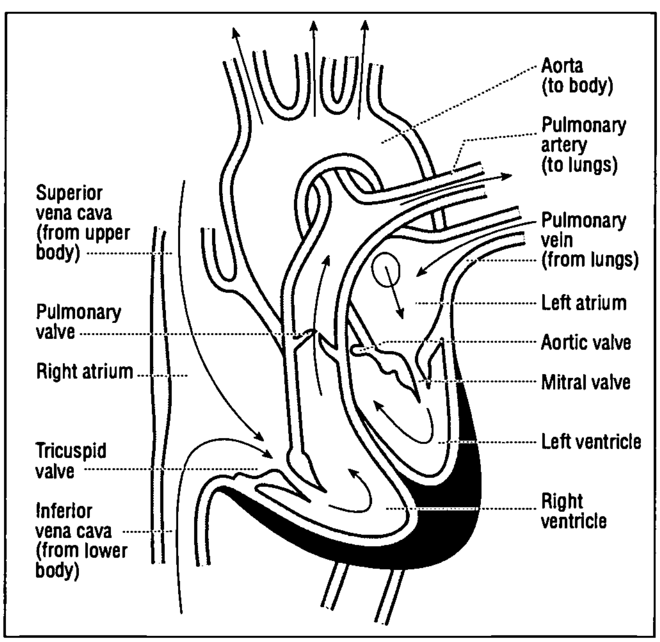


Figure 72 *Diagram of the heart and course of blood flow through the heart chambers.*

REGULATION OF BLOOD PRESSURE BY THE NERVOUS SYSTEM

The challenge of maintaining constant blood flow to the brain and other tissues while subjected to the effects of Earth's gravity is met by the regulation of blood pressure by the autonomic nervous system. The brain receives continuous information regarding the pressure exerted by the blood on the wall of the larger arteries. This is accomplished by pressure sensors (baroreceptors) strategically located in the wall of these vessels, especially one of the major arteries to the brain (internal carotid artery). These sensors transmit pressure information through nerves to the brainstem where the autonomic nervous system (Figure 73) monitors this information and reflexively makes the appropriate adjustment of the blood pressure. For example, if the blood pressure momentarily falls below a given set point, the autonomic nervous system increases the resistance to blood flow by reducing the diameter of various arteries within the body and increases the rate and force of contraction of the heart, which together result in an appropriate increase in blood pressure.

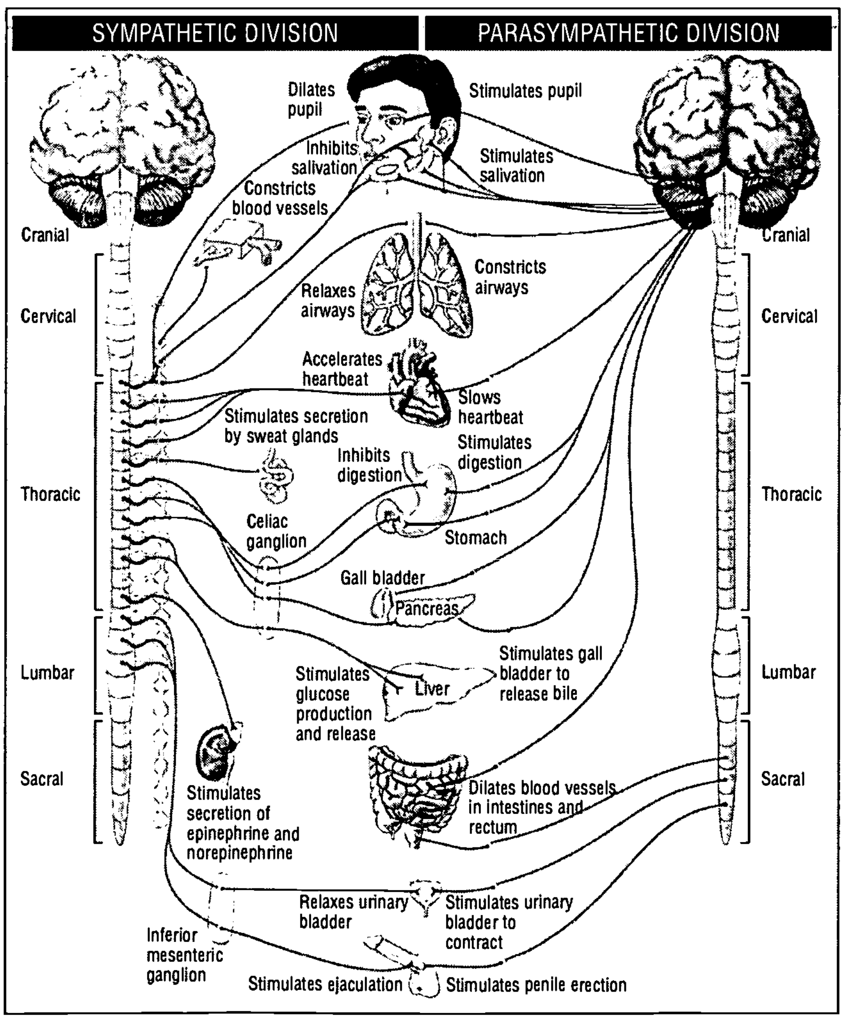


Figure 73 *Diagram of the Autonomic Nervous System.*

The Neurolab Autonomic Team investigated the adaptive changes in the regulation of blood pressure in the microgravity environment of space. They were particularly interested in understanding more about why some astronauts faint from low blood pressure when they try to stand upon their return to Earth from space missions. Focus has been directed on possible changes in the sensitivity of the pressure sensors and possible changes in the autonomic nervous system in its ability to effectively coordinate changes in arterial resistance and heart rate in the appropriate modulation of blood pressure, after exposure to microgravity for extended periods.

LEARNING ACTIVITY I:
Measuring Blood Pressure in Space

OVERVIEW

Students will learn how to measure heart rate and blood pressure accurately and to obtain consistent measurements during repeated tests.

SCIENCE & MATHEMATICS SKILLS

Observing, communicating, collecting quantitative data, creating charts and graphs, drawing conclusions

PREPARATION TIME

10 minutes

CLASS TIME

25 minutes

MATERIALS

Each group of students will need:

- Watch or access to clock with a second hand
- Stethoscope*
- Sphygmomanometer*
- Alcohol wipes to clean stethoscope ear plugs after each use
- Copy of student activity sheets: "Determining Pulse Rate Manually," "Determining Heart Rate with a Stethoscope," and "Measuring Blood Pressure with a Sphygmomanometer."

These may be obtained from the school nurse.

MAJOR CONCEPTS

- The heart supplies the energy to move blood through the system.
- Blood moves from where pressure is higher to where pressure is lower.
- Blood pressure is recorded as systolic (highest pressure in the pulse) and diastolic (lowest pressure in the pulse).

BACKGROUND

This lesson introduces students to two tools—the sphygmomanometer and the stethoscope—that are used to measure blood pressure and heart rate and engages them in measuring blood pressure and heart rate changes that occur when the body assumes different postures—lying, sitting, and standing. The Neurolab Autonomic Team was interested in obtaining information on the astronauts' blood pressures in the microgravity environment. They used more sophisticated instruments to continuously measure blood pressure and heart rate. Blood pressure is generally obtained by using a sphygmomanometer and a stethoscope. Heart rate can be obtained by using the stethoscope (Figure 74) to listen to the rate at which the heart beats or by palpating arteries that are close to the surface of the body, and counting the pulse beats.

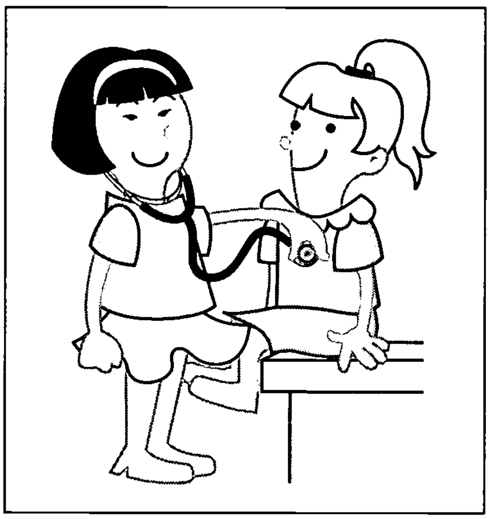


Figure 74 Diagram of student measuring heart rate with stethoscope.

During this activity, students will hear the sounds of the blood as it is pumped into the aorta to identify sounds caused by blood turbulence as a result of two sets of valves within the heart that close at slightly different times. The first and second heart sounds, which occur in close sequence, represent the closing of different valves. When using a stethoscope, the doctor will hear these valves' closure as "lup dup, lup dup, lup dup." Heart rate is determined by counting either the "lups" or "dups." Usually it is easier to count the latter during the relatively long pause. (This is the **diastole** or resting period that occurs between the second and first heart sounds.)

Students also will learn to find their pulse points and to take (or count) their pulse beats. Palpating pulse occurs as a result of the expansion of an artery from the blood pushed out by the contraction of the left ventricle. Expansion of an artery, or pulse, can be felt in the neck, at the front of the elbow, behind the knee, and in the foot. Most physicians and nurses palpate the radial artery pulse. It can be felt in the forearm, on the thumb side, where the forearm meets the palm.

Heart rate, or the speed at which the heart is beating, can be measured in several ways. The simplest method is to record the electrical activity of the heart with an electrocardiogram. However, counting heartbeats heard through a stethoscope or pulse beats felt in the wrist or neck for a period of time are other ways to determine heart rate.

Determining Pulse Rate Manually

PROCEDURE

***Note to Teacher:** You may want to invite a nurse to assist younger students in identifying heart rate by counting the number of pulse beats. Divide the class into teams of three. One student will be the subject, one will count the pulse beats, and one will record the results.*

1. Have the student counting the pulse beats place the tip of his/her index and middle fingers on the radius (the bone on the thumb side of the human forearm), and then gradually move the fingertips toward the center of the subject's wrist (Figure 75).

2. Tell the student not to begin counting the pulse beats until the subject is stationary. The student can begin counting the subject's pulse beats when the second hand of the watch is on 12. (Have the student do this for 30 seconds and he/she should record his/her answers.)

Figure 75 Photograph of a manual pulse rate count.

3. Have the student count the number of pulse beats felt during 30 seconds and record on chart (Figure 76).

4. Each pair of students should take at least three measurements of each other's pulse rate. Have students record the results. You also may want each student to calculate his/her average pulse rate. Record the average pulse rate of all the students on a class chart on the board.

5. Have the student repeat procedures three and four with the same subject and record the number of pulse beats in 30 seconds.

6. Ask the students whether, based on the results shown on their individual charts, the subjects of each of the tests were in a steady state. Why or why not?

Pulse Rate Data

Student Name	Pulse Rate

Figure 76 Chart for recording pulse rate.

STUDENT ACTIVITY SHEET
Determining Pulse Rate Manually

Name ______________________________ Date ______________

OBJECTIVE To learn how to measure heart rate accurately by counting pulses and to obtain consistent measurements during repeated tests.

MATERIALS
- Watch or access to clock with second hand.
- Note pad
- Pen or pencil

DIRECTIONS This activity requires a team of three. One student will be the subject. One student will count pulses and one will record the results.

PROCEDURE

1. The student being measured should sit comfortably in a chair with feet flat on the floor.
2. The student selected to take the pulse should place the tip of your index and middle fingers on the radius (the bone on the thumb side of the subject's forearm) and then gradually move the fingertips toward the center of the subject's wrist (Figure 77).
3. Do not begin counting the pulse beats until the subject is stationary. You can begin counting the subject's pulse beats when the second hand of the watch is on 12. (Do this for 30 seconds.)
4. Count the number of pulses felt during the 30 seconds and multiply the result by two to express the pulse rate as heart beats/minute. Record your answers (Figure 78).
5. Take at least three measurements of each other's pulses. Record the results.
6. Repeat procedures three and four with the same subject and record the number of beats.

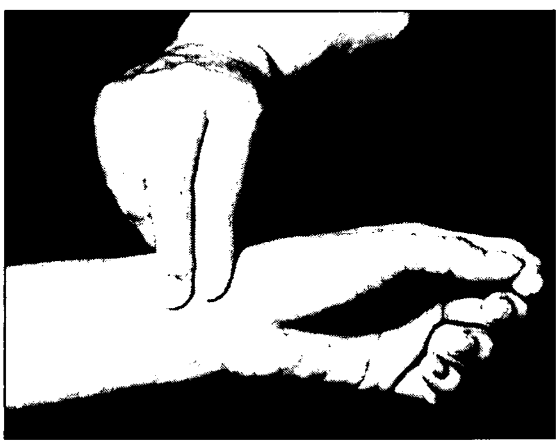


Figure 77 Photograph of a manual pulse rate count.

Pulse Rate Data

Student Name	Pulse Rate

Figure 78 Chart for recording pulse rate.

