Neurolab (STS-90): April 1998

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Introduction

Neurolab is the aptly named shuttle mission (STS-90) that is conducting a series of experiments aimed at better understanding how the nervous system develops and functions in the microgravity of space. Approximately four in ten astronauts become dizzy, nauseated and disoriented in the first two to three days of space flight, obvious outward signs that the lack of gravity greatly affects our sensory systems. Even though we have nearly four decades of experience with manned space flight in the U.S. alone, the effects of microgravity on our sensory organs – including the brain, spinal cord and nerves – are not well known. The Orbiter *Columbia* is traversing the earth at more than 28,000 kilometers per hour in a state of free fall, which generates microgravity.

The focus of Neurolab is basic space physiology as it relates to neurobiology. The nervous system faces special challenges in the weightlessness of space – space flight affects the nervous system's control on blood pressure, balance, motor coordination and sleep regulation. Other fundamental questions to be answered include: Can the nervous system develop normally in space? Can balance be learned in microgravity? How will gravity-sensitive body parts (e.g., the inner ear, the cardiovascular system, etc.) develop and cope in microgravity? These are important questions as we move closer in the coming years, to completing and inhabiting the International Space Station (ISS) where scientists will reside for extended stays.

In 1991, President George Bush and the United States Congress declared the '90s the "Decade of the Brain." NASA proposed Neurolab in response to this dictum and, after deciding upon critical questions of gravitational effects on neurobiology, began requesting proposal submissions. Criteria for winning proposals were set forth by a collaborative effort between NASA and the National Institutes of Health (NIH), and various International Space Agencies (Table 1). Of 172 proposals considered, peer reviewers from the NIH Division of Research Grants chose 32 studies. Neurolab is hosting 26 of the proposals, with six to fly on later flights.

Neurolab is truly an international mission with researchers and space agencies from Japan, Europe and North America participating. The international flavor of the mission extends to the Orbiter crew. Mission specialist David Williams is representing Canada and alternate payload specialist Chiaki Mukai is representing Japan.

Table 1. Space Agencies and Scientific Institutes Participating in Neurolab.

SPACE AGENCIES
Canadian Space Agency, Agence Spatiale Canadiene (CSA-ASC)
European Space Agency (ESA)
French Space Agency, Centre Nationale d'Etudes Spatiales (CNES)
German Space Agency, Deutsches Zentrum für Luft- und Raumfahrt (DLR)
National Aeronautics and Space Administration (NASA)
National Space Development Agency of Japan (NASDA)

SCIENTIFIC INSTITUTES
Department of Research Grants (DRG)
National Heart Lung and Blood Institute (NHLBI)
National Institute of Child Health and Human Development (NICHD)
National Institute of Neurological Disorders and Stroke (NINDS)
National Institute on Aging (NIA)
National Institute on Deafness and Other Communication Disorders (NIDCD)
National Institutes of Health (NIH)
National Science Foundation (NSF)
Office of Naval Research (ONR)

The Scientific Mission

The 26 studies are grouped into eight experimental teams: Neuronal Plasticity, Mammalian Development, Aquatic, Neurobiology, Autonomic Nervous System, Sensory Motor and Performance, Vestibular and Sleep (Table 2). The first four teams are using animal subjects; the second four are using human subjects. A fascinating aspect of Neurolab is that the crew specialists of necessity are serving as both experimenters and subjects. Animals on board include rats, mice, fish (two species), snails and crickets. In addition to measurements being taken during flight, pre- and postflight measurements are analyzed.

The Crew of Neurolab

A crew of nine – the commander, the pilot, three mission specialists and four payload specialists – are using Spacelab to decipher many key areas in which gravity, or the near absence of it, interacts in the development and workings of the nervous system. Biosketches of the crew are given on the Profile page preceding this article.

The mission and payload specialists performing the experiments have been training and specializing for Neurolab since May of 1996. Mission specialists include Williams and Richard Linnehan. Fellow payload specialists include Mukai, Jay C. Buckey, Jr., James A. Pawelczyk and Alexander W. Dunlap. Mission specialist Kathryn P. Hire is the engineer for the mission.

