EXAMINING THE EFFECTS OF SPACE FLIGHT ON THE HUMAN SENSORY AND BALANCE SYSTEM

VESTIBULAR EXPERIMENTS IN SPACELAB

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INTRODUCTION

Have you ever watched a scene on television where a person steps off a curb, a rushing vehicle blares its horn, and the person leaps back to safety in the nick of time as a car or truck thunders past? Have you ever experienced forgetting a certain word that you really want to use to describe something **but you just can't think of it**, and then the word comes to you in the middle of the night or some other time when it doesn't do you any good anymore?! But at least you finally remembered it! Also, how is it possible for an owl to dive, almost silently, out of the night sky and entrap a scurrying mouse in its clutches? Both organisms are on the move, yet the owl's timing is precise, and it neither crashes into the ground nor comes up empty-handed. Think about how elegant it is just for all of us to be able to walk, and to walk at varying speeds and over various obstacles. You may have never considered walking as elegant but that's because we take it for granted that our legs are going to get us places. Look at a nervous system that is not performing normally because it has been altered by drugs, or by disease, or by trauma to the inner ear, for example, and we get a glimpse of the awesome complexity that underlies the smooth physical and mental coordination we normally take for granted.

The examples that we just considered are just four small examples of the routine, everyday functioning of the human nervous system. Even a thousand examples would not be enough to describe its capabilities. Its presence in the body makes of each of us, in effect, a vast switchboard of humming, flashing, blinking signals, constantly sending and receiving messages - some urgent, some not - all concerned with the conduct of the body's affairs.

From the moment we are born to the moment we die, this communications network controls our every thought, our every emotion, every impression we get, and every single movement we make. Without it we could not plan, feel, move around, nor distinguish between pleasure and pain; we could be deprived of such amenities of life as the enjoyment of food, or music, or the color of a painting, or dancing and moving, or the pressure of a friendly handshake. In this chapter, we are going to examine how our brain and overall nervous system work together to provide us with the direction, guidance, and impulses necessary to move about and function day to day. In particular, we will discuss the influence of gravity on the sensory and balance centers within our brains and we will examine a space flight investigation that was designed to learn more about the major effects on our senses and our perceptions that result from the removal of gravity. This is our last chapter, so let's get started!

EARTH PHYSIOLOGY

The **nervous system**, operating through the use of **electrochemical impulses**, serves the body in a variety of ways. These impulses consist of electrical and chemical transmission pulses that travel through the body's extensive network of nerve fibers. The nervous system functions as the body's lookout; as gatherer of information about the world outside of us as well as the one within us; as the clearinghouse where this information is processed for instant use or future reference; as the body's general communications center; and as headquarters for mapping the strategy and making the decisions about everything the body does. The nervous system, in short, is the **initiator** of the body's muscular activity, and the **regulator** of our mental and physical functions. Here on Earth, it works hand in hand with gravity, predicting, planning, and executing our every physical move. After we examine the basic structure of the nervous system and discuss the various sensory and motor functions of our body, we should begin to see how the senses **unite** to provide information that enables us to maintain our **equilibrium**, or balance.

Let's begin with a description of our nervous system, brain, and sensory system.

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Structure and Function of the Sensory and Balance Organs of the Body

The dynamic system of controls that make up the nervous system is composed primarily of **nerve cells**, or **neurons**, that are woven together as tissue interspersed with other cells, called **glia**. The **brain** and the **spinal cord** serve as the system's main base of operations. From these organs, an extraordinary network of nerves reaches out to every part of the body. The **brain**, for all of its importance and glory, is really a modest looking structure. It is soft gray, and wrinkled, and about the size and shape of an average acorn squash. It weighs about three pounds and it has a four-inch-long, one-inch-wide central core, or **brain stem**, extending upward from the spinal cord (Figure 1). On either side of this core, and behind it, lies a mass of nervous tissue, the cerebellum. Draped over the brain stem and **cerebellum** is the **cerebrum**. Its outer layer, the **cerebral cortex**, is folded and convoluted to fit into the six-by-eight-inch vault of the skull; if flattened out, the cortex would cover more than two square feet in area. A deep crease (fissure) down the middle of the brain divides the cerebrum into two **hemispheres** connected by two bands that are much lighter in color than the gray exterior tissue of the brain. Here, as elsewhere in the nervous system, the two colors represent a significant difference:

- the **gray matter** is made up of gray **nerve-cell bodies**;
- the **white matter** is made up of **nerve fibers**, called **axons**, which extend from the nerve cell bodies and are **capable of conducting nerve impulses.**

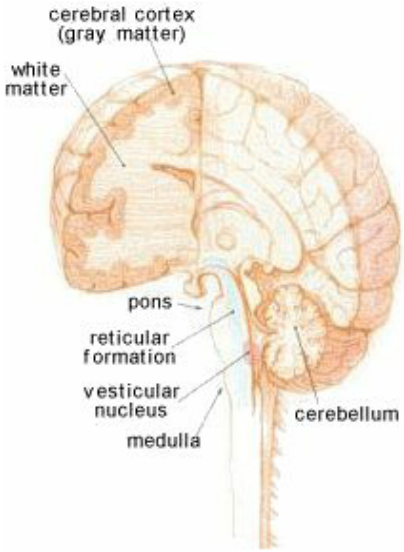
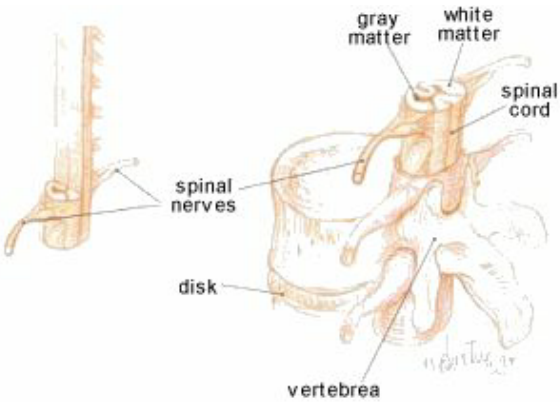
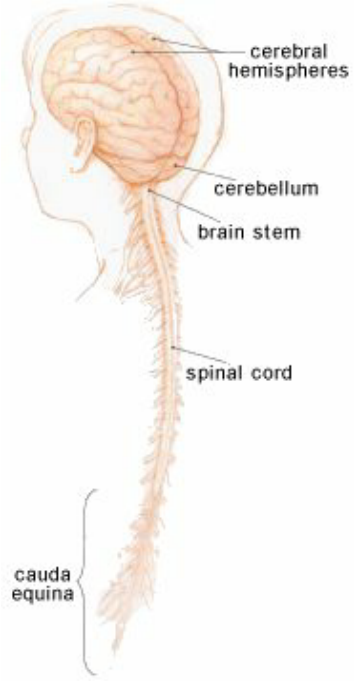


Figure 1. The human brain and spinal cord serve as the main control centers for every action of the body.

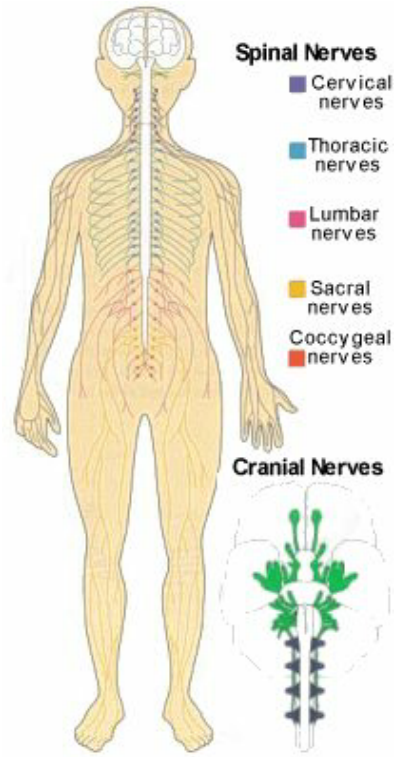


What gives these fibers their color, as well as a generally waxy look, is a fatty coating, **myelin**, which not only insulates the fiber but also makes it a speedier conductor. The **spinal cord**, which is about 18 inches long in an average sized adult, resembles a cable tapered at both ends; at its widest, it is a little more than half an inch across. Like the brain, the spinal cord contains both gray and white matter; the gray nerve-cell bodies form a column in the center of the cord, wrapped by the white bundles of nerve fibers (Figure 1). Surrounding the cord on the outside is a perforated tunnel of bone formed by the rings of the vertebrae - the body's backbone.