Listening to Heart Sounds with a Stethoscope

PROCEDURE

Note to Teacher: *This experiment should be done in pairs of students of the same gender.*

1. The first task is for students to learn how to use a stethoscope. They should take care to make accurate measurements. Students may work in pairs or groups of four, depending on materials available.
2. Have one student within each group place the stethoscope's earplugs in his/her ears. (As the stethoscope hangs down from the student's ears, the metal tubes should be held slightly in front of the student.)
3. Direct each student with a stethoscope to apply the bell (stethoscopes usually have two heads—a bell and a diaphragm (Figure 79) very lightly to the chest of another student (preferably male, so that the heart sounds will be louder). The diaphragm, applied firmly, is better for high-pitched sounds. The stethoscope should be placed to the left of the sternum (or breastbone) of the student who is being tested (Figure 74).

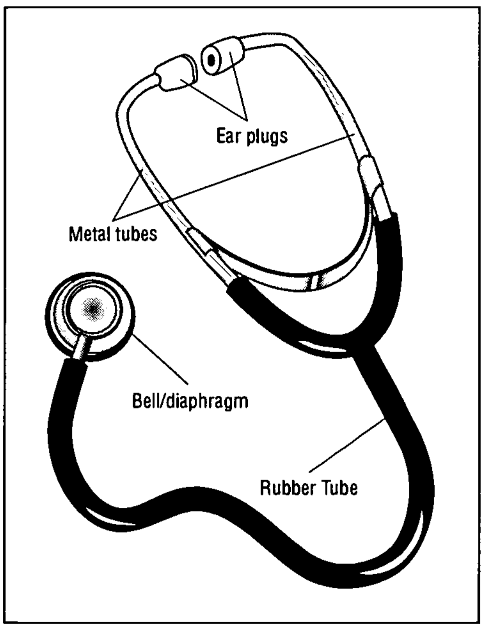


Figure 79 *Diagram of stethoscope.*

4. As the student listens, he/she should move the stethoscope around on the subject's chest, to the left of the sternum. Have students notice the loudness of the sounds. In general, sounds will be louder when the stethoscope is close to the structure generating the sounds (the heart, in this case) than when it is far away. Make sure that students are able to identify the two sounds ("lup dup") typically made by the heart.
5. Have the students take turns with the stethoscope, so that all have a chance to hear and identify heart sounds.

Determining Heart Rate with a Stethoscope

PROCEDURE

Note to Teacher: *This experiment requires at least three students. The experiment should be done by two students of the same gender. Another student should be the recorder.*

1. Have the student being measured sit comfortably in a chair with feet flat on the floor.
2. Have one student place the stethoscope's earplugs in his/her ears. (As the stethoscope hangs down, the metal tube parts should be directed slightly ahead).
3. Instruct the student to apply the bell of the stethoscope very lightly to the subject's chest on the left side of the breastbone.
4. Tell the student to listen to the subject's heart rates by moving the stethoscope around the subject's chest. Inform the student that sounds will be louder as you get closer to the heart valves. Have one student record the number of beats in 30 seconds on the chart on the Student Activity Sheet (Figure 80).
5. The student should take at least three measurements.
6. Have the students select another subject of the same gender and repeat procedures two and three.
7. To convert heart rate to beats/minute, students should multiply values in Figure 78 by two.

Individual Heart Rate Data

Student Name	Heart Rate Beats Per 30 Secs.
Student 1.	
Student 2.	

Figure 80 Chart for recording heart rate.

STUDENT ACTIVITY SHEET

Determining Heart Rate with a Stethoscope

Name ______________________________ Date ______________

OBJECTIVE To learn how to measure heart rate with a stethoscope.

MATERIALS

- Watch or access to a clock with a second hand
- Stethoscope
- Pen or pencil
- Note pad

DIRECTIONS Do the following procedures and record your data on the chart.

PROCEDURE

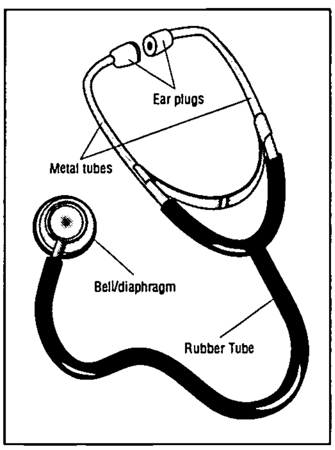


Figure 81 *Diagram of stethoscope.*

1. One person from your group should place the stethoscope's (Figure 81) earplugs in his/her ears. (As the stethoscope hangs down, the metal tube parts should be directed slightly ahead.)
2. This person should then apply the bell very lightly to the chest on the left side of the breastbone of a classmate who is the subject. (Students of the same gender should perform this activity on one another.)
3. The person applying the bell should listen to the classmate's heart rates by moving the stethoscope around the chest. Sounds will be louder when he/she gets closer to the heart's valves.
4. Listen to the number of beats while watching the clock.
5. Record the number of beats heard per 30 seconds on the chart (Figure 82).
6. Take at least three measurements.
7. Select another student (of the same gender) in the group and repeat procedures two and three.

Individual Heart Rate Data

Student Name	Heart Rate Beats Per 30 Sec.
Student 1.	
Student 2.	

Figure 82 *Chart for recording heart rate.*

Measuring Blood Pressure with a Sphygmomanometer

PROCEDURE

1. Introduce the students to the sphygmomanometer. Most of them will have had their blood pressure taken at some time at a doctor's office. Ask for a show of hands of students who have had their blood pressure measured.

2. With a student, demonstrate how to use the stethoscope and sphygmomanometer together to measure blood pressure.

3. Have the person being measured sit comfortably in a chair with feet flat on the floor.

4. Be sure that the person has not over-exerted himself/herself during the last thirty minutes, e.g., exercising.

Figure 83 Photograph of measurement of blood pressure.

5. Attach blood pressure cuff over the **brachial artery**. This artery is located inside the arm approximately one inch above the bend of the arm (Figure 83).

6. Place the earplugs of the stethoscope in the operator's ears.

7. Pump the blood pressure cuff up to approximately 200 millimeters of mercury.

8. Place the diaphragm of the stethoscope just above bend of arm. Slowly release cuff at two millimeters of mercury per second.

9. Listen carefully for the first two consecutive beats. This is your **systolic** blood pressure reading.

10. Continue to listen carefully until you hear the last of the two consecutive beats. This is your **diastolic** blood pressure reading.

11. Release the pressure from the cuff.

12. Record your readings (Figure 85).

13. Remove the cuff.

STUDENT ACTIVITY SHEET
Measuring Blood Pressure with a Sphygmomanometer

Name ______________________________ Date ______________

OBJECTIVE

To learn how to measure blood pressure with a sphygmomanometer (an instrument for measuring arterial blood pressure consisting of an inflatable blood pressure cuff, inflating bulb, a gauge showing the blood pressure, and a stethoscope).

MATERIALS

- Watch or access to clock with a second hand
- Stethoscope
- Sphygmomanometer
- Alcohol wipes to clean stethoscope ear plugs after each use
- Pen or pencil
- Note pad

DIRECTIONS

Do the following procedures and record your data in the table.

PROCEDURE

1. Have the person being measured sit comfortably in a chair with feet flat on the floor.

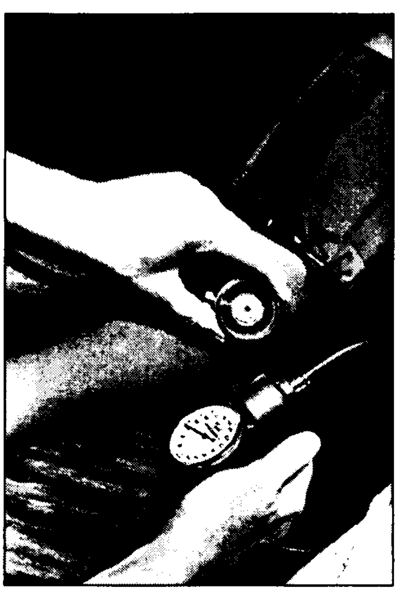


Figure 84 Photograph of measurement of blood pressure.

2. Be sure that the person has not over-exerted himself/herself during the last thirty minutes, such as by exercising.
3. Attach blood pressure cuff over the **brachial artery**. This artery is located inside the arm (Figure 84).
4. The operator should place the earplugs of the stethoscope in his/her ears; place diaphragm of stethoscope just above bend of subject's elbow.
5. Use the inflating bulb to pump the blood pressure cuff up to approximately 200 millimeters of mercury.
6. Slowly release cuff at two millimeters of mercury per second.

Name ______________________________ Date ______________

7. Listen carefully for the first two consecutive beats. This is your **systolic** blood pressure reading.

8. Continue to listen carefully until you hear the last of the two consecutive beats. This is your **diastolic** blood pressure reading.

9. Release the pressure from the cuff.

10. Remove the cuff.

11. Record your readings (Figure 85).

Blood Pressure Data

Student Name	Blood Pressure	
	Diastolic	Systolic

Figure 85 Chart for recording blood pressure.

SIGNIFICANCE OF THE TWO MEASURES TAKEN

- Blood pressure measures utilizing the stethoscope and sphygmomanometer cuff will yield the systolic and diastolic pressures.
- Heart rate can be monitored with a stethoscope placed near the valves of the heart.
- Taking pulse palpitations by placing the tip of the index and middle fingers on the radius will also yield heart rate.

  Pulse = heart rate

  Sphygmomanometer and stethoscope = diastolic and systolic pressures

Evaluation

At this point, your students should understand two basic tools necessary for studying the heart and circulatory system, the stethoscope and sphygmomanometer. They should also know how to measure and record individual heart rates.

REVIEW QUESTIONS

1. **What different methods can you use to measure heart rate?**
   The simplest way to measure heart rate is to count the pulse beats. Pulses can be found wherever an artery is accessible. Most people use the radial pulse, located at the wrist. Heart rate can also be measured from beat-by-beat blood pressure recordings or from the electrocardiogram.
2. **What is responsible for the movement we call pulse?**
   The pulse occurs when a sudden rush of blood stretches the artery. Arteries stretch as the left ventricle ejects part (over 55%) of its volume into the aorta—the largest artery.
3. **Why do we take measurements of both systolic and diastolic to determine blood pressure?**
   To determine the maximum and minimum pressures in the circulatory system.

THINKING CRITICALLY

1. Using the class data, have students determine if the heart rate and blood pressure averages they observed from their classmates are high, low or average for their age group. Ask students to identify and find resources necessary to make this determination.

SKILL BUILDING

1. Have students use resources at the library or on the Internet to investigate lifestyle habits that may cause high blood pressure (hypertension).
2. Based on their research, have students design a lifestyle for someone who may suffer from hypertension.

CONCLUSION

Explain that the astronauts on the Neurolab mission used different methods to study blood pressure. They used a small cuff device on the finger (photoplethysmograph) that actually measures the amount of light passing through the tissues of the fingers at different times (Figure 86). As the heart beats, light transmission through the finger varies with the amount of blood in the finger. The pressure in the cuff is regulated continuously to maintain light transmission in the finger at a constant level. Pressure in the cuff is measured by an electronic pressure gauge, and this measurement is used as an accurate index of actual blood pressure. You may want to make an overhead transparency of the photograph below to show to students.

When you believe your students are comfortable with, and have mastered measuring blood pressure, the next activity can be assigned as an extension to the previous one. It will allow students to see how the body adapts to changes of posture and the regulation of blood pressure.

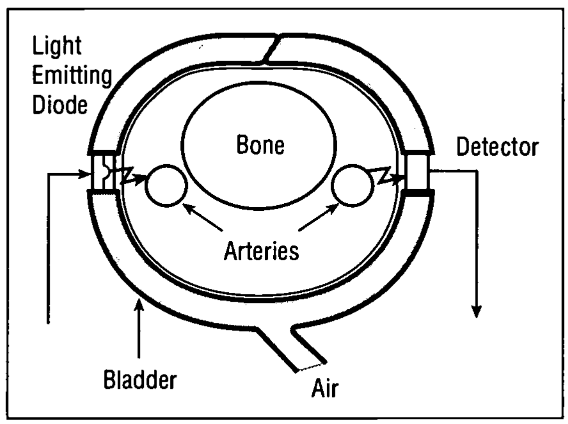


Figure 86 *Diagram of a Photoplethysmograph around a finger.*

LEARNING ACTIVITY II:
Changing Body Positions: How Does the Circulatory System Adjust?

OVERVIEW

Students will make and compare measurements of heart rate and blood pressure from three body positions: sitting, standing, and lying.

SCIENCE & MATHEMATIC SKILLS

Observing, communicating, collecting quantitative data, recording data in tables and graphs, interpreting data, drawing conclusions

PREPARATION TIME

None

CLASS

30 minutes

MATERIALS

Each group of students will need:

- Watch or clock with a second hand
- Stethoscope*
- Sphygmomanometer* (an instrument for measuring arterial blood pressure consisting of an inflatable blood pressure cuff, inflating bulb and a gauge showing the blood pressure)
- Alcohol wipes to clean stethoscope ear plugs after each use
- Copies of Activity Sheet: "Changing Body Positions"
- Table or bench long enough for a student to lie down

These may be obtained from the school nurse.

MAJOR CONCEPTS

- When a person is standing on Earth, his/her brain is above the heart and gravity is pulling fluids toward the Earth.
- The brain must have adequate blood flow.
- On Earth, blood flows to the brain because the pressure within the system is high enough to force blood upward against the pull of gravity.