Each specialist has contributed to previous shuttle and some Spacelab missions. Mukai and I, as alternates, continued to train with the crew up to the launch date, and we are supporting the mission during *Columbia*'s flight from the Payload Operations Control Center at the Johnson Space Center.

Table 2. Neurolab Consists of 26 Studies Grouped into Eight Teams. Principal investigators are listed for each team.

Neuronal Plasticity
Charles A. Fuller
University of California-Davis, USA
Gay R. Holstein
Mount Sinai School of Medicine, USA
Bruce L. McNaughton
University of Arizona, USA
Ottavio Pompeiano
University of Pisa, Italy
Muriel D. Ross
NASA Ames Research Center, USA

Mammalian Development
Kenneth M. Baldwin
University of California-Irvine, USA
Kenneth S. Kosik
Brigham and Women's Hospital, USA
Robert S. Nowakowski
Robert Wood Johnson Medical School, USA
Jacqueline Raymond
CNRS, France
Danny A. Riley
Medical College of Wisconsin, USA
Tsuyoshi Shimizu
Fukushima Medical College, Japan
Kerry D. Walton
New York University Medical Center, USA

Aquatic
Steven M. Highstein
Washington University School of Medicine, USA
Michael L. Wiederhold
University of Texas Health Science Center, USA

Neurobiology
Eberhard R. Horn
University of Ulm, Germany

Autonomic Nervous System
Friedhelm J. Baisch
DLR Institute of Aerospace Medicine, Germany
C. Gunnar Blomqvist
University of Texas Southwestern Medical Center, USA
Dwain L. Eckberg
Medical College of Virginia, USA
David Robertson
Vanderbilt University, USA

Sensory Motor and Performance
Alain Berthoz
CNRS/College de France, France
Otmar L. Bock
Institute for Space and Terrestrial Science, Germany
Charles M. Oman
Massachusetts Institute of Technology, USA

Vestibular System
Bernard Cohen
Mount Sinai School of Medicine, USA
Gilles R. Clement
CNRS/College de France, France

Sleep
Charles A. Czeisler
Brigham and Women's Hospital, USA
John B. West
University of California-San Diego, USA

The scope of Neurolab is daunting. We're hoping that what appears to be the last Spacelab flight will also be the most productive. NASA plans to retire Spacelab following this mission as the agency transitions into the era of the ISS. After that, the space agency will continue to conduct scientific experiments aboard another modular unit developed by SPACEHAB, a commercial space flight company. However, these missions should provide groundwork for bigger and longer studies aboard the ISS in the coming years.

The Scientific Teams

Neuronal Plasticity

The nervous system can compensate quite quickly and effectively, evidenced by the fact that people have been able to function in space. But we and other animals learn how to walk, maintain balance, control movement and even sense "up" and "down" under the force of gravity. Moreover, the constrained 24-hour light cycle on the surface of earth is severely perturbed in space where the extremely high speed of *Columbia* leads to about 16 sunrises per day. The lack of gravity and radically different light cues of space challenge the nervous system in many ways.

> Results from the Neuronal Plasticity and similar studies may have direct impact on human health since many people suffer balance disorders (approximately 90 million in the U.S.), jet lag, insomnia and some form of depression.

At the cellular level, neuronal plasticity functions as a way for the body to cope without gravity. Yet how this plasticity works is poorly understood. Neuronal plasticity is defined as the ability of neurons in fully developed animals to increase or alter their number of connections and synapses with other nerve cells.

The gravity sensor of the mammalian inner ear consists of calcium crystals called otoconia that rest on a layer of nerve cells termed maculae. Macular receptors detect gravity, tilt and linear motion. **Muriel Ross** has observed neuronal plasticity in the maculae of rats on previous Spacelab missions. Weight and movement are sensed by the otoconia. In compensation to the perceived decrease in trigger weight on the maculae, hair cell synapse numbers increase. Once back on the ground, the synapse numbers returned to preflight values. Neuronal plasticity of gravity sensation is currently under investigation in two rat studies on Neurolab.