The network of nerves that threads through the body is rooted both in the brain and in the spinal cord. Through the entire extent of the brain stem, between the brain and the spinal cord, are areas of neurons collectively known as the **reticular formation**. Many of the nerve fiber tracts that travel between the brain and spinal cord pass through the reticular formation. Some of the signals that enter the reticular formation are being sent by the balance organs of the body, particularly from the **vestibular apparatus** in the inner ear, the **cerebellum**, and both the sensory and motor regions of the **cerebral cortex**. The reticular formation seems to serve, then, as one of our body's integration sites to help interpret the multiple sensory and motor nerve signals that are constantly being sent throughout our system to the spinal cord and then up to the brain.

Figure 2.



From the brain, nerve fibers converge to form 12 pairs of **cranial nerves** serving the head, eyes, ears, throat, and some organs in the chest and abdomen. From the spinal cord, 31 pairs of **spinal nerves** pass out through openings between the vertebrae at various levels (Figure 2). Although they are not named individually, they are grouped according to the level of the vertebrae from which they arise, and each nerve is numbered in sequence in the following way:

- there are eight pairs of **cervical nerves**, numbered C1 through C8;
- there are twelve pairs of **thoracic nerves**, numbered T1 through T12;
- there are five pairs of **lumbar nerves**, numbered L1 to L5;
- there are five pairs of **sacral nerves** numbered S1 through S5;
- there is one pair of **coccygeal nerves** at the very base of the spinal cord.

From the upper part of the spinal cord, the cervical and thoracic nerves branch and rebranch to form nerve trunks leading to the upper torso, arms and hands. From the lower part of the cord, the lumbar, sacral, and coccygeal nerves branch and rebranch to form nerve trunks leading to the pelvis, thighs, legs and feet. In an adult, the spinal cord does not extend the entire length of the vertebral column, but it ends at the level between the first and second lumbar vertebrae. It is at this point that the lumbar, sacral, and coccygeal nerves descend to their exits beyond the end of the cord. These descending nerves form a structure called the **cauda equina**, which is so named because it is shaped somewhat like a horse's tail.

The nerves reach every millimeter of skin surface, every muscle, every blood vessel, every hone - every part of the body from tip to toe. Each nerve carries **electrochemical** impulses that are triggered by some **stimulus** and that travel at rates of anywhere from 1 to about 400 feet per second. The speed of the impulse depends on the size and type of the particular nerve fiber involved and the thickness of the coating of Javelin around it. Certain fibers which lock Javelin are comparatively slow transmitters.

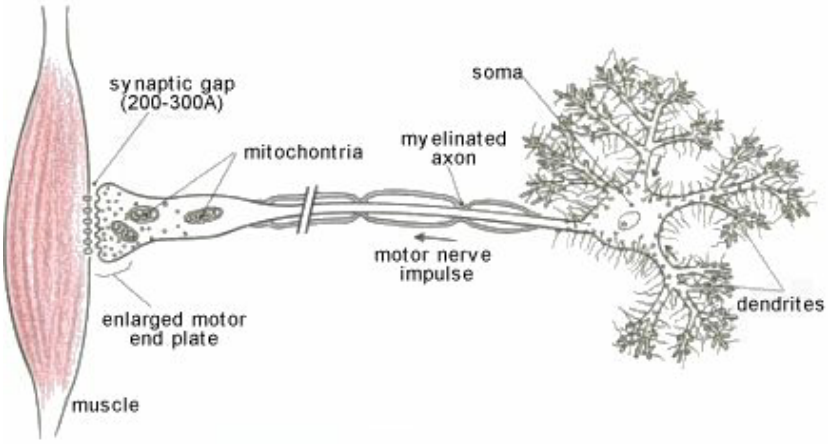


Figure 3. A typical motor neuron.

The basic unit of the nervous system, the neuron, has one structural characteristic that distinguishes it from all other cell types. Thin fibers that look like tiny tendrils (Figure 3) extend from the central part of each neuron. The central part of the neuron is the actual cell body, or Coma, and the fibers extending out from the soma are either called axons or dendrites depending on their function, but not all neurons have both. Let's distinguish between these two:

- **axons** are the primary **output** apparatus (for instance, they are used to activate muscle activity);
- **dendrites** primarily receive and integrate (mix and translate) **incoming signals**.

Some sensory neurons in the skin have only an axon, and some neurons in the **olfactory lobe** of the nose (olfactory = referring to the sense of smell) have only dendrites. A single axon generally protrudes from the soma, and commonly it will branch extensively toward its end. In contrast, a dense collection of dendrites often extends from the end of the soma.

Depending upon their location and function, neurons may be anywhere from a fraction of an inch to as much as three or four feet long (the longest reaches from the base of the brain to the big toe). It is via their **fibers** that the neurons perform their unique function of transmitting electrochemical signals to and from the brain and spinal cord. Upon receiving a signal, one neuron sends it on to another neuron lying adjacent to it across a kind of bridge that "sparks" the impulse across to the other side through electrical and chemical means. This sparking bridge is called a **synapse**. We will discuss this more, as it applies to muscle stimulation, later in this section. **Sensory signals** that produce sensations of sight, sound, pain, pressure, touch, heat or cold go from various parts of the body to the brain either directly or through the spinal cord. Back from the brain or the spinal cord go "orders" from **motor signals** to muscles in the fingers, toes, heart, intestines, and elsewhere. In this way, all of our parts work together to allow us to function in the world around us. There are three general classes of neurons, grouped according to their function:

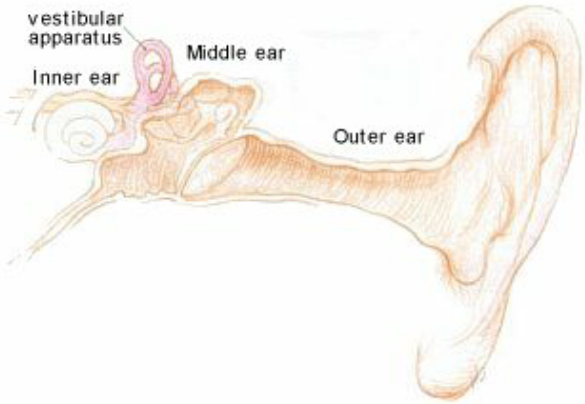
- **sensory neurons** carry sensory information to the spinal cord and brain;
- **motor neurons** carry directives from the brain and spinal cord, both to stimulate the contraction or relaxation of muscles and to spur the activity of glands;
- connecting neurons, called **interneurons**, shuttle the signals back and forth, through complex pathways, between the brain, spinal cord and other parts of the body.

Interneurons comprise over 99% of the more than 10 billion neurons in the nervous system, including most of the nerve cells of the brain itself. The entire system of neurons and their interneuron connections enable a nerve fiber to transmit up to **1000 separate impulses in a single second**, even pausing After each impulse has passed before handling the next.