BACKGROUND

This activity goes to the "heart" of one of the body's fundamental mechanisms: regulation of blood pressure. When you stand, blood tends to collect in the lowest parts of the body. Such translocation of blood could present problems if the body did not have a method to counteract it. For example, if you do not have adequate blood flow (and thus, oxygen) to the brain, you will faint. Fortunately, blood within the circulatory system flows under pressure that is high enough to counteract the force of gravity and allows blood to reach your brain even when you are standing.

This activity will demonstrate one way in which the body responds to changes in posture.

While conducting the activity, students will measure heart rate and blood pressure in three different body positions—(1) sitting, (2) standing, and (3) lying (Figure 87). Since students will be spending a short period of time in each position, they probably will find that heart rate and blood pressure have not reached a steady state when they make their measurements. Students should document these changes during the time spent in each of the positions. Measurements made every two minutes will allow students to observe some of the effects of changes of body positions.

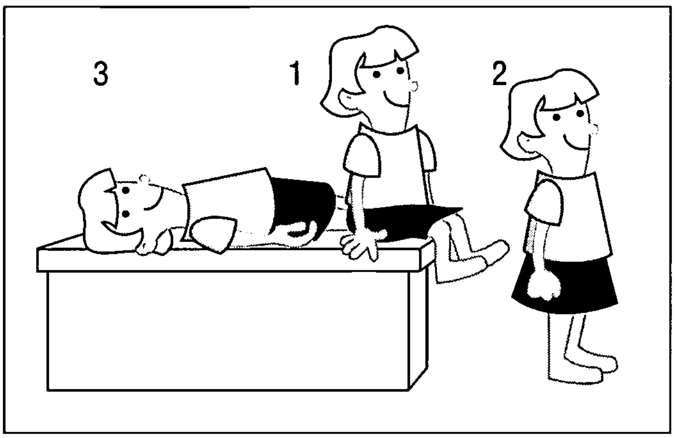


Figure 87 Diagram of three different body positions.

As discussed in the previous lessons and activities, scientists on the Autonomic Team used tools that allow for much more precise measurements of blood pressure and heart rate. After this activity, students should have a very good idea about how the body adapts to changes of posture, based on their own experimental data.

PROCEDURE

1. Have students conduct this activity in groups of four. One student in each group should serve as the subject, one should measure heart rate (measured as number of pulse beats felt in one minute), one should measure the blood pressure from the other arm, and the other should record measurements as they are called out (Figure 88).

2. Explain to the groups that they will be investigating changes in heart rate and blood pressure that occur when the body moves from sitting to standing to lying. Ask the students to think about and predict changes that might happen. Explain that measurements for each position will take seven minutes with a maximum of 30 seconds allowed for subject to change positions.

3. Pulse beats should be counted for 30 seconds and blood pressure should be measured within one minute. Both of these should be measured simultaneously within one minute. For each position, three sets of measurements are made at two-minute intervals. Students making measurements should call out their results to the group recorder, who should write the values on the data sheet.

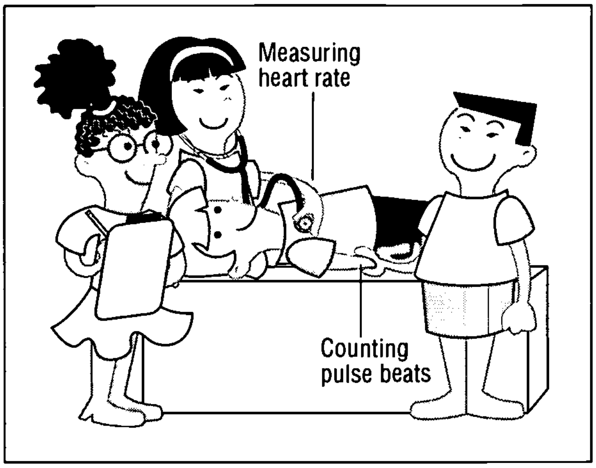


Figure 88 *Diagram of a group taking measurements of blood pressure and counting pulse beats while subject is lying on table.*

4. Have the groups conduct their experiments as follows:
   - Subject sits quietly for three minutes.
   - Students should take measurements of heart rate and blood pressure simultaneously for seven minutes.
   - After seven minutes, the subject should stand. New measurements should begin as they did in the previous trial.
   - After seven minutes, the subject should lie on table. Once again, measurements should begin as they did in the previous trials.

5. After all the data have been collected, the students should convert the 30 second counts of heartbeats into heartbeats per minute by multiplying each of the values by two. Have students create two charts: one of heart rate vs. time and another of blood pressure vs. time.

6. Ask the class to compare the two charts of heart rate and blood pressure. How are the two charts similar? How are they different? What do the results tell us about how the circulatory system adapts to posture changes? Have students think about what might happen to this activity were it conducted under conditions of microgravity.

Evaluation

REVIEW QUESTIONS

1. How does blood flow to the brain?
   Blood flows to the brain (and every where else in the body) on the basis of pressure. For blood to flow to the brain, the pressure must be lower in the brain than in the arteries that carry blood to the brain.

2. Where does the blood go when the body is in a standing position? In a sitting position?

Blood goes to the lowest part of the body, according to the degree of gravitational pull. Tall people, who have much higher columns of blood than short people, are more prone to experience reductions of blood pressure when they stand. Less blood is pooled in the sitting position because the height of the column of blood is less than in the standing position.

3. **What happens to blood flow, blood pressure, and heart rate when the body moves from lying to sitting?**
   The heart rate begins to speed; this occurs very rapidly, often within one second. Speeding of the heart helps to prevent a major fall in blood pressure. Also, the vessels constrict to increase resistance to flow and keep blood pressure up.

THINKING CRITICALLY

1. **Challenge your students to think about how the circulatory system might respond to changes in a microgravity environment. Which aspects of the system might stay the same? Which might be different?**
   Absence of gravity causes major changes in the circulation. The most important of these is that there is no gravitational pull of blood toward the feet when a person stands. Pressure in the feet is the same in lying and standing positions. Therefore, blood redistributes from the lower body to the upper body. The autonomic nervous system does not have to adjust to body positions as on Earth. This is not to say that there is no autonomic nervous system control of the circulation in space.

Figure 89A *Diagram of individual who feels faint.*

2. **Ask students to think about why people feel faint or dizzy (Figure 89A) when they stand up very rapidly. Or conversely, why are people instructed to put their head between their knees (Figure 89B) when they feel faint?**
   Rapid standing causes a rapid fall of blood pressure. The fall of pressure reduces blood flow to the brain momentarily, until the regulatory mechanisms in the brain and circulation can kick in and restore pressure to normal levels. By putting one's head between the knees, the head becomes dependent, pressure in the arteries of the brain increases, and blood flow to the brain increases.

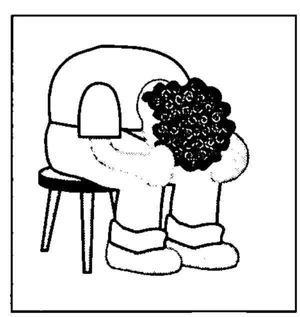


Figure 89B *Diagram of individual with head between the knees.*

SKILL BUILDING

1. After each group has graphed the sets of measurements they obtained from the experiment, have them produce a written interpretation of the data. Let each group share its write-ups with the class.

APPLICATION

Your students should now have a better understanding of how heart rate and blood pressure change in response to body movement. The Autonomic Team studied similar questions under conditions of microgravity. They used different methods, however, to gauge the postural responses in space. One of the main issues is that, although astronauts can stand in space, they (and their circulatory systems) do not experience the pull of gravity as they do on Earth. To simulate the gravity environment, the astronauts had the lower halves of their bodies enclosed in a chamber that was sealed around their waists. Suction was applied to the chamber so that a reduced pressure drew blood to the lower body. The actual chamber that was used is shown in Figure 90.

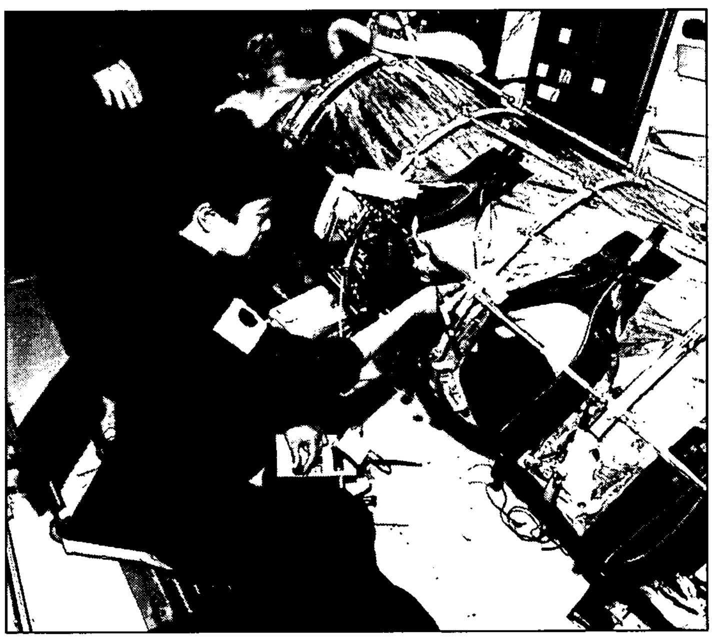


Figure 90 Photo of a pressure chamber.

STUDENT ACTIVITY SHEET
Changing Body Positions

Name ______________________________ Date ______________

OBJECTIVE To measure the changes of heart rate and blood pressure with changing body positions.

MATERIALS
- A watch or clock with a second hand
- Sphygmomanometer
- Stethoscope
- Pen or pencil
- Alcohol wipes
- Note pad

DIRECTIONS Follow the procedures and record data on the charts (Figures 91 and 92).

PROCEDURE

1. Four students are required to do this activity. (One is the subject, one counts pulses, one measures blood pressure, and one records results. Select the role each person in your group will perform.
2. Have one student from your group sit quietly in a chair with feet flat on the floor.
3. One student should count the number of pulse beats for 30 seconds, then multiply that number by two and call out the number to the recorder. (Heart rate is expressed as pulse beats per minute.)
4. Simultaneously, another student should measure blood pressure within one minute and call out the number to the recorder.
5. Take three separate measurements at two minute intervals.
6. The recorder should write the numbers called out on the chart.
7. Repeat procedures "2" – "6" with the student subject standing.
8. Repeat procedures "2" – "6" with student subject lying.
9. In order to calculate the heart rate, multiply the number of pulse beats per 30 seconds by two.

Heart Rate

Minutes	Seconds	Beats Sitting	Beats Standing	Beats Lying
Minute 1	30			
	30			
Minute 2	30			
	30			
Minute 3	30			
	30			

Figure 91 Chart for recording heart rate.

Blood Pressure

Minutes	Sitting		Standing		Lying	
	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic
1						
2						
3						

Figure 92 Chart for recording blood pressure.

LEARNING ACTIVITY III:
Baroreceptor Reflex Role Play

OVERVIEW

In this activity, the students will learn the importance of maintaining adequate arterial blood pressure through a role playing exercise which demonstrates the baroreceptor reflex (BR) arc—a human model of the BR loop. The BR arc will demonstrate how the brain processes information and sends out signals to the heart and arteries.

SCIENCE & MATHEMATICS SKILLS

Prediction, observing, collecting quantitative data and interpreting data

PREPARATION TIME

10 minutes

CLASS TIME

45 minutes

MATERIALS

- Index cards to be used as cue cards indicating students' roles (nine students per group)

MAJOR CONCEPTS

- If development in microgravity alters the development of the baroreceptor afferent neurons, the circuit may not function normally on Earth.
- The functions of each part of the baroreceptor reflex are required to properly maintain arterial blood pressure.

BACKGROUND

Baroreceptors are specialized neural receptors that sense changes in blood pressure. The baroreceptor reflex relies on sensing pressure changes in the **aorta** and **carotid artery**. If stimulation of the baroreceptors is altered, such as in a microgravity environment, a change would occur in the firing frequency of the nerves connected to the baroreceptors that send signals to the brain.

The baroreceptor reflex circuit includes both **sympathetic** and **parasympathetic** nerves to the arteries and heart in order to maintain proper arterial blood pressure. The baroreceptor reflex can either increase or decrease arterial blood pressure in order to return it to normal levels. If the arterial blood pressure increases, the firing rate of the baroreceptors increases, sending a greater frequency of impulses through the afferent (inflowing, i.e., towards the brain) baroreceptor nerves. The reflex in this instance will cause activation of the vagus nerve, decreasing the rate of heart contraction to reduce arterial pressure. If the pressure falls, decreased firing and frequency of impulse result. In turn, the sympathetic nerves are activated, thereby causing the heart to contract more rapidly and of blood vessels to constrict, which will increase arterial blood pressure.

Through this reflex circuit, arterial blood pressure is maintained. It is crucial to maintain blood pressure within this specified range because the organ functions of the body depend upon an adequate supply of blood at a relatively constant pressure.

PROCEDURE

This activity requires nine students per group.

1. Students should be arranged in groups of nine to represent the parts of the baroreceptor reflex loop according to the diagram in Figure 94.
2. Explain the role of each student so that the students will have a clear understanding of their roles before the activity begins (Figure 93).
3. Tell the student playing the **arterial pressure** (student #1) to squeeze the arm of the baroreceptor (student #2) firmly to represent increased pressure. In turn, instruct the baroreceptor (student #2) to use a number system to signal increased or decreased pressure to the baroreceptor afferent (student #3). The number system could be one to signal low pressure, two to signal normal pressure and three to signal increased or high pressure.