The inner ear sends information to multiple parts of the brain, including the cerebellum, the center of movement and balance control, and the hippocampus, where location of the body in reference to the space it occupies and memory, is determined. **Gay Holstein** is looking into the neural circuitry in the vestibular and nonvestibular areas of the rat brain to identify structural and chemical changes that occur during adaptation to microgravity.

In addition, her research team will study these areas during readaptation to gravity following the animals' return to Earth.

The hippocampus gets cues from the inner ear to determine the body's location. **Bruce McNaughton** is interested in understanding how animals navigate on Earth. To study this in the absence of gravity, animals will run on the Escher Staircase, a track that in microgravity guides the rats along a path such that the animal returns to its starting location after having turned through three-quarters, or 270°, of a circle. On Earth, an animal would sense this change through its ascending and descending movements. The researchers will take recordings directly from neurons in the hippocampus to decipher whether the animals realize that they are back where they started. This is relevant to humans because those with Alzheimer's disease often get lost due to short-term spatial memory loss – the loss of sense of location – which is believed to be stored in the hippocampus.

On Earth many body rhythms have adapted to this 24-hour period and are in 'synch' with the night-day cycle of their immediate environment. Body temperature, heart rate, brain activity patterns, and more importantly sleep patterns become set in response to sunrise and sunset. **Charles Fuller** and **Ottavio Pompeiano** are studying changes in the mammalian circadian systems. Fuller is measuring neuronal immediate-early genes (IEG) involved in setting the circadian clock, activated in response to changing light cycles, to get at cellular effects brought on by space flight. These IEGs and their encoded intracellular messenger products are key to the quick cellular responses of neurons to space flight. Gene products of c-*fos* and *jun*-B are of special interest to Neurolab investigators because currently they are the earliest markers of neuronal plasticity.

Pompeiano is also studying circadian rhythm changes through the IEGs, specifically how space flight modifies the expression of IEGs in the brain structures involved in the regulation of the sleep-wake cycle. At the molecular level he is studying whether the vestibular system undergoes "plastic" changes that might contribute to vestibular adaptation to microgravity and readaptation to Earth's gravity.

Mammalian Development

The Mammalian Development Team is considering the growth and maturing characteristics of nerve cells involved in gravity sensation, nerves that innervate muscle and the development of neurons in the brain in microgravity. Evidence is accumulating that if the nervous system does not receive normal forms of stimuli during discrete periods of development, it will not develop correctly. Not only do the organs that feed information to the brain need to develop normally, but the brain must be able to process the information correctly.

Earlier space flight studies indicate that gravity is crucial to some, but not all, normal developmental processes. In microgravity, quail chicks fail to develop the skills for self-feeding, but tadpoles that hatch and develop exhibit normal swimming behavior. Key goals then are to identify the critical periods of development when animals are sensitive to changes in gravity and which developmental systems are affected. Neurolab is hosting experiments with mice and rats that can only be performed in the absence of gravity to assess development of the musculature, cardiovascular tissue, the vestibular system.

> Information gleaned from the Mammalian Development experiments might be applicable in treatments for people suffering from neuromuscular diseases such as muscular dystrophy or from nerve, muscle and spinal cord injuries.

Jacqueline Raymond, Kenneth Kosik and colleagues are looking at changes in the structure and chemistry of the developing hippocampus and vestibular system. Neurons and connections in the vestibular nuclei monitor gravitational changes. The major question then is, how might these systems develop without the stimulus of gravity?

Also under study is the ability to learn basic motor skills. **Kerry Walton** and her colleagues are assessing motor development of rats aged 8 and 14 days old on the day of launch. The former group has not walked under the influence of gravity whereas the latter group has. Previous work on Earth indicated that gravity is key to learning such a basic motor skill. The Walton study is specifically assessing muscle loading – pushing against a resistance – by testing the young rats' ability to walk and their ability to recover from lying on their backs to an upright position in the absence of an "up" direction. Once *Columbia* touches down, the animals' ability to readapt to gravity will be assessed and the spinal cords and cerebella will be examined for any anatomical irregularities.