The sensory neurons keep the brain informed of what is happening to and in the body through a wide variety of sensory pick-up units called **receptors**. Some of these, called **tactile** or **cutaneous receptors**, are located at or near the skin surface and are especially sensitive to pain, touch, or pressure on the

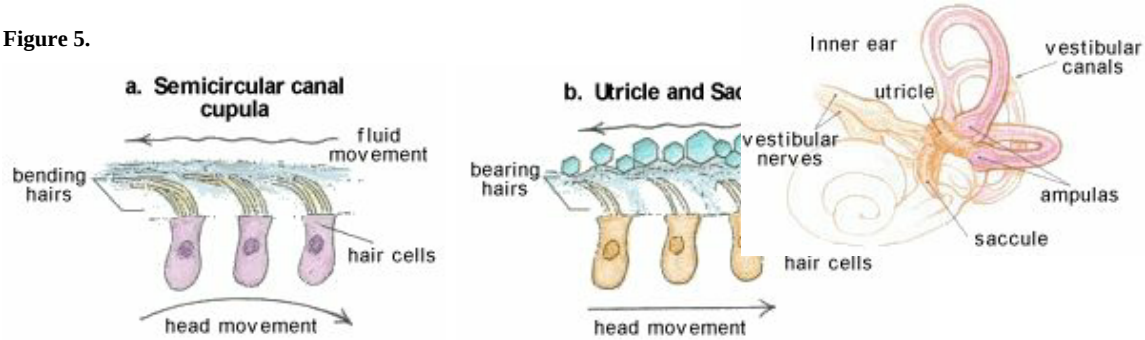
skin. There are special **thermoreceptors** that detect changes in body surface temperatures. The **proprioceptors** are the body's primary mechanical receptors, located in muscles, joints, and tendons, and they are sensitive to changes in muscle tension and movement. Other receptors on the tongue and in the upper parts of the nose respond to flavors and odors.

In the retina of the eye, special **photoreceptors** shaped like **rods** respond to light and shadow of different intensities and wavelengths, while receptors shaped like **cones** respond to color. Other receptors are embedded deep in the digestive tract, in the walls of the intestines; when the intestines are confronted by indigestible food or by gas, these receptors transmit signals of pain, which are then interpreted as cramps. Sensory receptors in the ear respond to vibrations caused by sound waves bouncing off the eardrum. Other sensory receptors in the ear react to and interpret **gravitational information** and initiate movement of our body here on Earth. How do we remain standing despite the perpetual pull of gravity? Why can you whirl around suddenly without falling down? The **vestibular organs** (Figure 4), also called the **vestibular apparatus**, in the inner ear help maintain equilibrium by sending the brain information about the motion and position **of the head** The vestibular organs consist of three membranous **semi-circular canals (SCCs)**, and two large sacs, the **utricle** and **saccule**. All the vestibular organs share a common type of receptor cell, the **hair cell**. Let's examine the structure and function of the vestibular organs a little more closely.



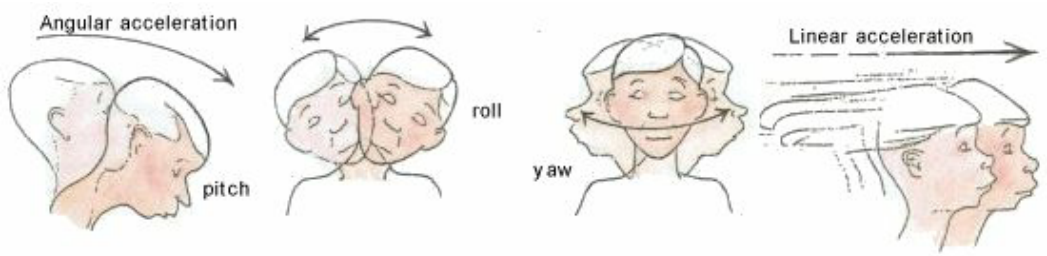
The three **semicircular canals (SSCs)** within the vestibular organ of each ear contain fluid and hair receptor cells encased inside a fragile membrane called the **cupula** (Figure 5). The cupula is located in a widened area of each canal called the **ampulla**. When you move your head, the fluid in the ampulla lags behind, pushing the cupula a very tiny bit which causes the hairs to also bend a very tiny bit. The bending hairs stimulate the hair cells, which in turn trigger sensory impulses in the vestibular nerve going to the brain to "report" the movement. Hair cells are amazingly sensitive. For example, a cupula movement of even a thousandth of an inch is detected by the brain as a big stimulus.

Figure 5.



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

Two other vestibular organs are located in membranous sacs called the **utricle** and the **saccule**. On the inside walls of both the utricle and the saccule is a bed (a **macula**) of several thousand hair cells covered by small flat piles of **calcium carbonate crystals** which look like sand, imbedded in a gel-like substance (Figure 5b). The crystals are called **otoliths**, a word which literally means "ear stones." In fact, the utricle and the saccule are often called the **otolith organs**.



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

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Uniting the Senses for Action

Several types of receptors acting in combination can produce very complex sensory experiences. We may find a particular food palatable or unpalatable, for example, not only because of how it tastes and smells, but also because of how it appeals to the eye. When you look out the window of a stationary train and see another train pull away, your eyes might suggest that **you are moving** until other receptors in your body inform you that **you're not**. We may simultaneously experience sensations of touch, pressure, heat and pain in lifting a pot from the stove. In fact, to take just one step, we first need to know the positions and **spatial relationship** of the parts of our body.

The term "spatial" here refers to "the space that it occupies" and does not refer to "space flight." The fact is that no matter where we find ourselves - on Earth, Mars or orbiting somewhere in outer space - there will always be "space" around us and it is the job of our vestibular system, brain, eyes, muscles, and our touch receptors to judge our position in space at all times. This not only includes a general **awareness of position**, but it also includes how the different parts of our body are positioned **relative to other parts of the body**. Even further, these organs help us develop and maintain the awareness of our own body **in relation to the pull of gravity**.

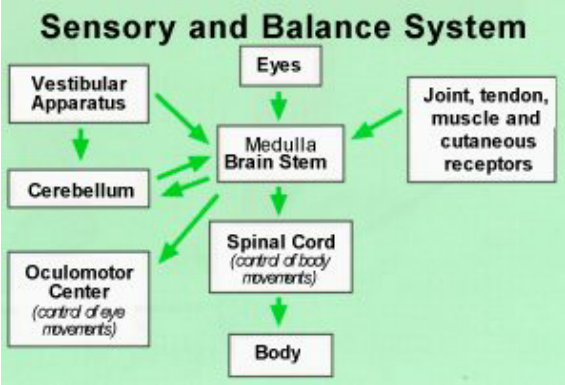
Let's consider the case of a person walking on a tightwire (Figure 6). This acrobat's subconscious mind can make extraordinarily delicate interpretations of signals from the vestibular organs and instantly send appropriate orders to his responsive muscles. The eyes, the ears, and the proprioceptors of touch contribute instantly and constantly to the vestibular information and keep him informed of the position of his entire body at every moment; none of these senses alone would be enough to keep the acrobat balanced. In fact, receptors lodged in the muscles, joints, ligaments or tendons fire off signals to the brain any time a muscle contracts or a joint moves or is subjected to added pressure and tension. While the sensory neurons are bringing in information from all parts of the body to the brain, motor neurons are at the same time carrying directions from the brain to the muscles, where signals travel from a nerve through the synapse, and directly to the muscle fiber. These signals cause the muscles to move. Let's examine how this works.

Figure 6.

The fibers of motor neurons terminate in tiny flat plates, called **motor end plates**, which lie in close contact with individual muscle fibers (refer back to Figure 3). This is called the **neuromuscular junction**. Here the nerve ending is separated from the muscle only by a tiny gap called the **synaptic cleft**. This gap would be large enough to actually stop the motor signals in their tracks except for a special chemical reaction that takes place at the gap. As the impulse reaches the motor end plate, the nerve ending releases a chemical transmitter known as **acetylcholine**, which initiates events in the muscle cell. With the muscle's contraction, another substance, an enzyme called **cholinesterase**, begins breaking down the accumulated acetylcholine and clearing it away so that the next arriving nerve impulse can set the cycle in motion again. It is this rechargeable chemical cycle that efficiently bridges the gap between motor nerve ending and muscle cell so that muscle action can be stimulated.