Position	Role	Task
1	Arterial pressure	Squeeze the arm of student #2
2	Baroreceptor	Assign the numeric value according to pressure to student #3
3	Baroreceptor afferent	Relay the numeric value to student #4 or #5
4	Vasomotor center	If the number is low (low pressure), student #4 becomes activated
5	Vagal center	If the number is high (high pressure), student #5 becomes activated
6	Vagus nerve	Receive information from student #5 and tell student #8 (heart) to decrease rate of pumping
7	Sympathetic nerves	Receive information from student #4 and tell student #8 (heart) to increase rate of pumping and tell student #9 (arteries) to constrict to increase pressure
8	Heart	Tell student #1 what to do
9	Arteries	Tell student #1 what to do, then student #1 tell student #2 what to do

Figure 93 Chart of students' positions, roles and tasks representing the baroreceptor reflex loop.

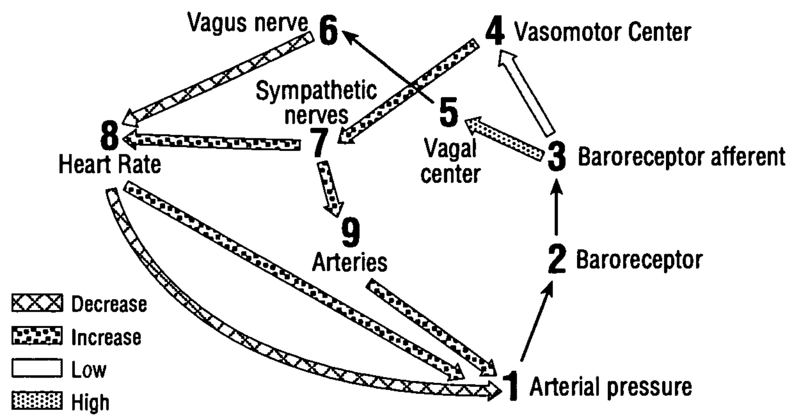


Figure 94 *Diagram of a baroreceptor reflex loop involved in maintaining proper blood pressure.*

4. Direct the baroreceptor (student #2) to report these numbers to the two areas of the medulla—the vasomotor center (student #4) and vagal center (student #5).

EXPLANATION

Note to the teacher: *At this point, use procedures 5 through 8 to help the students understand how the baroreceptor reflex loop works.*

5. Once the baroreceptor signals high pressure, the **vagal** center will tell the vagus nerve to go into action.

6. The vagus nerve goes to the heart and tells it to stop pumping quite so hard and fast. The heart will tell arterial pressure to relax the grip on the baroreceptor's arm to reduce the number reported by the baroreceptor to two, normal pressure.

7. If the baroreceptor signals number one (low pressure), the vasomotor center tells the sympathetic nerves to go into action.

8. The sympathetic nerves tell the heart to increase its pumping rate and the arteries to constrict. The arteries and the heart tell the arterial pressure to increase the grip to two, normal pressure. In this case, the baroreceptor would signal normal pressure.

Once pressure is back to normal, you can introduce certain things that would change the pressure. For instance, you could say that a lion was just spotted and the heart should automatically tell pressure that it increased its pumping, the vessels should tell pressure that they constricted and the pressure should go to number three (high pressure).

Evaluation

REVIEW QUESTIONS

1. **What two things are primarily responsible for making arterial blood pressure increase or decrease?**
   The rate at which the blood is pumped into the arteries by the heart and the resistance to blood flow within the arteries are primarily responsible for changes in arterial blood pressure.

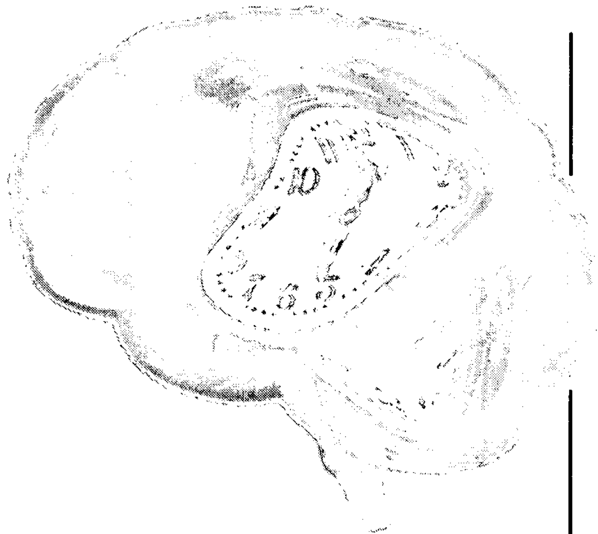
2. **What areas of the brain are involved with the baroreceptor reflex?**
   The areas of the brain that are involved in the baroreceptor reflex is the vasomotor center and vagal center.

3. **What part of the loop might microgravity influence through its presence during human development?**
   Any part of the baroreceptor reflex loop could be influenced by lack of gravity during human development. The baroreceptor nerves were studied on Neurolab.

4. **Why is blood pressure so important?**
   An appropriate blood pressure is important to maintain blood flow through the blood vessels to the brain and other vital organs.

THINKING CRITICALLY

Have your students write a brief paragraph and explain why they do not faint when they stand up. You also can have them explain why they feel light-headed for a few moments when they stand up quickly.



Sleep and Circadian Rhythms

Lessons and Activities

GRADES 5–12

Section V

Sleep and Circadian Rhythms

TOPIC

How did the Neurolab astronauts' sleep patterns change in microgravity?

Did these changes affect the astronauts' reaction times and/or performances?

INTRODUCTION

Human sleep occurs in a daily circadian rhythm. The periods spent between sleep and wakefulness (or rest and activity) are coordinated with the environmental light/dark cycle. The circadian timing system (CTS) acts as a master control to ensure that the various physiological "systems" of the body (including the nervous system, the respiratory system, the cardiovascular system, and others) work together in a synchronized and coordinated fashion. If the CTS is not working properly, an organism's health and performance will be negatively affected.

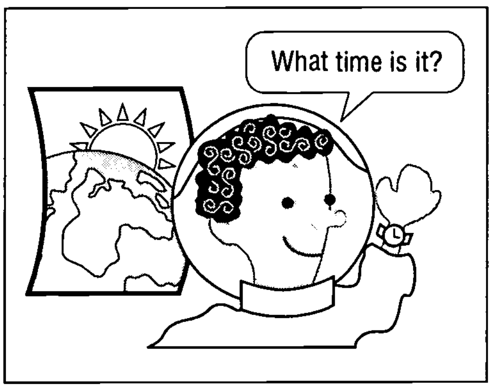


Figure 95 *Diagram illustrating an astronaut's CTS having no normal "day" or "night" cycle.*

When astronauts fly in space, there is a sunrise and sunset every 90 minutes (one each orbit). Considering that the Space Shuttle is flying at 17,000 miles per hour and that the astronauts need to control the Shuttle for landing and maintaining orbit, we can begin to understand why it is important that astronauts remain alert and focused. However, since the astronauts' circadian timing systems have no normal "days" or "nights" (Figure 95), the astronauts' rhythms must rely on the light schedule of the Space Shuttle and their internal clocks.

Things To Know

CIRCADIAN TIMING SYSTEM

The Circadian Timing System (CTS) contains a "clock" located within the hypothalamus of the brain. This "clock" helps to synchronize bodily functions with the external environment. Through its connections with the retina of the eye, it receives and monitors information about the external light/dark cycle. Based on this information, the clock organizes an animal's physiology, biochemistry, and behavior. The CTS ensures that the body's internal environment is appropriate for the tasks that the body has to perform. By coordinating the body's internal clock with sunrise and sunset, the body synchronizes the daily rhythms that help optimize the body for daily living.

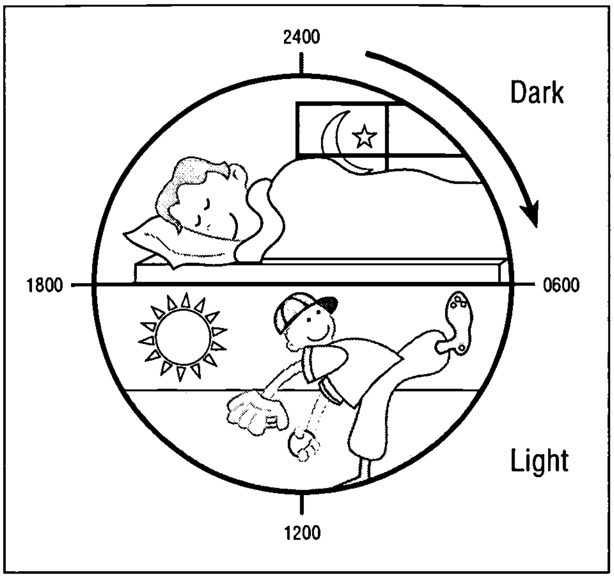


Figure 96 Diagram illustrating the 24-hour light/dark cycle.

Our circadian clocks tell our bodies when it is time to go to sleep and when it is time to wake (Figure 96). For example, in humans, our body temperatures rise before we awaken, remain high during the day when we are active, and drop as we sleep at night. People whose rhythms are not working properly may fall asleep at the wrong time, or may not be able to sleep when they should. This can be dangerous, since certain activities, such as driving, learning in school, working, or even playing, require us to be alert.

The CTS influences sleep and wakefulness through its connections with various brainstem nuclei. These nuclei use several neurotransmitters to determine the degree or level of sleep or wakefulness (alertness). This is accomplished through brainstem projections to the thalamus and cerebral cortex. In turn, the CTS modulates this neuronal circuitry to appropriately adjust the durations of sleep and wakefulness, as well as the levels of consciousness during the 24-hour light/dark cycle.

Experiments in which individuals have been deprived of environmental time clues (for example, the light of day) have shown that the body's daily cycles are driven by the CTS clock. For example, the subjects in these experiments continue to eat and sleep on a daily cycle, but the timing of that cycle is determined by the internal clock, which is close, but not equal to, the 24-hour day. Without the CTS or daily light/dark cues, individuals would generally wake up and go to sleep later each day. However, the length of time spent in sleep and/or wakefulness would remain relatively the same during a typical 24-hour cycle. The importance of proper CTS function is illustrated by the fact that conditions such as jet-lag, problems resulting from working night shifts, and some sleep and mental disorders are associated with dysfunction of the CTS.

During space missions, astronauts may have disrupted sleep and work schedules. This can produce physical symptoms, such as fatigue and general feelings of discomfort (malaise). This could affect the ability of crews to perform their tasks during a mission. The Neurolab Sleep and Circadian Rhythms Team examined nervous system regulation of sleep and wakefulness during the mission and examined how alterations in sleep patterns affected astronauts' abilities to carry out certain tasks in space.

The Neurolab experiments examined the physiology of the Circadian Timing System (CTS) and homeostatic control (equilibrium in the body with respect to various functions) of animals exposed to space flight. This data was compared to those of animals kept in similar environments on Earth. Some of the animals were exposed to a light-dark cycle and some were exposed to constant light. The constant light environment did not provide any time cues to the animals, allowing the scientists to examine the innate characteristics of these animals' CTS clocks.

SLEEP AND RESPIRATION

Scientists also believed that astronauts' sleep patterns and quality of sleep would be affected by other factors as well. For example, they hypothesized that, during sleep, the relationship between respiration and heart rate would change in microgravity. They also believed that, during sleep, there would be less oxygen in the arterial blood. Therefore, the astronauts would awaken more easily. The scientists also tested the hypothesis that, when the astronauts were awake, breathing responses to carbon dioxide and low oxygen (hypoxia) levels were increased in microgravity. They believed this would also disrupt sleep. The scientists expected to find that in microgravity, the chest and abdomen do not move in synchrony during sleep, thereby adding to sleep disruption.

LEARNING ACTIVITY I:
The Geophysical Light/Dark Cycle

OVERVIEW

Students will discover how the light/dark cycle is dictated by the rotation of Earth. In addition, they will examine the annual changes in the duration of light each day as the planet orbits the sun.

MAJOR CONCEPTS

- The light/dark cycle is accelerated for astronauts orbiting Earth.
- Changes in the light/dark cycle may lead to disruptions of sleep and other bodily cycles.

SCIENCE & MATHEMATICS SKILLS

Observing, communicating, modeling, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

- Globe
- Flashlight
- Pencil

BACKGROUND

Astronauts do not experience the 24 hour light/dark cycle that is normal for Earth. Instead, while they are orbiting the planet, they experience sunrise and sunset every 90 minutes. Thus, their Circadian Timing Systems (CTS) cannot use external light cues to reset their internal clocks. In general, body functions that occur rhythmically every 24 hours are called circadian rhythms. The body's primary biological clock is the suprachiasmatic nucleus located in the hypothalamus. It regulates many of the body's internal, or endogenous (produced within the organism), rhythms.

The external light/dark cycle, in other words, the hours of daylight (diurnal cycle) and hours of darkness (nocturnal cycle), is particularly important in maintaining regularity of the CTS. The sleep/wake cycle is particularly susceptible to becoming disrupted by changes in external light-dark cues. The sleep/wake cycle is one of the endogenous rhythms of the body.