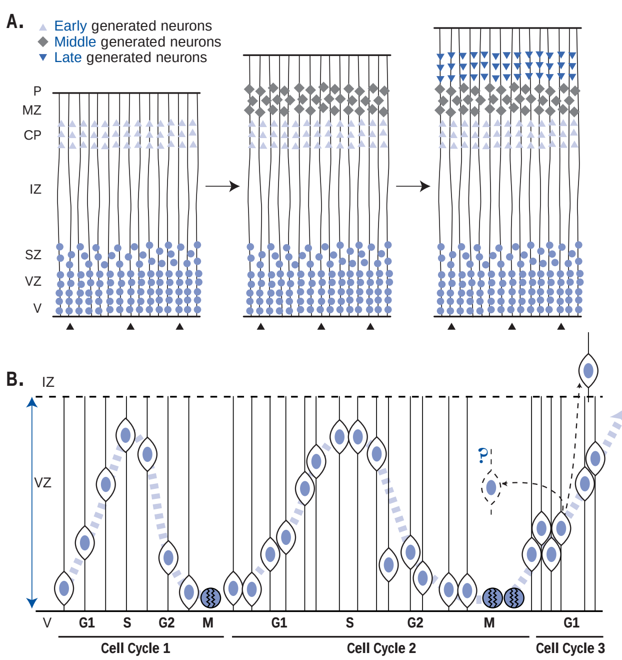
Danny Riley and colleagues are looking into the development of neuromuscular tissue by specifically studying changes in the fibers of the soleus and extensor digitorium longus (EDL) muscles of the hindlimb. These muscles contain "slow twitch" and "fast twitch" fibers that are highly sensitive to gravity. The soleus contains weight bearing muscles used to generate force for continuous and prolonged activity, such as standing. The EDL contains muscles adapted to producing force for rapid movement. The hypothesis is that the soleus muscle requires gravity for proper postnatal development whereas the EDL muscle does not. The study is examining the nerves that innervate these muscles, the neuromuscular junctions and the amounts of slow and fast twitch fibers.

Kenneth Baldwin and colleagues are also studying muscle development with an emphasis on myosin, which is under the influence of both gravity and thyroid hormone. This is key in generating muscle tension. He will test the hypothesis that, under the influence of microgravity, the inappropriate forms of myosin will develop thereby causing problems in muscle function upon returning to gravity.

Tsuyoshi Shimizu and colleagues are looking at development of the neonatal rat heart, specifically the arterial baroreceptors located in the walls of the aorta and carotid arteries. These receptors gauge arterial blood pressure. Previous space flight studies revealed that cardiovascular changes occur in humans as well as in laboratory animals. Under the force of gravity, the body must work to force blood from the heart up to the brain. The brain uses information from the baroreceptors to maintain a steady influx of blood. The question then is, without gravity, what information will the baroreceptors pass on to the brain concerning blood pressure? Shimizu's hypothesis is that the severe decrease in gravitational force alters the physical structure of the aortic nerves and hence the sensory signals received by the brain during development.

A study proposed by **Richard Nowakowski** and colleagues is directed at early neuronal development: Is the proliferation of neuronal precursors affected by gravity? These researchers are looking at the cortex in fetal mice. Cortex cells are produced in a common area and then migrate and differentiate during development. Using a dual-labeling technique, Nowakowski and colleagues are tracking the development and cell cycle of the cells of the cortex and will compare these results to animals during the same developmental period on Earth. This experiment is aimed at determining whether gravity affects a developmental process well before any behavioral disturbances could affect the brain.

Abbreviations:
CP, cortical plate;
IZ, intermediate zone;
MZ, marginal zone;
P, pial surface;
SZ, subventricular zone;
V, ventricular surface;
VZ, ventricular zone.
Images produced by permission of R. Nowakowski.