Determining which muscles contract and which relax in the continuous adjustments required to maintain our body's balance and keep us upright here on Earth is a function of the **"lower centers"** of the brain, the **brain stem** (including the reticular formation) and the **cerebellum**. From Figure 7, you can see that the brain stem **receives input** from four major sources and **transmits output** to three major regulators of body movement and perception. The brain stem and the cerebellum also participate in the control of our heart rate, respiration, and digestion. In addition, when appropriate signals from our gut receptors, various chemical signals from the brain, and unfamiliar and confusing sensory signals are received and integrated, the brain stem reticular formation is the site in the brain that can trigger vomiting. Other areas of the brain are also very involved with our senses, perceptions, and responses to movement. Somewhat **"higher centers"** of the brain regulate such complex motor activities as walking, running, and reaching for objects as well as body temperature and appetite. The **"highest center"** of the brain, the **cerebral cortex**, consists of distinctive areas called the **sensory cortex** and the **motor cortex** (Figure 6). The cerebral cortex gives us our awareness of sight and sound, as well as our delicate sensations of weight, texture and form. It also initiates emotional responses such as fear and anger, and enables us to experience pleasure or pain. With all of its importance, the nervous system is well cared for by our bodies. Let's discuss what it takes to keep our nerves alive.

Figure 7.



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Metabolism and Protection of our Nervous System

The complicated and busy nervous system consumes energy at an astounding rate. Nerve cells, therefore, require far more fuel, oxygen and glucose, than other cells; thus they must have a continuous and rich supply of blood or they will die quickly. Nerve cells in the brain alone use up as much as 20 % of all the oxygen available in the adult body, for they are working at a frantic pace for 24 hours a day. That may seem curious, since we think of sleep as "giving the brain a rest." But the brain is indisputably active during sleep periods. Quite aside from maintaining breathing and the rate of heartbeat, the brain may use these periods to try to search out answers to particularly difficult problems and to reconsider experiences of the day that were flowing in too fast to be dealt with carefully at the time.

Night or day, the brain's need for constant supplies of blood and the oxygen it carries never slows. Normally, during the course of every 24 hours, we lose some neurons simply because they wear out and die. Fortunately, great numbers would have to die to produce any noticeable effect, but the small losses inevitably accumulate. Neurologists today believe that the slow loss of mental efficiency that occurs in old age, the process we call **senility**, is a direct result of day-to-day destruction of a few neurons here and there, until the total loss begins to mount up and is accelerated by narrowing of blood vessels to the brain. Whatever the cause of the loss, once a neuron is destroyed, it ceases to exist. No new nerve cell will ever take its place; **a year-old baby has all the neurons it will ever have**. If a nerve fiber is only cut, and the cell itself is not killed, a new fiber may eventually grow out along the course of the cut fiber. But if the nucleus of the neuron is destroyed, the cell is gone forever. The only exception is the **olfactory system**, in which neurons are continuously stimulated to grow.

Because the body could not tolerate the loss of too many neurons, and because nervous tissue is very fragile, the nervous system operates behind an impressive wall of protection. The brain is encased in the tough armor plate of the skull. The spinal cord is enclosed in a strong but flexible bony sheath made up of the vertebrae. Both brain and spinal cord, furthermore, are surrounded by a clear **cerebrospinal fluid** which serves, among other purposes, as a shock absorber.

The rest of the nervous system is also well protected. The nerve trunks throughout the body are deeply buried between layers of muscle, except in such rare places as the point where the **ulnar nerve** crosses the elbow just beneath the skin (Figure 8). This is the easily shockable "funny bone." The shock that vibrates in the fingers and courses up the spinal cord to the brain when the back of the elbow is struck is really an **electric impulse**, originating not in a bone but in the ulnar nerve. This nerve extends the entire length of the arm and is well protected everywhere except at that one tender spot. (The misleading term "funny bone" may have stemmed from a word play on "humerus," the large bone in the upper arm.)

Figure 8.

Many of the delicate receptor endings of sensory nerves are also carefully shielded. The nerve endings in the **retina** lie at the back of the eye, which is buried in a deep bony socket; they are protected from too much light by the self-adjusting shutterlike covering of the iris. Sound receptors and balance receptors are encased deep within the ear in tiny bony caverns in the skull. Certain receptors, such as those sensitive to pain, touch, heat and cold, which lie at or near the surface of the skin, are relatively exposed. They are so widely distributed, however, that the loss of a few here and there is not usually important.

Under this massive cloak of protection, the nervous system conducts its complex activities with efficiency and **experience**. Nerve impulses are transmitted so rapidly that a whole sequence of actions, interpretations, and responses can take place before we are even aware that anything has happened. In fact, a single stimulus may fire off thousands upon thousands of responses within a fraction of a second. After being accustomed to operating in a gravitational environment, however, the brain and nervous system must be reprogrammed in space to allow for many strange new signals and new movement possibilities, such as floating. This results in new levels of disorientation for the first few hours or days of weightlessness. The problem is that the brain and nervous system have no **experience** in the microgravity environment of space. In fact, over two-thirds of all astronauts experience **space motion sickness** for up to the first three days in space. The symptoms of this malady are similar in many respects to the symptoms of motion sickness on Earth. Such space sickness appears to continue until the brain and nervous system gain some microgravity experience and begin to **adapt**. A great deal of work is being done to characterize, understand, and develop strategies to alleviate this problem. We are going to look at some of the things that are being done regarding space motion sickness, and we will examine some other very interesting effects of space flight on the sensory and balance system. We're coming closer to the end of the book, so let's move on!

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SPACE PHYSIOLOGY

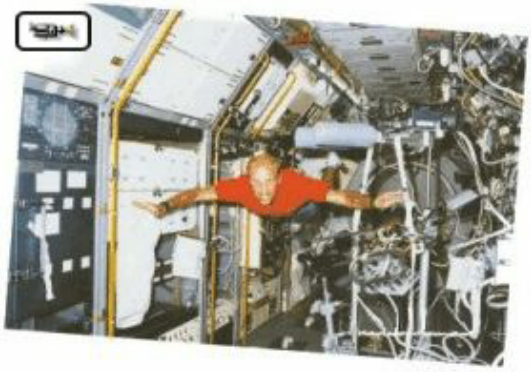
In space, the normal, ever-present effects of gravity on our bodies disappear, and this change profoundly affects our **perception** of **body orientation** and **equilibrium**. This change is the most dramatic of all of the physiological changes experienced during space flight. As a result, astronauts often disoriented and, in many cases, sick. The part of the nervous system that is primarily responsible for the balance mechanisms in the body is called the **n eurovestibular system**. We will focus on that system during the remainder of this section.

We've already learned that the awareness and perception of our body's orientation **on Earth** is attributed, in part, to the detection of gravity by the **otolith organs** (the utricle and the saccule), and to the detection of head rotational movements by the **semicircular canals**, both of which are in the inner ear. Gravity sensors in the joints and touch sensors in the skin are also involved, and the eyes contribute by sensing the body's relationship to other objects. **In space, however, the weightless environment provides a different stimulus to the otolith organs, and the resulting signals no longer correspond with the visual and other sensory signals sent to the brain. This signal conflict causes dis orientation.** That is, your brain has difficulty making sense of the fact that, although you **see** the floor and the ceiling, there is no other **sense realism** connected to the concept of "up" and "down" (Figure 9). The touch and balance mechanisms are completely confusing the brain because you don't realize how quickly you'll bounce back from something that you touch because there is nothing to anchor your position. immediately upon experiencing weightlessness, you feel as though you are simply a floating set of eyeballs, not even knowing where your limbs are because they have no weight associated with them to give your brain clues about their whereabouts! The complete collection of environmental and physical data th at your brain is trying to comprehend **does not make sense**.

Figure 9. There is no "up" or "down" in space.