The CTS maintains coordination of the organism by monitoring the environment and resetting an internal clock to match the external environment. Disruptions in this process can affect alertness and performance. When astronauts fly in space, their CTSs have nothing (no normal "days" or "nights") by which to set themselves. Thus, the astronauts' rhythms must rely on the light schedule of the Space Shuttle and their internal clocks, which may also be altered by the absence of the force of gravity during space flight. This activity will help students understand the changes that occur in the light/dark cycle experienced by astronauts while they orbit Earth.

PROCEDURE

1. Have students mount a flashlight (Figure 97) so that it is stationary and directed at a globe.

2. Instruct students to rotate the globe slowly from west to east (or left to right) to mimic the daily rotation of Earth.

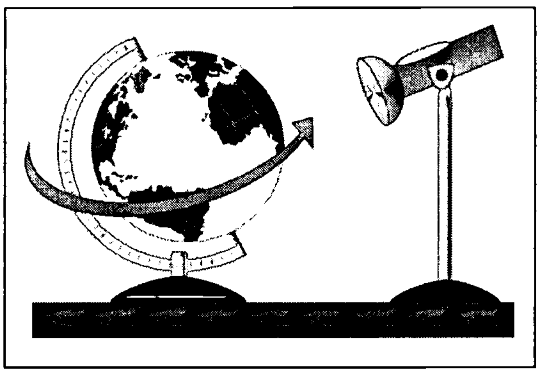


Figure 97 Diagram of the geographical light/dark cycle.

3. Direct students to change the angle of the tilt of Earth as it faces the sun. The students should observe how the tilt of Earth's axis alters where the sun shines upon the surface. Have them identify when a particular part of Earth is experiencing "day" and when it is experiencing "night."

4. Help students visualize the accelerated light/dark cycle that occurs during orbit by having one student rotate a pencil or other object around the globe as it continues to spin on its axis.

5. Discuss the implications of changes in the light/dark cycle for astronauts aboard an orbiting space craft.

Evaluation

REVIEW QUESTIONS

1. **What causes light/dark cycles on Earth?**
   The sun and the rotation of Earth.

2. **How do these cycles change for astronauts aboard a spacecraft in orbit?**
   The Shuttle orbits once every 90 minutes, which provides a "sunrise" and "sunset" every 90 minutes. (Of course, if the astronauts are not near a window, this is not seen.)

THINKING CRITICALLY

1. Ask students what happens if the Circadian Timing System is not working properly.
   The sleep/wake cycle will be interrupted and other functions in the body will no longer be properly coordinated.

2. Ask students to think about what might happen to people whose rhythms are not working properly?
   How might these problems affect certain types of jobs here on Earth?
   They might become sleepy at inappropriate times (e.g., on the job); excessive tiredness; decrease in motor performance (e.g., driving, riding a bike, catching a ball), etc.

SKILL BUILDING

1. Have students construct a list of types of jobs that might cause problems with the Circadian Timing System, or that might work against the body's natural sleep/wake cycles.

2. Have students use the Internet or library resources to learn about recently discovered ways to reset the body's internal clock to reduce or eliminate jet lag. How is this related to problems experienced by astronauts?

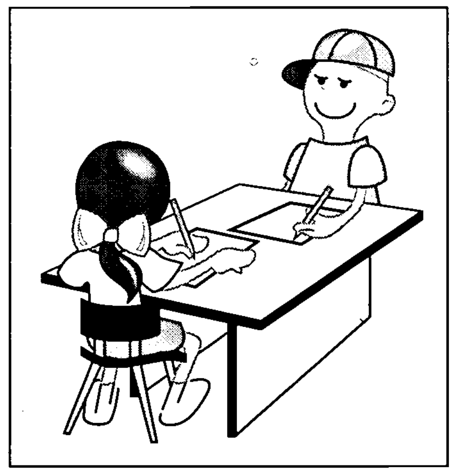


Figure 98 *Diagram of students constructing job lists.*

LEARNING ACTIVITY II:
How Quick Are Your Responses?

OVERVIEW

In this activity, students will learn what reaction time is and how it is measured.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, calculating averages, drawing conclusions

PREPARATION TIME

10 minutes

CLASS TIME

50 minutes for each of two parts

MATERIALS

Each group of students will need:

- Ruler
- Scissors
- Pen or pencil
- Meter stick
- Note pad

MAJOR CONCEPTS

- Reaction time can vary even for the same individual.
- When subjects are tired, reaction time can be slower.

BACKGROUND

When the sleep/wake cycle is disrupted, people can become fatigued and may not perform as well as they usually do in a variety of situations. This activity will allow students to learn about reaction time (the time interval between the presentation of a stimulus and the body's voluntary reaction to that stimulus) and how reaction time might be affected by lack of sleep.

A Reaction Time Test will be used as a means of determining the time it takes to react or respond to a given/presented stimulus. Usually, such tests are performed multiple times to account for the normal range of variation in measurements. In Neurolab, a computerized test determined astronauts' reaction times accurately. The corresponding test to be used on Earth depends on gravity and will not work in the weightless environment of space.

Reaction times can vary even for the same individual, because when subjects are tired, reaction times can be longer. This lesson focuses on the normal range of reaction time, how it is measured, and how it varies with alertness level.

PROCEDURE

Part One: Learning to Measure Reaction Times

Have students work in pairs to do the following activity:

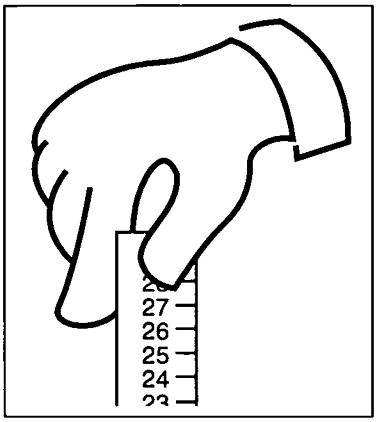


Figure 99 Diagram of the forefinger and thumb position.

1. Before beginning, have each student assess, on a scale of one to ten, how sleepy they are—with "1" being not at all sleepy, "5" being somewhat sleepy and "10" being ready to fall asleep instantly.
2. Within each team, have one student hold a ruler with centimeters (between the thumb and forefinger) vertically at the 30 cm mark with the 0 mark toward the floor (Figure 99).
3. Instruct the student's partner to position his/her forefinger and thumb at the 0 cm end of the ruler without touching it, so that he/she will be able to grab the ruler easily by closing his/her finger and thumb together (Figure 99).
4. Tell the partner to observe the ruler carefully and then have the first student release the ruler.
5. Direct the partner to close his/her thumb onto the ruler to stop it as soon as the ruler moves.
6. Have the student mark the place where the partner's fingers were when he/she stopped the ruler. The student should discard the first result if the ruler moved less than five centimeters.
7. Have the students repeat the release/catch process 20 times and record and average the results on a chart (Figure 100).
8. Have the students change places so that all will have an opportunity to do this activity.
9. As a class, plot the average values of each student's reaction times as a histogram, as shown in Figure 101. Have students think about what really is being measured in the activity, and how distance in centimeters reflects reaction times.
10. Have students calculate the average value of their reaction times and the average value of their sleepiness scores. To do so, add the values together and divide the sum by the number of values.
11. Ask the students to identify the normal range of reaction times in their class population. Example: If sleepiness score is a "3" and the average reaction time is ___, add 3 + ___ and divide the sum by ___ (number

Reaction Times

Release #	Result
1	______
2	______
3	______
4	______
5	______
6	______
7	______
8	______
9	______
10	______
11	______
12	______
13	______
14	______
15	______
16	______
17	______
18	______
19	______
20	______
Average	______

Figure 100 Example of chart for recording reaction times.

of values.) Discuss reaction time variance and alertness level. Ask the students about the times when distances less than 5 cm occurred during the trials. Why was it important to discard these results?

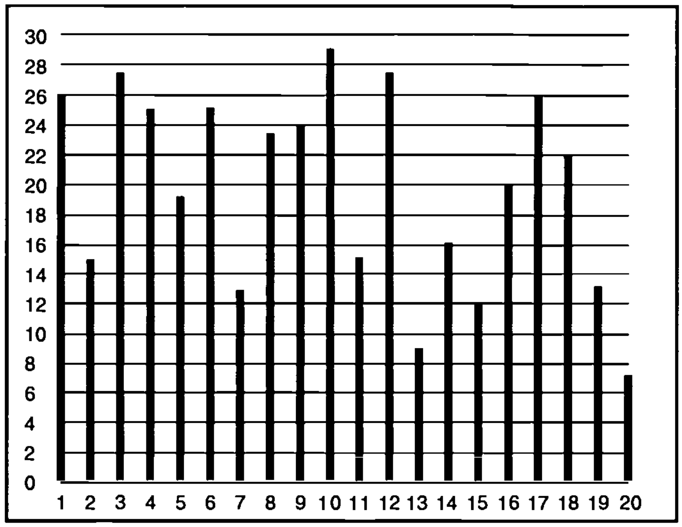


Figure 101 *Example of histogram of the values of students' reaction times.*

Part Two: The Effects of Being Tired on Reaction Times

This exercise is designed to test the students' reaction times after they are feeling tired. Have students follow the steps below in order to obtain accurate results.

1. Have each student take a ruler home.

2. Inform students that they will need to ask someone at home to help them with this activity, and suggest that the students perform this activity on a Friday or Saturday night so as not to disrupt their weekly routines.

3. Have students ask their parent(s)/guardian(s) for permission to stay up one or two hours beyond their normal bed time. (Remind the students that their partners also will have to stay up.)

4. Instruct students to perform 20 trials of reaction times tests before they go to bed. Inform them that they must be feeling tired and ready to go to bed before doing this exercise. (Ask students to evaluate how sleepy they feel using the same scale as in the previous activity.)

5. Direct the students to repeat the activity after they have each had a good night's sleep. (Again, ask them to evaluate how sleepy they feel using the same scale as in the previous activity.)

6. Have students calculate their average reaction times during each trial (night and morning).

7. Compile another set of class averages and a histogram (Figure 101) as before. Have students discuss the results. Have them think about and discuss the physical and mental symptoms of being tired and how these might have affected their reaction times.

Evaluation

Students should now have some understanding of how lack of sleep or fatigue can influence their abilities to respond quickly.

REVIEW QUESTIONS

1. **What happens to reaction time when one is sleepy or tired?**
   Reaction time is slower.

2. **What are physical signs of being tired?**
   What are mental signs of being tired?
   One physical sign of being tired is inaccurate motor coordination.
   A mental sign of being tired is lack of concentration.

THINKING CRITICALLY

1. Ask the students whether or not the sleepiness scores were greater just before going to bed or in the morning.

2. Ask the students whether or not reaction times were longer in their tests performed just before going to sleep or in their tests done in the morning at school.

3. **Discuss with the students what would happen if one was not allowed to sleep for the whole night, and then performed the reaction time test. (Make sure students understand they should NOT do this!)**
   The reaction time would become slower if there were no sleep during the whole night.

SKILL BUILDING

1. Have students conduct a survey of family and friends by asking them to report their sleepiness scores throughout a 24-hour cycle. Are any general trends obvious among all persons surveyed. When are most people alert? When are most people sleepy? How could this information be used to design job or school schedules?

LEARNING ACTIVITY III:
Measuring Your Breathing Frequency at Rest

OVERVIEW
Students will learn to measure their resting breathing rates.

SCIENCE & MATHEMATICS SKILLS
Observing, collecting and recording quantitative data, charting data, drawing conclusions

PREPARATION TIME
None needed

CLASS TIME
50 minutes

MATERIALS
Each team of students will need:

- Watch or access to a clock with a second hand
- Chair
- Pen or pencil
- Note pad

MAJOR CONCEPTS

- Breathing rate is controlled by the interaction of special pacemaker cells in the brain.
- Breathing frequencies are different for each person.

BACKGROUND

Breathing involves the movement of air in and out of the lungs. This facilitates the exchange of O_2 (oxygen) and CO_2 (carbon dioxide) between the blood and the external environment, a process known as **respiration**. The levels of O_2 and CO_2 are tightly regulated and help to determine the rate of breathing frequency. Changes in the control of breathing can lead to altered levels of O_2 and CO_2 in the blood. During space flight, the respiratory patterns and motions of the chest and abdominal wall are altered. Neurolab scientists used an array of measurements to correlate the changes in respiratory patterns and oxygen levels in the blood that occur during sleep and with sleep disturbances.

The number of breaths taken per minute is referred to as breathing frequency or respiratory rate. In a resting person, the average is around 15 breaths per minute, although there are large variations from person to person. Breathing frequency is usually altered while exercising or doing other activities in order to provide the body's cells and tissues with a continuous and adequate oxygen supply. The name given to the amount of air that is inhaled or exhaled in a single normal breath is "tidal volume," because breathing occurs cyclically—"in" then "out," "in" then "out"—rather like the tides in the ocean.

Special receptor cells (ventilatory chemoreceptors) near major blood vessels and on the ventral surface of the brainstem (medulla oblongata) are designed to detect levels of oxygen or carbon dioxide in the blood (often referred to as "blood gases") and cerebrospinal fluid (CSF), respectively. These receptors utilize neuronal pathways to send messages to other centers in the brain which adjust ventilation according to the levels of blood gases detected. Scientists now believe that the microgravity environment in space affects the regulation of ventilation and that this may also affect sleep cycles in space.