▲ **Figure 1.**

Development and migration of cells within the mammalian cerebral neocortex. The mouse neocortex is built in approximately 11 cell cycles. Panel A: Neurons that are generated in early, middle and late stages occupy discrete regions within the neocortex. Panel B: Neurons migrate and differentiate as the cells progress through each cell cycle. During each cell cycle, the nuclei of the cells move from the ventricular surface (V) toward the outer part of the ventricular zone and then back to the ventricular surface.

Aquatic

Michael Wiederhold and colleagues are studying gravity sensing systems in snails (*Biomphlaria glabrata*) and swordtail fish (*Xiphophorus helleri*). Snails and fish possess simpler gravity-sensing systems than those in humans, that develop quickly and are easy to study. Small particles of calcium carbonate rest on hair cells connected by nerves to the cerebral ganglia. The swordtail fish have a vestibular system similar to that in humans, but it develops much more rapidly. The particles are called otoliths in humans and fish, and are called statoliths in snails. The fish and snails are housed in the Closed Equilibrated Biological Aquatic System (CEBAS) developed by the German Space Agency.

Information gathered from the Aquatic studies may shed light on the mechanisms involved in motion sickness experienced by humans. It may also help in the understanding of some pathologies involving human otoliths, such as benign paroxysmal positional vertigo. Advances in data collection are also sought for the electrode in use for recording nerve impulses. It is hoped that it might help the deaf by connecting the ear to the brain for those with hair cell damage in the inner ear, or as an interface for signaling to motor prostheses.

Previous studies on the vestibular system of newts revealed that the volume of stones (called otoconia) increase in animals that developed in space. Ground-based experiments on snails that underwent development in a centrifuge – "hypergravity" – showed that statolith size is determined by the force of gravity. In an unknown manner, the pull of gravity signals the statolith that correct growth is achieved. In space, however, there is no signal, and the particles grow to a larger size.

Will a snail or fish with increased lithic particles behave differently? The animals are being videotaped so that we can study their movements compared to control animals on Earth. For instance, snails, both newly hatched and adults, preferentially crawl in a downward direction. Wiederhold and his team will also study the space flight-conditioned snails' crawling behavior once back on the ground.

Steven Highstein and colleagues are studying the function of the vestibular system. They are recording vestibular nerve impulse data from the oyster toadfish (*Opsanus tau*) using a newly developed telemetry system designed by the Japanese Space Agency, NASDA. The study is being conducted in the Vestibular Function Experiment Unit (VFEU), also designed by NASDA. The VFEU is a closed, aquatic habitat specifically designed for housing fish on space flights. The telemetry system monitors the self-orientation, that is the body displacement signals, sent from the gravity sensors to the brain. Comparative data is being collected from preflight through postflight stages of the mission, with the ascent and descent stages of the flight being the most important.

Neurobiology

To what extent do genes predetermine normal development versus the extent to which environmental cues (e.g., gravity) exert control is the key question of the Neurobiology Team. Under the direction of **Eberhard Horn**, experiments are addressing the gravity-sensing organs located in appendages, the cerci, on the abdomen of the domestic cricket (*Acheta domesticus*). The cerci contain gravity sensors connected to a relatively simple nervous system in this common insect. The cricket's nervous system can be studied comprehensively, in space as well as on Earth. Moreover, crickets possess a second sensory system comprised of air current receptors.

On Earth, crickets try to hold their heads as vertical as possible, even when the body is not vertical. For example, when rolling, a cricket will make compensatory movements to keep its head vertical. Once the cricket groups return to Earth, Horn and others will measure this behavior to determine the efficiency and accuracy of the synaptic connections of the cerci. The researchers are using electrodes to measure the rate of nerve impulses transmitting sensory stimuli from both the gravity-sensing organ and the air current receptors. Crickets can regenerate cerci under the influence of gravity. How well, or whether they will be able to do so following neural development in space, will also be determined.

During flight, crickets are housed in the Botany Experiment Incubator (BOTEX) developed by the German Space Agency. The incubator contains a rotating compartment for simulating gravity. Horn and colleagues are studying two groups of crickets in early development; one group is maturing in microgravity and the second is maturing in simulated gravity.