When "free floating" in microgravity, the otolith organs no longer provide a **vertical reference signal** to the brain; rather, they respond only to **linear acceleration**, forward and backward, up and down, left and right. As an astronaut begins to adapt after a few days, he can begin to process this strange information in an appropriate way. He learns to propel himself around by pushing off walls, ceiling and floors and he can "fly" through the Spacelab cabin (Figure 10). In an effort to reinterpret the meaning of the otolith signals, and to provide some sort of a reference "down" axis, which seems to be required for comfort by some people, the nervous system seems to adapt and respon d more to **nonvesitibular signals**, particularly visual, proprioceptive, and tactile cues.

Figure 10. Floating in microgravity.



The **practical aspects** of neurovestibular research in space include the prediction, prevention, and treatment of space motion sickness; the reduction of risk in an emergency egress (escape) in the event of an accident; and the long-term is sues of human adaptation to very long duration flights en route to Mars. The **underlying research questions** deal with the fundamental role of gravity in the development of specialized sensory organs, the neural connections that are associa ted with the vestibular systems under altered environmental conditions, and the levels of the brain at which these reversible adaptive processes take place.

In order to explore the full range of neurovestibular adaptation to space flight, a series of human experiments was performed on a variety of missions under the direction of Dr. Laurence Young from the Massachusetts Institute of Technology (MIT) in Cambri dge, Massachusetts. Dr. Young brought together a large team of U.S. and Canadian researchers who developed a set of investigations aimed at documenting both **physical vestibular changes** and **perceptual changes** and to invest igate the mechanisms involved in these changes. Through the results of these experiments and others, investigators hope to also understand the nature of **vestibular adaptation to weightlessness** and the relationship of head movement and flu id shift to space motion sickness symptoms.

As in all of the other chapters, we will examine some of the **actual results** from Dr. Young's experiments that were obtained on several different space flight missions. His original hypotheses for the study were simple but direct statement s about his expectations and predictions related to the outcome of the experiment. Dr. Young's hypotheses were as follows:

Hypothesis 1

In the process of vestibular adaptation in weightlessness, the incoming otolith signals are inhibited and replaced by an increasing influence of visual and somatosensory orientation cues.

Hypothesis 2

Space motion sickness is caused by the sensory conflict between otolith signals, which are altered in space, and visual, somatosensory, and semicircular canal cues, which remain unaltered in space.

Before we begin our examination of Dr. Young's space flight results, let's participate in three "Student Investigations" designed to clarify certain important concepts from this chapter. These activities will prepare you to understand more about your sens ory and balance system so that you will have a better background for understanding Dr. Young's space flight experiment.

Prev: Earth Physiology | Next: Student Investigations

YOUR PERSPECTIVE

In this section, you are presented with two opportunities to study your neurovestibular system. These exercises were designed to manipulate your vestibular system to enable you to see how you perceive motion with and without your senses of sight, hearing, touch and muscular movements. Both Student Investigations involve some form of spinning, moving, tilting, or rotating. They should not only be fun, but also very interesting because they illustrate how your sensory and balance system can sometimes play t ricks on you.

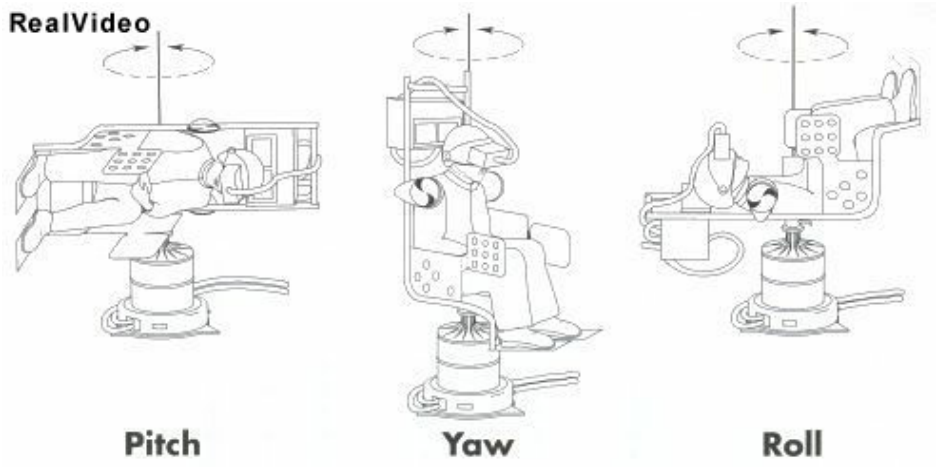
Student Investigation 1 involves carrying out an experiment similar to one that was done in space using a rotating chair. This exercise will help you understand more about your **sensation** of rotational movement and how it can be influenc ed by the kinds of signals you are receiving. Student Investigation 2 is an exercise that involves two simple but elegant demonstrations that enable you to understand how your vestibular system and your visual cues can be a powerful team to help you mai ntain balance. So let's get started!

Prev: Space Physiology | Next: Student Investigation 1

STUDENT INVESTIGATION 1

The Rotating Chair Experiment

Figure 11. An Earth-bound version of the rotating chair. It is capable of rotating a subject in three axes: pitch, yaw, and roll.



Background

In order to study how rotational effects might be perceived differently during space flight, a simple piece of equipment was designed to provide a rotational stimulus as well as a means for measuring important vestibular parameters in humans during rotation. It is called the **rotating chair**, which is exactly what it is! The chair, together with all of its computerized components and detection devices, is essentially an **angular accelerometer**, an instrument that measures acceleration or detects and measures vibrations. With the use of the chair and all of its supporting equipment, one can:

- initiate and maintain a controlled rotational stimulus;
- quantify (measure in numbers and units) the rate of rotation;
- measure various physiological variables during rotation.

Dr. Young's science team utilized this equipment on two different space missions to examine how gravity influences the interaction between the visual and semicircular canal pathways to the brain. **Recall that it is our semicircular canals that are responsible for informing our brain about our rotational movements and, remember most of all, that they are mostly unaffected by gravity.**

For this Student Investigation, you are going to repeat the exact **protocol**, or technique, that was used in space, but you will observe and measure your own **per** (during) and **post** (after) **rotatory perceptions** (perception = a conscious feeling or sensation) during and After being spun in a rotating chair. You will compare your perceptions with and without other sensory cues. Before we begin, let's discuss the operation and significance of the rotating chair.

Here on Earth, when using the chair to carry out preflight and postflight measurements, the chair sits on a very sophisticated, motor-driven rotation device that can spin the chair in three axes; pitch, yaw, and roll (Figure 11). In space, however, the chair can be used without the motor-driven rotator and may be spun by hand. The chair even has a different name in space! It is known as the **Body Restraint System (BRS)**. It seems that everything in space is called something different from its counterpart on Earth. For instance, the "Waste Management System" in space is called the bathroom here on Earth! Let's get back to the subject of rotation and the description of the BRS.

In order to accurately measure the angular acceleration of the human **subject** being spun on the BRS, the subject must wear a head-mounted accelerometer recording unit that is attached to a belt-mounted digital tape recorder. In order to measure per- and post-rotatory perceptions in space, the astronauts were spun in the chair for one minute with their eyes closed. Using a pocket voice recorder, they were asked to verbally respond when their **sensation** of spinning was over. There were two main objectives to this study:

- to determine the **perceived** spinning time which is usually much less than the one minute of actual spinning time;
- to determine whether the subject perceives themselves spinning after the chair stops, and in what direction.

Does your perception change when you open or close your eyes during rotation? What is the explanation for your response? Does gravity change the way you perceive this on Earth? We will be considering some of these questions and others as we examine our own responses to the rotating chair.