Oxygen is essential for many processes within the body, especially cellular respiration. The air we breathe contains about 21% oxygen and 0.05% carbon dioxide. Carbon dioxide is produced as waste during cellular respiration and must be released out of the body through the lungs. Exhaled gas normally contains about 5% carbon dioxide. Both oxygen and carbon dioxide combine with components of the blood in reversible biochemical reactions.

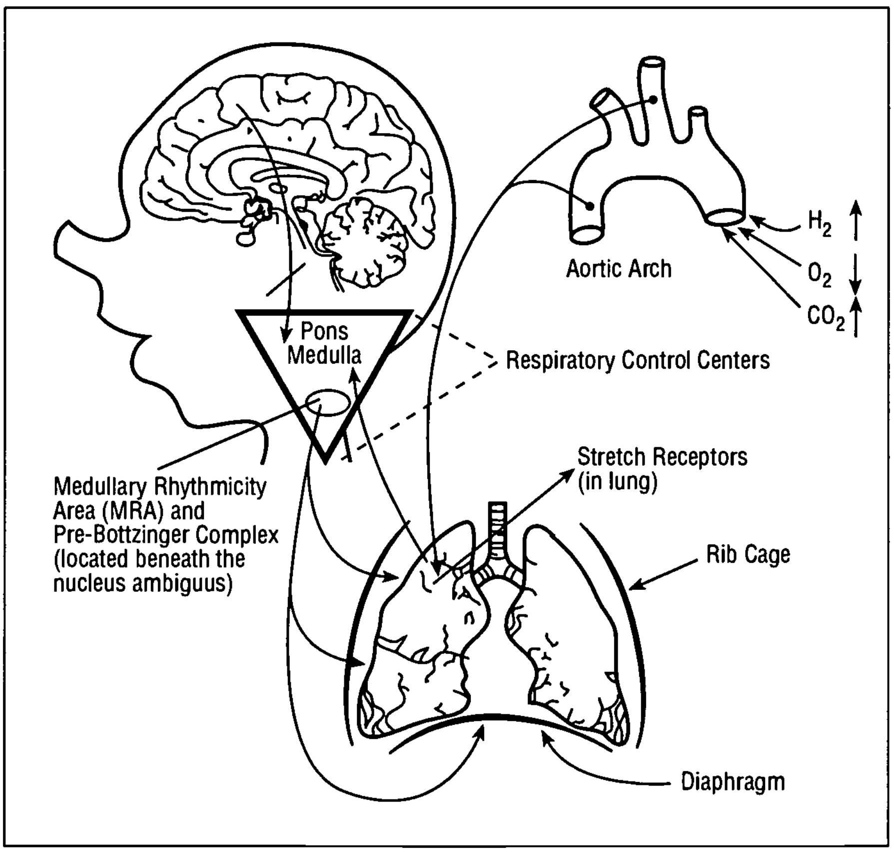


Figure 102 Diagram of the centers in the brain.

Centers in the brain (Figure 102) control breathing rate. Although there are several respiratory control regions in the nervous system, two main sites are primarily responsible for regulating breathing and the supply of oxygen to the lungs as well as the rest of the body. One site is the ventral surface of the medulla in the brainstem. This site detects only pH or carbon dioxide levels in the blood. The other main site is the carotid bodies, found in the neck. These sites are sensitive to carbon dioxide, oxygen and pH, although their principle purpose is to detect low blood oxygen levels. These receptors are known as chemoreceptors because they sense and respond to specific dissolved chemicals in plasma. These ventilatory chemoreceptors send signals to the nervous system whenever blood gases deviate from the desired set point (e.g., low oxygen or high carbon dioxide).

PROCEDURE

1. Have students work in pairs. Direct one student of each pair to sit quietly with his/her eyes closed.

2. Instruct the partner to observe the student's breathing carefully by watching the rise and fall of the chest, counting the number of complete breaths that the student makes over the course of one minute using the watch or clock. Have the partner record the number of breaths per minute.

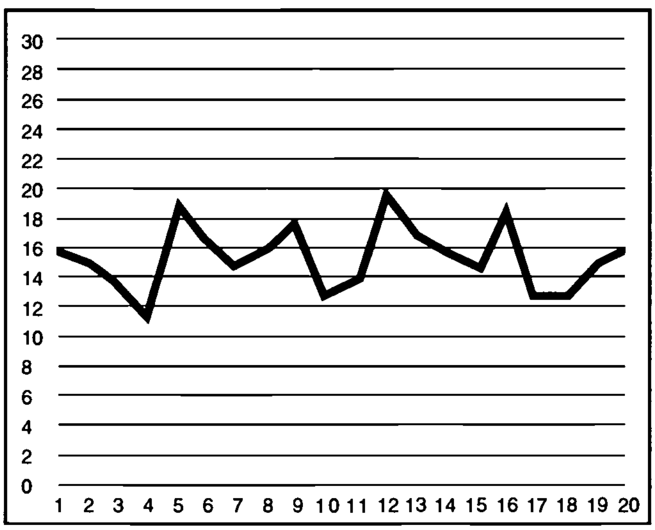


Figure 103 Example of a line chart used to plot values of students' breathing frequencies.

3. Direct the students to change places with their partners, so all students can find their breathing rate at rest.

4. Have the class plot the values of breathing frequencies as a line chart. It should look something like the diagram in Figure 103. Have the students calculate the mean (average) value or breathing frequency for the entire class.

5. To calculate a mean value, add the values together and divide the sum by the number of values.

6. Discuss the results with the class. Have students identify the range of breathing frequencies in the class.

Evaluation

REVIEW QUESTIONS

1. What is breathing rate?
   Number of breaths per minute.
2. What regulates breathing rate?
   A large number of things contribute—the blood levels of CO_2, O_2, limb motion, e.g., running. The main influence is blood CO_2.

THINKING CRITICALLY

1. Is the class mean (average) resting breathing rate close to 15 breaths per minute? Why do most people have similar resting breathing rates?
2. The results farthest from the mean should be considered. Is this normal? (The answer is probably "yes," because there is some range in breathing frequencies in any given population.)

SKILL BUILDING

1. Survey the class about exercise habits and physical activities. Are students able to detect any relationship between physical activity and resting breathing rate?
2. Have students use resources on the Internet and in the library to investigate the effects of certain respiratory disorders on breathing rate and ventilation in general.

LEARNING ACTIVITY IV:
How Long Can You Hold Your Breath?

OVERVIEW

Students will learn how reduced carbon dioxide levels in the blood lower the need to breathe by comparing breathing rates before and after hyperventilation.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

Each team of students will need:

- Pen or pencil
- Watch or access to a clock with second hand
- Chair
- Note pad

MAJOR CONCEPTS

- The brain acts as a central collection agent of information about breathing from carbon dioxide sensors, the oxygen sensor, mechanical sensors of breathing movements, and the cerebral cortex.
- Amounts of carbon dioxide in the blood affect breathing.

BACKGROUND

Carbon dioxide, produced from cellular respiration, is carried in the blood in three main forms:

1. dissolved as CO_2 (5%)
2. bicarbonate ions (HCO_3) (75%)
3. bound to hemoglobin and other blood proteins (Carbamino compounds) (20%)

Carbon dioxide levels are monitored by cells on the ventral medulla in the brainstem and by the carotid bodies in the neck, which respond to changes in CO_2 levels and pH levels. Unlike the brainstem, the carotid bodies also respond to plasma O_2 levels.

A raising of the arterial blood carbon dioxide levels above normal is called **hypercapnia**. Hypercapnia can result from insufficient ventilation to clear carbon dioxide from the lungs. This might occur with a lung disease that impairs carbon dioxide removal from the blood, even when ventilation is adequate. In general, increases in blood carbon dioxide levels lead to increases in ventilation. Conversely, hyperventilation (rapid shallow breathing) may drastically lower carbon dioxide levels in blood and will trigger a slowdown in ventilation.

Oxygen levels also affect ventilation. Hypoxia results from insufficient fresh air reaching the lungs, the blood, and tissues.

The Neurolab team investigated the changes that space conditions cause in ventilation and the regulation of blood gases. Under microgravity conditions, changes in cerebral blood flow may affect the chemoreceptors in the brain. Sleep may be affected because ventilation, or lack of ventilation, is a powerful wakening stimulus. If there are alterations in the control of ventilation in weightlessness, then these may contribute significantly to the poor quality of sleep that Shuttle crews sometime experience.

PROCEDURE

Note to teacher: *encourage the students not to cheat by changing their normal breathing patterns before starting this activity. Students with respiratory ailments, such as asthma or allergies, should not participate in the breath-holding part of this activity.*

1. Have students conduct this activity in pairs: one student will be the "subject," and the other will be the "observer." Make sure that the observer has a pen and a watch with a second hand.

2. Have the subject student sit quietly (no talking or moving) in a chair.

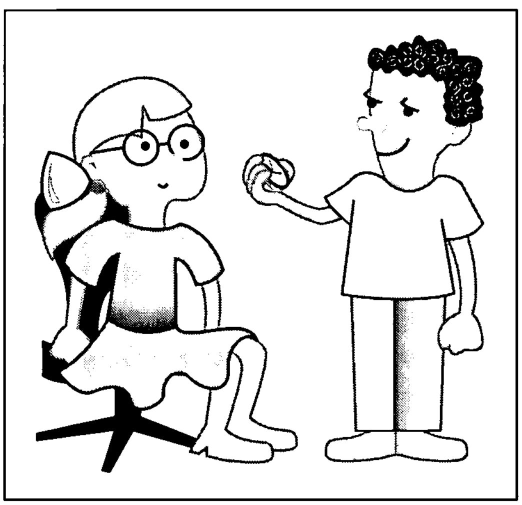


Figure 104 *Diagram of student recording how long student can hold her breath.*

3. Instruct each subject to inhale normally, then tell him/her to stop breathing and signal the observing student by raising his/her finger. The observer should note the starting time.

4. Each subject should hold his or her breath as long as he/she possibly can (Figure 104). Tell each student to force himself or herself to continue holding his/her breath even if he/she feels like he/she has to breathe.

5. Instruct each observer to record how long his/her subjects held their breaths.

6. Ask the subject to take a short rest, then to breathe rapidly and deeply for 30 seconds (this is called hyperventilation). Immediately after hyperventilating and at the end of an expiration (outward breath), have each subject hold his/her breath, and signal the observing student as before.

7. Again, instruct the subject to hold his/her breath as long as possible.

8. Have the observer record how long the subject held his/her breath.

9. Have the students switch roles, so that each student has an opportunity to do the activity.

10. Have the members of the class compare the breath-holding times with and without prior hyperventilation.

11. Check to see if there is any difference. Hyperventilation reduces the level of carbon dioxide in the lungs by blowing it off. The resultant reduction in blood carbon dioxide lowers the need to breathe.

12. Ask your students if, at the point they thought they really had to breathe, they could talk themselves out of it, even if only for a few seconds. (There is a strong voluntary component to ventilation.)

13. Have your students compare the individual results of breathing frequency from Activity One and breath-holding time for this activity. Is there a correlation? Although it may be hard to see, in general, people with a lower response to inhaled carbon dioxide can hold their breath for a longer period of time than those with a higher response.

14. Ask the students to describe what finally forced them to breathe. (The answer is, their brain.) The brain acts as a central collection agent of information from a lot of places—carbon dioxide sensors, the oxygen sensor, mechanical receptors that sense the absence of breathing movements, and the cerebral cortex. The complex interaction of all these inputs will finally make the students react by breathing.

Evaluation

REVIEW QUESTIONS

1. **What limits how long one can hold his/her breath?**
   Many things—CO_2, O_2, pulmonary stretch receptors, voluntary control. CO_2 is the most important in normal people.

2. **Where are carbon dioxide levels detected in the body?**
   They are located on the ventral surface of the medulla—the base of the brain (Figure 105).

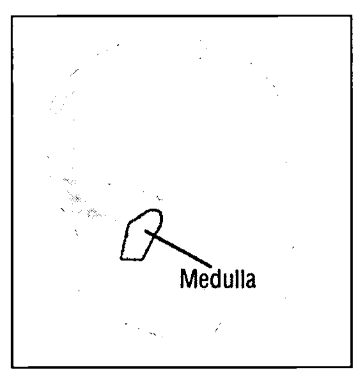


Figure 105 Diagram of the location of the medulla.

3. **How can levels of carbon dioxide in the body be changed by breathing patterns?**
If you breathe less, CO_2 increases, if you breathe more, CO_2 decreases. Exercise produces more CO_2, which means we must breathe more to eliminate it.

THINKING CRITICALLY

1. **What factors, other than high carbon dioxide, might cause breathlessness?**
Low levels of oxygen, or hypoxia. If you have skied at high altitudes, you may have experienced this. The factors that contribute to increased breathing during exercise are many, complex, and still not completely understood. Nevertheless, we have all experienced the sensation of being short of breath and of breathing more when we exercise.

2. **Why might the control of ventilation change in weightlessness?**
The major reasons are: (1) changes in cerebral blood flow alters the central CO_2 response; and (2) changes in carotid chemoreceptor responses in the neck that senses O_2. (Evidence suggests reason #2 may be more important in weightlessness.)