Autonomic Nervous System

For the Autonomic Nervous System (ANS) Team, the prime interest is studying automatic control of blood circulation. Low blood pressure is a well known and unfortunate side effect of extended space flight. Barometric receptors sense gravitational forces resulting in the body's response by forcing blood up to the head against the downward pull of gravity. If these receptors are not working correctly, less blood goes to the brain, leaving a person feeling dizzy, a condition called orthostatic intolerance.

The ANS controls blood pressure in two ways: it can change the rate of heart pumping and the diameter of the blood vessels thereby changing the resistance of blood flow. High and low pressure receptors send competing signals to the spinal cord and brain where the cardiovascular controlling centers (the medulla oblongata and hypothalamus) integrate the information and send out their own signals to the heart and the arteries to control blood pressure. What happens to this system in the lack of gravitational forces and in the early stages of a return to gravity is not understood. **Friedhelm Baisch, Gunnar Blomqvist, Dwain Eckberg** and **David Robertson** are looking into this problem.

Crew specialists on Neurolab are conducting tests on each other to determine all aspects of autonomic circulatory control to understand what changes when gravity is eliminated. Blood flow to the brain is being measured using the noninvasive transcranial Doppler technique. The other innovative technique, microneurography, includes an acupuncture-sized tungsten needle placed in the peroneal nerve, just below the knee. This electrode directly measures nerve signals coming from the brain into blood vessels. Measurements are being taken while the ANS is challenged by a number of stressors. Negative pressure to the lower body, pressure to the hand and cold temperature all affect blood pressure, but through different receptors. These are being used to distinguish differences seen by the receptors that relay gravity forces to the brain. The crew is also to inject labeled norepinephrine into the bloodstream, and analyze its release and clearance, to determine whether the blood pressure system is underactive in space, as some hypothesize.

Sensory Motor and Performance

The Sensory Motor and Performance Team is testing how subjects adapt to common activities without having gravity as a guide. Motor skills are learned and mastered under the influence of gravity with signals from the inner ear feeding the brain. Gravity causes objects to "fall down." Our whole idea of up and down is set by the gravitational pull of Earth from the center of our body toward the Earth. In the absence of gravity, what inputs do our muscles and joints receive and what cues does the inner ear provide?

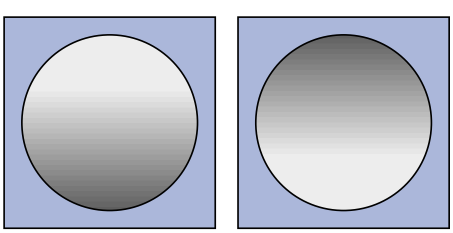
The results are expected to provide insight into how the brain successfully integrates information from the eyes, inner ears and joints. Such information holds promise for testing patients with neurological disorders, for working and living on the ISS and in improved designs of future spacecraft.

Ball catching requires that the brain predicts the effect of the impact and trajectory of the ball. It has been suggested that the brain has internal models of the effect of the gravitational field on both arm dynamics and ball kinematics. A nice way to test this 'internalization' of newtonian mechanics is to catch a ball in microgravity and observe the reorganizations that occur in the motor commands. **Alain Berthoz** and colleagues are studying the ability of the CNS to accept and interpret new forms of stimuli in space. Experiments are using the Kinelite system, developed by the French Space Agency, CNES. An overhead spring-loaded device propels a ball "downward" and crew members try to catch it. The system captures three-dimensional images and electrical impulses in the arm. The ball is propelled at varying speeds to test the sensory-motor actions. (Unlike on Earth, where the ball falls with constant acceleration, the ball "tossed" by the Kinelite apparatus travels at a constant velocity.)

Otmar Bock and colleagues are focusing on eye-hand coordinated movements in microgravity. Crew members are using the Visuo-Motor Coordination Facility (VCF) to assess changes in eye-hand coordination during adaptation to microgravity. The VCF, developed by the Canadian Space Agency specifically for these tests, presents targets that the astronauts point to, grasp at and track as the images move around and change in size. Astronauts will wear gloves with light-emitting diodes on the fingertips for precise three-dimensional tracking of movements by the VCF.