Dr. Young's science team also measured eye movements during and after rotation. After a person is rotated and then stopped abruptly, the person's eyes respond in the opposite direction to the original spin direction for a period of time. This phenomena is known as **nystagmus**, and it represents the eyes attempt to help stabilize our visual field of view After movement. The word "nystagmus" comes from the latin word for "nodding," and it refers to a sawtooth like motion: slow in one direction (**slow phase**) and quick in the other (**fast phase**). As an example of this sawtooth motion, think about when you see students who are dozing off to sleep in class and their head falls to one shoulder in slow stages, and then quickly is brought back erect! This funny display can be considered "head nystagmus." Ocular nystagmus occurs when the eye is driven in one direction and then quickly jumps back in the other direction.

The eye movements can be left-right (**horizontals nystagmus**), up-down (**vertical nystagmus**), or torsional nystagmus. Nystagmus is also classified by the stimulus that produces it. When we look out the window of a moving car, or watch a moving stripe displayed on a computer screen, our eyes naturally tend to follow the objects we see, and the resulting eye movement is called **optokinetic nystagmus** (opto = refers to the eye, kinetic = refers to movement). For the rotating chair experiment, the eye movements that occur are typically those of horizontal nystagmus.

The comparison of eye response to motion on Earth and in space can give the researcher some valuable information about how gravity influences our

perceptions of motion. We will be examining the interaction between vestibular and visual signals and gravity in the next Student Investigation. This investigation examines our rotational perceptions.

It is important as we proceed on to our activities, to make sure that you READ ALL OF THE DIRECTIONS BEFORE BEGINNING this Student Investigation. Also, you can probably use a swiveling desk chair, or a piano stool that rotates to carry out this exercise. Your teacher will give you instructions and help direct your activities, but it is up to each group of students to develop their own hypothesis about what they expect to happen, to carry out the experiment, and to explain their results. Let's get started.

Materials

Each group will need:

- A rotating chair
- Two stopwatches
- A blindfold

Procedure

Remember to read all of the steps before beginning.

Step 1

Break into small groups of at least four people. Select one person to serve as the **subject**, another to serve as the **chair operator**, and two people to serve as **timers**. Every person in your group will have an opportunity to serve as a subject.

Step 2

The chair operator and the timers must practice rotating the chair at a particular frequency so that they can become familiar with the approximate speed for each revolution, **which they must maintain** while the subject is seated. Just as in the actual space Right experiment, the operator should rotate the chair at 120° per second. Since an entire circle is 360°, the students can calculate how long one revolution should last and this should be practiced before a subject sits down. The operator should also practice how to maintain a constant velocity for one minute and how to bring the chair to a quick and smooth stop. It is important to note that this experiment can produce symptoms of motion sickness in some people. If any subject finds the test makes them nauseous, they should stop and change subjects.

Step 3

Have the subject sit down on the chair. The subject's feet should not touch the floor. Also, the subject should hold their hands on their lap, if possible. The subject should be spun smoothly at a rate of 120° per second for one full minute and it is very important that the chair operator bring the chair to a **quick, smooth stop**. You will be spinning each subject under each of the three differing conditions. These conditions are:

- with eyes open during rotation;
- with eyes closed during rotation;
- with eyes closed during rotation, followed by voluntarily pitching the head forward immediately after the chair has stopped rotating, with the eyes still closed.

These conditions will be explained more fully in the steps that follow. However, before you spin anyone, your group should develop an hypothesis to predict the results of two responses for each condition. The two responses that you will be measuring are:

- the subject's **perceived spin time during rotation;**
- the subject's **perceived spin time after stopping.**

Step 4

Before each spin, the subject will be reminded to respond verbally when they perceive the spinning to have started and to have stopped. This applies for the period of time during the spin and after the chair has stopped. The subject may begin to feel an oscillating, back-and-forth motion during the spin but should try very hard to distinguish this from the rotational sensation. The subject should only report on the beginning and end of the sensation of spinning, both during and after the spin.

The two timers have different, but important roles.

- The first timer will be responsible for timing the one minute rotation.
- The second timer will be responsible for timing the subject's perception of rotation during the spin, and then again After resetting the timer, immediately After spinning has stopped.

At any point during or after the one minute rotation, the subject will let everyone know when their perception of rotation has started (at which time the second timer starts the stopwatch) and when their perception has stopped (at which time the second timer stops the stopwatch).

This will occur for each of the three conditions stated above and as indicated in Step 5.

Step 5

The spinning protocol is performed first when the subject's eyes are open. It is performed again with the subject blindfolded. It is performed a third time with the subject, again blindfolded, being asked to bend at the waist while pitching the head forward and down 90°, abruptly and immediately **after the operator stops the chair**. The subject should stay nose down for about 30 seconds after bending. The operator should wait about two minutes between the three rotations per subject.

Step 6

The data that is collected by the second timer should be recorded carefully. There will be three sets of data for each subject, one set each for the conditions of: eyes open, eyes closed or blindfolded, and eyes blindfolded along with pitching the head forward After the rotation has ended. **Each set of data** will include:

- the conditions of rotation (eyes open, eyes closed, or eyes closed and pitch forward),
- the actual spin time (approximately 1 minute),
- the perceived spin time during the actual spin,
- any difference (+ or -) between actual and perceived spin times;
- the perceived spin time After the spinning has been stopped.

You should use a copy of the data sheet, shown in Table 1, that your teacher will provide for you. **Do not write in the book.**

step 7

The data for each subject can be grouped and averaged for the whole class or just for each group to determine the average perceived spin time during the rotation and After the rotation for each of the three conditions. These differences can be compared and used to answer the questions. Read the questions before you begin so that you will know what to expect.

Table 1. A comparison of actual and perceived spin times during and after various conditions of ratation.

	During Rotation			**After Rotation**	
Conditions of Rotation	Actual Spin Time (seconds)	Perceived Spin Time (seconds)	Actual-Perceived Spin Time (seconds, + or -)	Perceived Spin Time (seconds)	Comments and Observations
Eyes Open					
Eyes Closed					
Eyes Closed and Head Pitched Forward					
other conditions					
other conditions					

Questions

1. Is the visual cue an important contributor to your perception of rotation?
2. Do you think that hearing or touch cues are important contributors to your perception of rotation? Explain.
3. How did being blindfolded affect your perception of rotation, both during the spin and right after spinning? Did the perceived direction of rotation reverse after the chair was stopped? Would the effect be the same in space as on Earth? Explain.
4. How did pitching the head forward immediately after spinning affect your perception of rotation? Would the effect of pitching your head forward be the same in space as on Earth? Hint: The semicircular canals are your angular detection receptors (which are mostly unaffected by gravity) and your otolith organs are your linear detection receptors (which are fully affected by gravity). Explain.
5. Were your hypotheses supported or refuted from the results of your data analysis? Did you obtain similar results for most of your subjects or were the data hard to interpret?

Prev: Your Perspective | Next: Student Investigation 2

STUDENT INVESTIGATION 2

An Examination of How Your Eye Contributes to the Body's Need to Balance: The Vestibulo-Ocular Reflex (VOR) and Nystagmus

Background

If you'll recall, all of the various signals generated by the body about its orientation relative to the world around us, are connected and **integrated** within the brain and central nervous system. Each of our senses provides a unique signal, and when any one signal is eliminated or changed, the brain must **adapt** to using only those signals that are available. Think of a person who is blind or deaf or even one who is paralyzed with no feeling in their limbs. For such individuals, the brain has certainly had to program itself to analyze and comprehend sensory information differently from those with all of their senses intact. In fact, research has shown that brain structures actually do differ, in both appearance and function, among those with different sensory capabilities. In this exercise, we are going to examine how our **visual system** serves our balance system.

Sight has two main functions in its interaction with the nervous system: to receive and transform images into **cognitive signals** for the brain to analyze, reflect upon, and **then** act on; and to receive and transform images into **spatial orientation signals** for the brain to analyze and **immediately** act on without reflection. In either case, the eyes receive energy from the **electromagnetic spectrum** (Figure 12) and transform that energy into nerve impulses that lead to the brain. Only a limited part of this spectrum can excite the **photoreceptors** (rods and cones in the eye that receive light) in the **retina** of the eye. Electromagnetic energy with wavelengths between 400 and 700 nanometers (nary) comprise **visible light**. It is in their role of providing spatial information signals that the eyes work so closely with our other senses to complete "the picture" of how our bodies are physically oriented. We will discuss this in a moment, but let's first look at the structure of the eyeball.