3. **What effect might the change in the control of ventilation have on sleep in weightlessness?**
It may alter the "sleep architecture," which will increase arousals (awakenings) and reduce the quality of sleep.

SKILL BUILDING

1. **What represents the fizz in bottled or canned soda (Figure 106)? Why can't we see the bubbles unless the bottle or can is opened?**
CO_2. Under pressure, the CO_2 remains dissolved in the soda liquid. The reduction in pressure brings it out of the solution.

Use resources on the Internet or in the library to learn more about the relationship between pressure and dissolved gases.

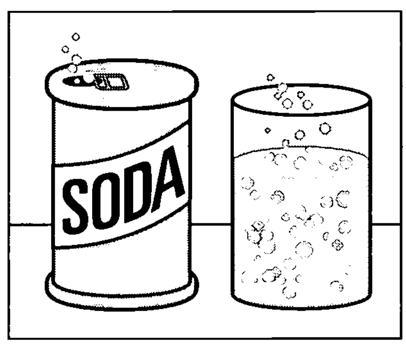


Figure 106 Diagram of carbonated soft drinks.

LEARNING ACTIVITY V:
Raising the Level of Carbon Dioxide in Your Blood

OVERVIEW

In this activity, students will learn about the effects of increased carbon dioxide in the bloodstream.

SCIENCE & MATHEMATICS SKILLS

Observing, collecting and recording quantitative data, drawing conclusions

PREPARATION TIME

None needed

CLASS TIME

50 minutes

MATERIALS

Each team of students will need:

- Large paper bag
- Pen or pencil
- Watch or access to a clock with a second hand
- Note pad
- Chair

BACKGROUND

When carbon dioxide levels increase in arterial blood, receptors in the medulla within the brainstem trigger an increase in breathing frequency. In this activity, blood carbon dioxide levels are increased by having students cover their mouths and noses with a paper bag as they breathe. Within the bag carbon dioxide levels will increase because of the higher concentration of carbon dioxide in exhaled air. Because the carbon-dioxide rich air is "rebreathed," it leads to increases in the carbon dioxide in arterial blood or hypercapnia.

PROCEDURE

1. Have students work in pairs to conduct this activity.

   Note to teacher: *Some students may find this exercise uncomfortable. Students with respiratory ailments should not participate as subjects). As in previous activity, one student within each pair should be the "subject," and the other should be the "observer."*

MAJOR CONCEPTS

- Breathing can be involuntarily modified by raising the level of carbon dioxide in the blood.
- Increasing the CO_2 in the blood will stimulate ventilation.
- Unlike some other rhythms in the body, breathing can readily be modified by will. One can, given some thought, breathe more slowly and with larger breaths. If a person is distracted, however, breathing will return to his/her personal "normal" frequency.

2. Within each team, have the student "subject" sit quietly (no talking or moving). Have the observing student count the number of breaths taken by the subject over each 15-second segment of a two minute total time period and record the results.

3. After two minutes, have each subject place a paper bag over his/her nose and mouth, and continue to breathe in and out, as in the diagram in Figure 107.

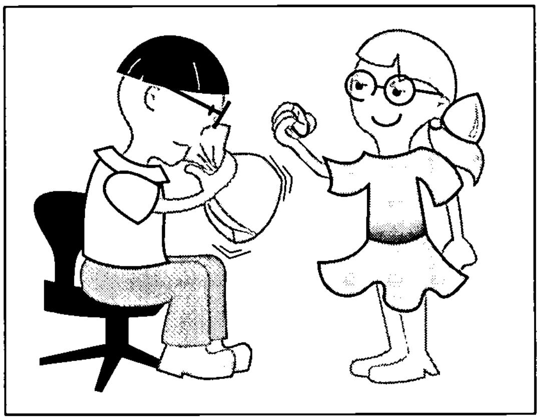


Figure 107 *Diagram of student breathing in and out of paper bag.*

4. Tell the subject to try to keep a good seal against the face and nose to ensure that only air from within the bag is breathed. Encourage the subject to relax as much as possible and breathe normally.

5. Direct each observing student to watch the bag and write down the number of breaths taken by the subject every 15 seconds. The observing student should record the number of breaths for two minutes or until the subject removes the bag (if students feel faint they should remove the bag and breathe normally).

6. After the subject removes the bag, have the observing student ask the subject to rate how breathless he/she feels on a scale of one to ten. (One is "not breathless at all," five is "moderately breathless" and ten is "as short of breath as one could possibly be.") The observing student should record this data.

7. Have the students exchange places and repeat the activity.

Evaluation

REVIEW QUESTIONS

1. What type of breathing response occurs when blood levels of carbon dioxide occur?
   Breathing frequency and tidal volume (size of breaths) increase and total ventilation increases.

2. Where are the changes in arterial blood concentrations of carbon dioxide detected?
   On the ventral surface of the medulla in the base of the brain. This is termed a "central" response.

THINKING CRITICALLY

1. **Why did breathing frequency increase when the mouth and nose were covered with the paper bag?**
   As carbon dioxide began to build up in the bag, this "re-breathing experiment" served to increase the carbon dioxide in the arterial blood. This condition of hypercapnia stimulates the central ventilatory chemoreceptor in the ventral medulla, causing an increased breathing frequency.

2. **What happened to the tidal volume over the course of the re-breathing experiment?**
   An increase in both breathing frequency and tidal volume results in a large increase in total ventilation.

3. **What might happen to a person if the levels of arterial carbon dioxide increased while they were sleeping?**
   Breathing might increase and they could be awaken.

SKILL BUILDING

1. Have students pool their observations and create a class chart of breathing rates.

Appendices

Glossary

NASA Resources for Educators

Teacher Reply Card

GRADES 5–12

Section VI

Glossary

Acetylcholine–The neurotransmitter at motor neuron synapses, in autonomic ganglia and a variety of central synapses; which causes cardiac inhibition, vasodilation, gastrointestinal peristalsis, and other parasympathetic effects.

Afferent–Inflowing; conducting towards a center, denoting certain arteries and veins.

Alpha Receptors–A type of receptor for the neurotransmitter, norepinephrine.

Ampula–A saccular dilation of a canal or duct.

Aorta–Large artery that carries blood from the heart to be distributed by branch arteries throughout the body.

Aortic–Relating to the aorta on the aortic orifice of the left ventricle of the heart.

Aperture–An inlet or entrance.

Artery–A relatively thick walled, muscular, pulsating blood vessel conveying blood in a direction away from the heart.

Atrium–A chamber or cavity to which are connected several chambers or passageways. Usually used to describe a chamber of the heart that receives blood from the veins.

Autonomic–Acting independently of volition; relating to the autonomic nervous system.

Axons–Tail-like branch of a neuron that carries the action potential from the nerve cell body to a target.

Axonal–Pertaining to an axon.

Baroreceptor–Any sensor of pressure changes. For regulation of blood pressure, important baroreceptors are located in the aorta and arotid arteries.

Beta Receptors–A type of receptor for the neurotransmitter, norepinephrine.

Brainstem–The entire unpaired subdivision of the brain, composed of the thombencephalon, mesencephalon, and diecephalon as distinguished from the brain's only paired subdivision the telecephalon.

Bifurcation–A forking; a division into two branches.

Cupula–A delicate membrane within the semicircular canals that contains fluid and receptor hair cells.

Carotid Artery–Either of the two main arteries that supply blood to the head.

Catecholamine–Refers to several neurotransmitters, such as epinephrine, norepinephrine and serotonin.

Caudal–Pertaining to the tail.

Cerebellum–Prominent hindbrain structure concerned with motor coordinator, posture, and balance. Composed of a three-layered cortex and deep nuclei.

Cholinergic–Refers to synaptic transmission mediated by the release of acetocholine.

Chordamesoderm–That part of the protoderm of a young embryo which has the potentiality of forming notochord and mesoderm.

Coagulate–To convert a fluid or a substance in solution into a solid or gel.

Coriolis Effect–Occurs when the head is in motion and constantly changing direction.

Cortex–The outer portion of an organ, such as the brain.

Corticospinal–Of or relating to the cerebral cortex and spinal cord; the corticospinal fibers are columns of motor fibers that run on either side of the spinal cord and are continuations of the pyramids of the medulla oblongata.

Cytokinesis–Changes occurring in the protoplasm of the cell outside the nucleus during cell division (mitosis).

Cytology–The study of anatomy, physiology, pathology, and chemistry of the cell.

Dendrite–One of the two types of branching protoplasmic processes of the nerve cells (the other is the axon).

Diencephalon–That part of the prosencephalon composed of the epithalamus, dorsal thalamus, subthalamus, and hypothalamus.

Distal–Far from the point of attachment of origin. Situated away from the center of the body.

Distend–To enlarge from internal pressure.

Dorsal–Pertaining to the back.

Dorsal Thalamas–The large part of the diencephalon located dorsal to the hypothalamus and excluding the subthalamus and the medial and lateral geniculate bodies.

Ectodermal Cells–The outer layer of cells in the embryo.

Efferent–Conducting (fluid or a nerve impulse) outward from a given organ or part thereof.

Electrocardiogram–Graphic record of the heart's integrated action currents obtained with the electrocardiograph.

Embryo–An organism in the early stages of development.

Embryonic–Of, pertaining to, or in the condition of an embryo.

Epi–Upon, following, or subsequent to.

Epinephrine–A catecholamine that is the chief neurohormone of the adrenal medulla.

Epithalamus–A small dorsomedial area of the thalamus corresponding to the hadenula and its associated structures.

Escher, M.C. (June 17, 1898 – March 27, 1972)–Native graphic artist of The Netherlands who designed the Escher Staircase.

Exteroceptors–One of the peripheral end organs of the afferent nerves in the skin or mucous membrane, which respond to stimulation by external agents.

Extracellular–Outside the cells.

Fascicle–A band or bundle of fibers, usually of muscles or nerve fibers.

Fiber–A strand of nerve tissue, especially axons or dendrites.

Folia–Plural of folium; a broad, thin, leaflike structure.

Frontal Lobe–The portion of each cerebral hemisphere, anterior to the central sulcus.

Gametocytes–A cell capable of dividing to produce gametes.

Gametes–One of two haploid cells undergoing karyogamy.

Ganglion–An aggregation of nerve cell bodies located in the peripheral nervous system.

Glossopharyngeal–Relating to the tongue and the pharynx.

Gradients–Change of temperature, pressure or other variable as a function of distance, time, etc.

Gyric–Plural of gyrus; one of the prominent rounded elevations that form the cerebral hemispheres.

Hippocampus–The complex internally convoluted structure that forms the medial margin (hem) of the cortical mantle of the cerebral hemisphere.

Hypertension–High blood pressure.

Hypo–Prefix denoting deficient, below normal.

Hypothalamus–The ventral and medial region of the diencephalon forming the walls of the ventral half of the third ventricle.

Inertial–The tendency of a physical body to oppose any force tending to move it from a position of rest or to change its uniform motion.

Inhibition–Depression or arrest of a function.

Innervation–The supply of nerve fibers functionally connected with a part.

Karyogamy–Fusion of the nuclei of two cells, as occurs in fertilization or true conjugation.

Lateral–On the side farther from the median.

Lumen–Space in the interior of a tubular structure, such as an artery of the intestine.

Medulla–The caudal (hind) portion of the brainstem.

Medial–Relating to the middle or center.

Meiosis–A special process of cell division comprising two nuclear divisions in rapid succession that result in four gametocytes, each containing half the number of chromosomes found in somatic cells.

Meninges–One of the membranous coverings of the brain and spinal cord.

Mesencephalon–That part of the brain stem developing from the middle of the three primary cerebral vesicles of the embryo.

Metencephalon–The anterior of the two major subdivisions of the rhombencephalon.

Microtubule–Any of the minute cylindrical structures in cells distributed in the protoplasm and made up of protein subunits.

Migration–Passing from one part to another.

Mitosis–Cell division that results in nuclei having the same number of chromosomes as the parent nucleus; the usual process of cell division with non-reproductive tissues.

Mitotic–Relating to or marked by mitosis.

Mitral–Relating to the mitral or bicuspid valve of the heart.

Myelencephalon–The brain.

Myelinated–Refers to an axon that is ensheathed in the fatty, insulating substance, myelin.

Neonatal–Relating to the period immediately succeeding birth and continuing through the first 28 days of life.

Nerves–A whitish cordlike structure composed on one or more bundles of myelinated or unmyelinated nerve fibers, or more often mixtures of both, coursing outside of the central nervous system, together with connective tissue within the fascicle and around the neurolemma of individual nerve fibers.

Neural–Relating to any structure composed of nerve cells or their processes, or that on further development will evolve into nerve cells.

Neurolemma–A cell that enfolds one or more axons of the peripheral nervous system.

Neurons–Nervous system cell consisting of the nerve cell body, dendrites and axon.

Neurotransmitter–Any specific chemical agent released by a presynaptic cell, upon excitation, that crosses the synapse (gap between cells) to stimulate or inhibit the postsynaptic cell.

Neurula–Stage in embryonic development after the gastrula state, in which the prominent processes are the formation of the neural plate and the plate's closure to form the neural tube.

Neurulation–Processes involved in the formation of the neurula stage.

Norepinephrine–A neurotransmitter found in the brain and sympathetic nervous system.