Charles Oman and coworkers are using a virtual reality display system to decipher the shift from visual and vestibular cues to visual cues only in microgravity. They are looking at how people use vision, the vestibular organs and pressure cues to determine their orientation and to identify objects in the environment.

These experiments are aided using NASA's Virtual Environment Generator (VEG), a head-mounted display showing three dimensional computer-generated virtual reality scenes. The studies test the influences of visual scene content and symmetry on the crew members' perceptions of up and down. Finally, it will explore how the perceived direction of "down" alters the subject's ability to recognize shapes and interpret curvature from shading. For example, whether the brain interpretes a flat but shaded circle as concave or convex depends on a "light from above" assumption. Where "above" is assumed to be depends on orientation of the circle to the head, and also to the perceived direction of gravity. Many of the tests are being performed with the astronauts free floating or restricted by a "constant force spring" harness to provide artificial downward cues exerted on the shoulders and hips.



▲ **Figure 2.**

Shading provides visual cues to interpreting three-dimensional shape. The shape on the right appears convex and the shape on the left appears concave when viewed upright. However, if the page is turned upside down, the results change.

Vestibular System

The vestibular system is composed of parts of the inner ears. We use input from the eyes and the inner ears, with processing in the brain, to focus the eyes on external objects. Experiments on Earth show that eye movement is not the same when a person is in motion parallel to the force of gravity compared to the same movement perpendicular to the gravity force. The aim of the vestibular team is to address adaptation mechanisms of humans to space flight and to a gravity environment upon their return. Coping with gravity following space flight is every bit as challenging as adjusting to the lack of gravity.

Studies of the Vestibular Team, under the direction of **Bernard Cohen** and **Gilles Clement**, are asking what changes occur in the inner ear and how the brain ignores or reinterprets signals from different sensory inputs. Vestibular investigations are using centrifugation and eye movement as windows on the workings of the inner ear. On the ground, the eyes reflect the workings of the inner ears. The eyes, for example, move in directions opposite to those encountered by the body or head. Corrective actions to eye movement come into play when motion reaches an extreme. Similarly, if the body is tilted one way, the eyes will roll in the opposite direction. The eyes and the vestibular system are closely coordinated.

Crew members on Neurolab are using an off-axis rotator (i.e., centrifuge), spinning at 45 revolutions per minute, to simulate the force of gravity, and to stimulate the vestibular system with spinning and tilting motions. Video cameras capture the responding eye movements. In darkness, the spinning motion is felt by the person strapped into the chair, but this dissipates as the chair attains a constant angular velocity. After this time, rotation is not sensed but rather the occupant feels as if he or she is tilting. This is due to the spinning motion's effect on the inner ear, which becomes equivalent to resting on one's side. The hypothesis is that crew members' brains reinterpret the information coming from the inner ear and these changes are reflected in the eye movements.

Sleep

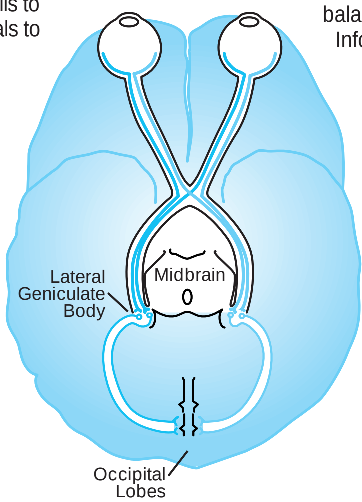
Finally, the Sleep Team is addressing why astronauts sleep so poorly on shuttle flights. Typically, sleep is reduced about two hours per day in space flight. Tied in with poor sleep are the extreme changes in circadian rhythm. Our bodies tend to establish biological rhythms based on a circadian rhythm. For instance, we become accustomed to daily periods of light and dark repeated just once a day. On a typical shuttle mission, this pattern of light and dark repeats itself roughly 16 times a day with sunrise occurring about every 90 minutes.