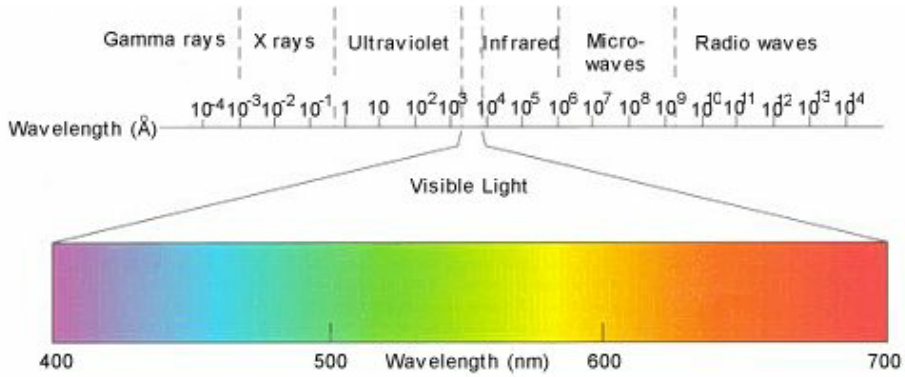
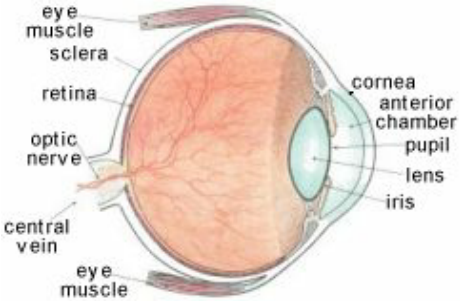


Figure 12. (a) The electromagnetic spectrum is shown in units of Angstrom (1 Å = 10^{-10} meter). (b) The spectrum of visible light comprises a very small range of wavelengths shown in units of nanometers (1nm = 10^{-9} meter).

Figure 13 illustrates the major parts of the eyeball. The outermost layer of the eye is a tough coat of connective tissue called the **sclera**. This can be seen externally as the white of the eyes. The tissue of the sclera is continuous with the transparent **cornea**. Light passes through the cornea to enter the **anterior chamber** of the eye. Light then passes through an opening called the **pupil**, within a colored muscle called the **iris**. The iris regulates the diameter of the pupil and, therefore, the amount of light entering the eye. Light that passes through the pupil enters the **lens**. The lens is responsible for refracting (deflecting or bending) light and focusing the image that we receive. The **retina**, which is the inner layer of the back portion of the eyeball, is considered the **neural layer** (neural refers to neurons and the nervous system) and it contains photoreceptors that are activated by light. Neurons in the retina contribute fibers that are gathered together in a region called the **optic disc** to exit the retina as the optic nerve. This is also the site of entry and exit of blood vessels.

Figure 13. The internal anatomy of the eye.



The role of the visual signal is very powerful in our balance system. In fact, the visual and vestibular signals function particularly close together to create our **vestibulo-ocular** (ocular refers to the eye) **reflex (VOR)**. This reflex is an effort of the semicircular canal to compensate for the changing visual field that arises when we move our head. Let's consider how the visual and vestibular systems work together to help maintain balance and how a combination of sensory information provides **confirmation** of your movement.

Visual cues normally work to confirm the orientation information provided by the vestibular, proprioceptive, tactile, and motor signals. For example, tilt your head toward your right shoulder. The following events will occur simultaneously:

1. The image of the stationary (not moving) visual field on your retina rotates as though your external visual field were moved **counter-clockwise**, your semicircular canals signal a **clockwise** movement of your head, and together they come up with an estimate of the change in head angle.
2. In addition, your eyes roll **opposite** to the direction of tilt to stabilize the changing visual field. This is the obvious part of the VOR called **ocular counterrolling.**
3. Your otolith signals register a new head orientation with respect to the vertical force of gravity, and this helps you confirm your semicircular canal and visual cues. Of course, in space, this otolith signal is not activated.
4. And if all of that wasn't enough, your neck joint angle receptors and probably your neck muscle sensors also confirm the new head position.

These events illustrate a clear case of confirming visual and vestibular signals, leading to a strong perception of **spatial orientation**. As you know, spatial orientation is affected by the absence of gravity. We'll learn more about that subject when we review the results of Dr. Young's space flight investigation. For now, we are about to begin our own investigation. For this Student Investigation, we are going to participate in two very simple activities: Part A is a demonstration that allows you to experience the power of the VOR, and Part B is designed to help clarify your understanding of ocular counterrolling. Each of the two exercises should be carried out independently by each student so that everyone will have a personal experience with these two examples of different vestibular and visual signal interactions. READ ALL OF THE DIRECTIONS AND QUESTIONS BEFORE BEGINNING YOUR ACTIVITIES. This is important so that you can develop your hypotheses before you begin the exercises and so that you will know what questions to consider as you perform each activity. Let's get started!

Materials

Part 1: A watch with a second hand or a stopwatch for each group of two students.

Part 2: A small mirror for each student.

Procedure

PART 1

Your Vestibulo-Ocular Reflex (VOR)

1. For this demonstration, each student will individually perform two kinds of movements (A and B) that might seem very similar, but that are really very different. Teams of two students should work together so that each can make sure the other is carrying out the movements correctly and can time the movements of his or her partner.

Figure 14.

A. For the first movement, you will hold your hand in front of your face and look at it from the side with your thumb about 12 to 18 inches in front of the tip of your nose (Figure 14). Then you will begin moving your **hand** back and forth, to an angle of about 10° on either side of the nose, in front of your **stationary head**. Increase the back-and-forth speed of your hand until the image of your hand **blurs**. The blurring occurs as the image of your hand begins to slip on the retina. (This is a hint that may help you answer some of the questions!)
B. For the second movement, you will be moving your **head** back and forth in front of your **stationary hand**, increasing the speed until your hand blurs again.

For each of the two situations, A and B. you will determine the **frequency** of movement of either your hand or your head **at the point that blurring occurs**. The frequency can be determined by counting the number of complete back and forth movements over a 5 second period and multiplying that number by 12 to obtain a **frequency per minute**.
Develop a hypothesis before you begin your demonstration regarding which movement ends in a blur at a lower frequency than the other, the hand movement or the head movement, and **why**. Begin your experiment with the help of your lab partner, who will time the 5 second period necessary to determine movement frequency at the point of blurred vision. During this 5 second period for each movement, count the number of complete back-and-forth movements for both A and B. Then calculate the frequencies and compare them. Answer the following questions in complete sentences.

Questions

1. How were the two movements different?
2. Why were you able to focus on your hand longer during one movement than the other?
3. What were the primary sensory signals that were used in each movement?
4. Hypothesize about what you would expect if you carried out this experiment in space and why.
5. Combine the answers to Questions #2 and #3 to state what you have learned about the vestibulo-ocular reflex.

PART 2

Recognizing the Effect of Ocular Counterrolling

1. For this demonstration, each student will perform two kinds of movements (A and B) that, as in the previous exercise, might seem very similar but that use very different vestibular and visual signals. (That's a hint for you to be able to answer one of the questions at the end.) Teams of two students should work together so that one student can verify that the other student is carrying out the movements correctly and can record the other student's observations. Read the following descriptions before you begin this exercise.
   A. For the first movement, you will hold a mirror in front of your face so that you can see your eyes very clearly. You will then begin to slowly tilt your head toward your right shoulder. While tilting, carefully observe your eyeball. You will be looki ng for any kind of movement. If you're unable to detect eye movement, tilt your head a little bit faster, but not too much for you not to see the eyes. Verbally describe your eye movement to your lab partner so that your observations can be recorded.
   B. For the second movement, you will again hold a mirror in front of your face so that you can see your eyes clearly. This time, however, you will be **lying on your back**. You will begin to slowly tilt your head toward your right shoulder again while observing your eyes. Verbally describe your eye movement to your lab partner so that your observations can be recorded.
2. Before you begin any part of this exercise, develop an hypothesis about what you expect the eye to do in each movement situation and why. Then begin your experiment based on your teacher's instructions. Compare any differences in eye movement that you observe. Finally, answer the following questions.