Nucleus–In cytology, typically a rounded or oval mass of protoplasm within the cytoplasm of a plant or animal cell, in which the chromosomes are located.

Occipital Lobe–The posterior, somewhat pyramid-shaped, part of each cerebral hemisphere.

Olfactory–Relating to the sense of smell.

Optics–The science concerned with the properties of light, its refraction and absorption, and the refracting media of the eye in that relation.

Organs–Any part of the body exercising a specific function as of respiration, secretion, digestion.

Organogenesis–Formation of organs during development.

Otolith–Crystalline particles of calcium carbonated and a protein adhering to the gelatinous membrane of the maculae of the utricle and saccule.

Oxygenation–Addition of oxygen to any chemical or physical system.

Palpating–Examination with the hands, for example, when feeling the heart or pulse beat.

Parasympathetic–Pertaining to the division of the autonomic nervous system that organizes the body's responses that save energy and balance the body's various systems.

Parietal–Relating to the wall of any cavity.

Peripheral–Relating to or situated at the periphery (or edge) of something or extremeties; the outer part or surface.

Periphery–The part of a body away from the center.

Peristalsis–The movement of the intestine or other tubular structure, caused by successive waves of involuntary muscular contractions.

Pharynx–The upper expanded portion of the digestive tube, between the esophagus below and the mouth and nasal cavities above and in front.

Pitch–An up and down movement.

Plasma–The fluid portion of the circulating blood.

Postnatal–Occurring after birth.

Postganglionic–Relating to or being an axon originating from a cell body within an autonomic ganglion.

Postsynaptic–Pertaining to the area of the distal side of a synaptic cleft.

Presynaptic Cell–Pertaining to the area on the proximal side of a synaptic cleft.

Preganglionic–Situated proximal to or preceding a ganglion, referring specifically to the preganglionic motor neurons of the autonomic nervous system (located in the spinal cord and brainstem).

Proliferation–Growth and reproduction of similar cells.

Prophase–The first stage of mitosis or meiosis, consisting of linear contraction and increase in thickness of the chromosomes.

Proprioception–The sense or perception, usually at a subconscious level, of the movements and positions of the body and especially its limbs, independent of vision.

Prosencephalon–The anterior primitive cerebral vesicle and the most rostral of the three primary brain vesicles of the embryonic neural tube.

Pulmonary–Relating to the lungs, to the pulmonary artery, or to the aperture leading from the right ventricle of the heart into the pulmonary artery.

Proximal–Nearest the trunk or the point of origin said of part of a limb, or an artery or a nerve.

Pyro–Prefix referring to fire, heat or fever.

Radius–The lateral and shorter of the two bones of the forearm.

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

Replicate–One of several identical processes or observations; to repeat.

Rhombencephalon–That part of the developing brain that is the most caudal (towards the tail) of the three primary vesicles of the embryonic neural tube.

Roll–To cause to revolve by turning over and over on or as if on an axis.

Rostral–Towards the front or head.

Somatic–Relating to the soma or trunk, the wall of the body cavity, or the body in general.

Saccule–One of the otolith organs of the vestibular system.

Spatial–Relating to space or position in three dimensions.

Sternum–A long, flat bone, articulating with the cartilages of the first seven ribs and with the clavicle, that forms the middle part of the anterior wall of the thorax.Breast bone.

Stethoscope–An instrument originally devised by Laennec for aid in hearing the respiratory and cardiac sounds in the chest, but now modified in various ways and used to listen to vascular or other sounds anywhere in the body.

Stress–Reactions of the body to forces of a deleterious nature, infectious, and various abnormal physiologic equilibrium.

Sub–Prefix, denoting beneath, less than the normal, inferior.

Subcortical–Beneath the cerebral cortex.

Sulcus–One of the grooves or furrows on the surface of the brain, bounding the several convol-untions or gyri.

Sympathetic Ganglia–Those ganglia of the autonomic nervous system that receive efferent fibers originating from preganglionic visceral motor neurons in the intermediolateral cell column of thoratic and upper lumba spinal segments.

Sympathetic–Part of the autonomic nervous system of vertebrates that organizes and regulates the body's response to stress.

Synapse–The functional membrane-to-membrane contact of the nerve cell with a target cell (another nerve cell or other type of cell).

Synthesis–A building up, putting together, composition stage in the cell cycle; production of a molecule through chemical processes.

Tectum–Any rooflike covering or structure.

Telencephalon–The anterior division of the prosencephalon, which develops into the olfactory lobes, the cortex of the cerebral hemispheres, and the subcortical telencephalic nuclei, and the basal ganglia.

Temporal Lobe–The lowest of the major subdivisions of the cortical mantle, forming the posteri-or two-thirds of the ventral surface of the cerebral hemisphere.

Thalamus–The large ovoid (an oval egg-shaped form) mass of gray matter that forms the larger dorsal subdivision of the diencephalon.

Tricuspid–Having three points, prongs, or cups. As the tricuspid valve of the heart.

Ulna–The medial and larger of the two bones of the forearm.

Utricle–The larger of the two membranous sacs in the vestibles of the labyrinth, lying in the elliptical recess.

Vagal–Relating to the vagus nerve.

Vagus Nerve–The nerve responsible for slowing heart rate; part of the parasympathetic nerve system.

Vasoconstriction–Narrowing of the blood vessels.

Vasodilation–Widening of the lumen of blood vessels.

Vasomotor–Causing constriction of the blood vessels.

Vein–A blood vessel carrying blood toward the heart; all the veins except the pulmonary carry dark or oxygenated blood.

Ventricle–The thick-walled chambers of your heart that pump blood into your lungs and body.

Ventro–The belly.

Ventrolateral–Both ventral and lateral.

Vestibulo-Ocular Reflex (VOR)–A reflex that allows your eye to remain fixed on an object although your head or the object is moving.

Vestibular–Relating to the sense of balance.

Yaw–A side-to-side movement.

NASA Resources for Educators

NASA's Central Operation of Resources for Educators

NASA's Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue and an order form by one of the following methods:

- NASA CORE
  Lorain County Joint Vocational School
  15181 Route 58 South
  Oberlin, OH 44074
- Phone: (440) 774-1051, Ext. 249 or 293
- Fax: (440) 774-2144
- E-mail: nasaco@leeca.esu.k12.oh.us
- Home Page:http://spacelink.nasa.gov/CORE

Educator Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Educator Resource Center (ERC) network. ERCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Educators may preview, copy, or receive NASA materials at these sites. Because each NASA Field Center has its own areas of expertise, no two ERCs are exactly alike. Phone calls are welcome if you are unable to visit the ERC that serves your geographic area. A list of the centers and the regions they serve includes:

AK, AZ, CA, HI, ID, MT, NV, OR, UT, WA, WY
NASA Educator Resource Center
Mail Stop 253-2
NASA Ames Research Center
Moffett Field, CA 94035-1000
Phone: (650) 604-3574

CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT
NASA Educator Resource Laboratory
Mail Code 130.3
NASA Goddard Space Flight Center
Greenbelt, MD 20771-0001
Phone: (301) 286-8570

CO, KS, NE, NM, ND, OK, SD, TX
JSC Educator Resource Center
Space Center Houston
NASA Johnson Space Center
1601 NASA Road One
Houston, TX 77058-3696
Phone: (281) 483-8696

FL, GA, PR, VI
NASA Educator Resource Laboratory
Mail Code ERL
NASA Kennedy Space Center
Kennedy Space Center, FL 32899-0001
Phone: (407) 867-4090

KY, NC, SC, VA, WV
Virginia Air and Space Museum
NASA Educator Resource Center for
NASA Langley Research Center
600 Settler's Landing Road
Hampton, VA 23669-4033
Phone: (757) 727-0900 x 757

IL, IN, MI, MN, OH, WI
NASA Educator Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135-3191
Phone: (216) 433-2017
AL, AR, IA, LA, MO,TN
U.S. Space and Rocket Center
NASA Educator Resource Center for
NASA Marshall Space Flight Center
P.O. Box 070015
Huntsville, AL 35807-7015
Phone: (256) 544-5812

MS
NASA Educator Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529-6000
Phone: (228) 688-3338

NASA Educator Resource Center
JPL Educational Outreach
Mail Stop 601-107
NASA Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099
Phone: (818) 354-6916

CA Cities Near the Center
NASA Educator Resource Center for
NASA Dryden Flight Research Center
45108 N. 3rd Street East
Lancaster, CA 93535
Phone: (805) 948-7347

VA and MD's Eastern Shores
NASA Educator Resource Lab
Education Complex
Visitor Center Building J-1
NASA Wallops Flight Facility
Wallops Island, VA 23337-5099
Phone: (757) 824-2297/2298

Regional Educator Resource Centers

Regional Educator Resource Centers offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as RERCs in many states. A complete list of RERCs is available through CORE, or electronically via NASA Spacelink at http://spacelink.nasa.gov

NASA On-line Resources for Educators

NASA On-line Resources for Educators provide current educational information and instructional resource materials to teachers, faculty, and students. A wide range of information is available, including science, mathematics, engineering, and technology education lesson plans, historical information related to the aeronautics and space program, current status reports on NASA projects, news releases, information on NASA educational programs, useful software and graphics files. Educators and students can also use NASA resources as learning tools to explore the Internet, accessing information about educational grants, interacting with other schools which are already on-line, and participating in on-line interactive projects, communicating with NASA scientists, engineers, and other team members to experience the excitement of real NASA projects.

Access these resources through the NASA Education Home Page:
http://www.hq.nasa.gov/education

NASA Television

NASA Television (NTV) is the Agency's distribution system for live and taped programs. It offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science. NTV is transmitted on the GE-2 satellite, Transponder 9C at 85 degrees West longitude, vertical polarization, with a frequency of 3880 megahertz, and audio of 6.8 megahertz.

Apart from live mission coverage, regular NASA Television programming includes a Video File from noon to 1:00 pm, a NASA Gallery File from 1:00 to 2:00 pm, and an Education File from 2:00 to 3:00 pm (all times Eastern). This sequence is repeated at 3:00 pm, 6:00 pm, and 9:00 pm, Monday through Friday. The NTV Education File features programming for teachers and students on science, mathematics, and technology. NASA Television programming may be videotaped for later use.

For more information on NASA Television, contact:
NASA Headquarters
Code P-2
NASA TV
Washington, DC 20546-0001
Phone: (202) 358-3572
NTV Home Page:http://www.hq.nasa.gov/ntv.html

How to Access Information on NASA's Education Program, Materials, and Services, EP-1998-03-345-HQ

This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the ERC network, or electronically via NASA Spacelink. NASA Spacelink can be accessed at the following address: http://spacelink.nasa.gov

The Brain in Space

A Teacher's Guide with Activities for Neuroscience

EDUCATOR REPLY CARD

To achieve America's goals in Educational Excellence, it is NASA's mission to develop supplementary instructional materials and curricula in science, mathematics, geography, and technology. NASA seeks to involve the educational community in the development and improvement of these materials. Your evaluation and suggestions are vital to continually improving NASA educational materials.

Please take a moment to respond to the statements and questions below. You can submit your response through the Internet or by mail. Send your reply to the following Internet address:

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

You will then be asked to enter your data at the appropriate prompt.

Otherwise, please return the reply card by mail. Thank you.

1. With what grades did you use the educator guide?
   Number of Teachers/Faculty:
   ______ K-4 ______ 5-8 ______ 9-12 ______ Community College
   College/University - ______ Undergraduate ______ Graduate

   Number of Students:
   ______ K-4 ______ 5-8 ______ 9-12 ______ Community College
   College/University - ______ Undergraduate ______ Graduate

   Number of Others:
   ______ Administrators/Staff ______ Parents ______ Professional Groups
   ______ General Public ______ Civic Groups ______ Other

2. What is your home 5- or 9-digit zip code? _ _ _ _ _ — _ _ _ _

3. This is a valuable educator guide?
   ❑ Strongly Agree ❑ Agree ❑ Neutral ❑ Disagree ❑ Strongly Disagree

4. I expect to apply what I learned in this educator guide.
   ❑ Strongly Agree ❑ Agree ❑ Neutral ❑ Disagree ❑ Strongly Disagree

Fold along line and tape closed.

5. What kind of recommendation would you make to someone who asks about this educator guide?
   ❑ Excellent ❑ Good ❑ Average ❑ Poor ❑ Very Poor

6. How did you use this educator guide?
   ❑ Background Information
   ❑ Demonstrate NASA Materials
   ❑ Group Discussions
   ❑ Integration Into Existing Curricula
   ❑ Lecture
   ❑ Team Activities
   ❑ Critical Thinking Tasks
   ❑ Demonstration
   ❑ Hands-On Activities
   ❑ Interdisciplinary Activity
   ❑ Science and Mathematics Standards Integration
   ❑ Other: Please specify: ______________________

7. Where did you learn about this educator guide?
   ❑ NASA Educator Resource Center
   ❑ NASA Central Operation of Resources for Educators (CORE)
   ❑ Institution/School System
   ❑ Fellow Educator
   ❑ Workshop/Conference
   ❑ Other: Please specify: ______________________

8. What features of this educator guide did you find particularly helpful?
   ____
   ____

9. How can we make this educator guide more effective for you?
   ____
   ____

10. Additional comments:
   ____
   ____

Today's Date: ______________________

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