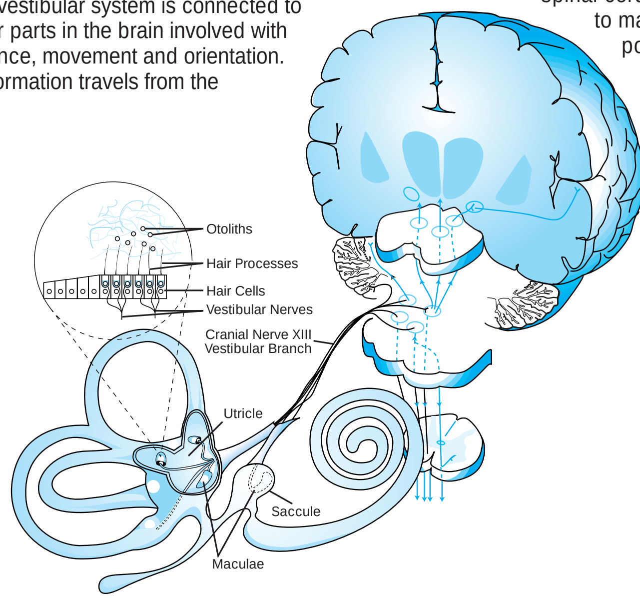
How Balance Works

The inner ear contains two balance-sensing organs – one composed of the saccule and utricle to detect and convey information on position relative to the gravitational force, and the second composed of three semicircular canals, which convey information on movement to the brain. Tiny particles of calcium carbonate lie on specialized hair cells in the saccule and utricle and stimulate the hair cells to send signals to the brain voicing “up,” “down,” tilt and acceleration in a particular direction.

The three semicircular canals, also lined with specialized hair cells, are arranged at near 90° angles and can detect movement in three dimensions. These two balance and motion-sensing organs comprise the vestibular system.

The vestibular system is connected to other parts in the brain involved with balance, movement and orientation. Information travels from the vestibular system to the eyes to keep them focused on the target at hand during movement. Connections also reach into the hippocampus, important to knowing locations and navigating, and the cerebellum, for producing smooth, precise and coordinated movements. Vestibular information travels down the spinal cord to muscles to maintain posture and balance.





On Shuttle missions, astronauts become shift workers, trying to complete multiple tasks in 12-hour shifts. Privacy, as well as quarters, are at a premium, and noises, the excitement of the mission and a host of other factors conspire to make sleep all the more difficult. Not a minor problem when more than 50% of astronauts use some form of sleeping medication on missions. Cumulative sleep loss becomes a greater problem as missions become longer.

The goal of the Sleep Team is to improve the quality of sleep for future missions. **Charles Czeisler** and colleagues are investigating melatonin as a possible sleep enhancer and its effects on “daytime” performance. **John West** and colleagues are looking at how changes in the control of respiration affect sleep and, in turn, how disturbances in sleep affect respiration. Some crew members are taking melatonin, and some placebos, prior to sleeping. Electrode-laced caps on the subjects’ heads are recording electrical impulses from the brain, muscles, eyes and heart. Melatonin excretion levels are being analyzed from urine samples. These measurements along with temperature recordings are used to establish the circadian rhythms of the crew members.

Respiration may be key to understanding the altered and often poor sleep experienced in space. The lack of gravity alters the motions on the chest and abdominal walls. Irregular breathing, high carbon dioxide levels in the blood and low oxygen levels result in poor sleep on Earth. West and colleagues are testing the hypothesis that sleep disturbances in space are the result of changes in breathing, which lead to altered oxygen and carbon dioxide levels in the blood and irregular breathing patterns. Crew members are breathing special gas mixtures while the composition and flow rates are recorded using a specialized gas analyzer.

Concluding Remarks

If all the experiments being performed on Neurolab are successful, we will be given a much greater insight into the interaction of space and its associated lack of gravity on the nervous system of humans who will work, live and perhaps raise children aboard the ISS in the coming decades.