Questions

1. Why was there a difference in eye movement when you tilted your head while in a vertical position versus when you tilted your head while in a horizontal position? (The hint is in the question!)
2. What are the rotational axes (pitch, yaw, or roll) that you participate in for each of the two different movements, and which sensory organs are at work to detect movements in each of the two instances?
3. What is ocular counterrolling and why does it occur?
4. What does this demonstration indicate about the vestibulo-ocular reflex?
5. Hypothesize about what you would expect if you carried out this experiment in space and why.
6. How is this demonstration in Part 2 similar to and different from the demonstration in Part 1 of this Student Investigation?

Let's move on to examine the results of Dr. Young's space flight investigation!

Prev: Student Investigation 1 | Next: Space Flight Investigation

THE SPACE FLIGHT INVESTIGATION

Based on what you have already learned about vestibular function, can you guess which group of athletes might be particularly susceptible to motion sickness in microgravity? In fact, an unusually high percentage of **gymnasts** have been show n to experience intense motion sickness when flying in the KC135 airplane, the microgravity parabolic airplane that we spoke of in a previous chapter. Presumably, this is because they have developed an unusual and intimate relationship with gravity here o n Earth. Gymnasts are so much "in tune" with gravity in order to perform their amazing flipping, flying, flowing routines that when gravity is removed, it becomes a greater loss for them than for most other people.

But what is it about gymnastic movements that causes these athletes to develop such an intense relationship with gravity? As we've learned, movements **of your head** cause a variety of sensory confirmation steps and compensating factors to o ccur in your body. Here on Earth, the vestibular organs operate only to detect **head movements** relative to gravity, while the other sensory systems that we reviewed in detail earlier detect our **body movements**. With the gym nasts' active head accelerations, both rotational and linear, their vestibular systems are kept very busy indeed and they have developed an unusually sensitive vestibular organ. Of course, gymnasts generously use their proprioceptive sense to feel the ben ding and movements of the joints and tendons as well as the many muscle contractions that occur for each move, their tactile and hearing senses to feel and hear the pressure of the air rushing past them as they fly through the air, and their sense of sigh t to watch everything rush past them, upside down and then right side up again!

The best and most accessible indicators of vestibular function to use in order to study and understand how the balance system of the body works, are the movement and various reflex mechanisms embedded **in the head**, particularly the eye. Ho w do researchers measure head movements and reflexes? Although we can't enter the skull to directly observe and measure vestibular function, we do have what is considered a "window" to the inside of the head that we can use to observe some of the events t aking place in the head as we move it. That window is the **eye**, and its movements are an **indicator** of vestibular function. That is, many of our eye movements reflect what is occurring in our head and brain. You have already learned in Student Investigation 2 about the **vestibulo-ocular reflex** and how, when tilting your head, this reflex causes the rolling of the eyeballs **in the opposite direction to the head movement**, a phenomenon called **ocular counterrolling**. Another kind of eye movement occurs when something in your visual field is moving and your eyes shift in one direction and then quickly jump back in the other direction to stabilize the image. This is called nystagm us and was the topic of Student Investigation 1. In order to record the nystagmus response, a person may wear specially designed contact lenses that mark certain portions of the eye with a "starburst" design so that any movement of the eye can be detected. Then the eye movements are videotaped for analysis.

Eye reflex activity can also be measured by placing **electrodes** on the face or temples near the eye and recording the electrical signals that are produced by the **rotation of the eyeball**. The eye itself ha s an electrical field around it, due to the intense metabolic activity in the retina. This field moves with the eye, and you can pick it up with electrodes placed on the skin around the eye. The voltage reading that you can pick up, which is usually very small, is proportional to eye movement. The technique to measure and record this reflex is called **electrooculography (EOG)**. (Electro = refers to electrical signals, oculo = refers to the eye, and in research, graphy = the recording of the data). Flinching and blinking are examples of these eye reflex contractions but there are many others that we don't even realize are occurring during our day-to-day balancing act.

Of course, **muscle reflexes in the neck** are also good indicators of various head movements since, After all, it is the neck muscles that are used to move the head. Try tilting the top half of your body over to the side as you sit there loo king straight ahead, and feel the neck muscles activate. Your neck is performing corrective reflex movements the whole time you are moving. The electrical signals produced by these reflexed can also be measured using a technique called electromyography (EMG) (myo = muscle.) In fact, EMG is also used to study the balance reflex responses of the leg muscles in relation to movement. We will be discussing both EOG and EMG in association with our examination of Dr. Young's space flight experiment in this secti on.

Dr. Young's experiment consisted of six different tests to assess **sensory-motor adaptation**:

1. A **rotating chair** was used to test movements of the eye and the vestibulo-ocular reflex (VOR). One chair protocol (procedure) required that the test subject be rotated about a vertical axis and stopped suddenly.
2. A second procedure using the rotating chair required the subject to pitch his or her head forward **after the chair is stopped** to investigate the phenomenon of **nystagmus dumpin**. We investigated our own nystagmus dumping response in Student Investigation 7.1. Both procedures using the rotating chair were designed and conducted by Dr. Charles Oman from the Massachusetts Institute of Technology.
3. In a different test, a specially designed **rotating dome** was used (Figure 15). When a subject sees the dot-patterned dome rotating in one direction, clockwise or counterclockwise, directly in front of her face, she senses movement in the opposite direction. The subject uses a joystick to indicate her perceived direction and velocity of rotation.
4. In the **awareness of position task**, crew members were asked to view various targets on a visual screen and then, with their eyes closed, point to them with a light pointer (Figure 16). This allowed investigators to examine if any changes occur in the accuracy and control of limb position due to space flight. This particular part of the entire experiment package was designed and conducted by Dr. Douglas Watt from McGill University in Montreal, Canada.
5. Also, the **otolith-spinal reflex**, or the reflex that causes one to catch oneself when sensing a fall, was tested in the "drop" experiment. For the study, a crew member wore a harness with bungee cords attached to the floor to serve as a substitute for gravity. The person then hung by the arms holding a suspended T-handle (Figure 17). When the T-handle automatically released and dropped the crew member, EMG electrodes measured the electrical activity in the leg muscle to determine the relationship between the vestibular system and muscle reflex responses in space. Dr. Douglas Watt was responsible for this part of Dr. Young's overall experiment package.
6. Crew members also wore an **Acceleration Recording Unit** to measure the acceleratory forces of their head movements, both natural and exaggerated, and recorded any space motion sickness symptoms on a pocket voice recorder. The goal of this experiment was to see if there was a connection between the vigor with which head movements were made and the intensity of space motion sickness. This particular experiment was carried out by Dr. Charles Oman, and he found that people who moved their heads more were also the ones who were sicker.

Figure 15. The rotating dome experiment.

Figure 16. The awareness of position task.

Figure 17. The otolith-spinal reflex test.

We'll find out the results of a subset of these studies next as we examine how Dr. Young designed and carried out his experiment. In particular, we will be reviewing two main measurement sets, including:

- the effects of space flight on the vestibulo-ocular reflex (VOR) and on other visual components of balance;
- how one's awareness of position and posture can change in microgravity and how the otolith-spinal reflex may contribute to those changes.

Let's begin our examination of how the sensory and balance system responds to the microgravity of space by looking at the results of measurements from three important visual components. You certainly know about VOR and nystagmus by now. In the next section, you'll meet a new sensation that everyone has experienced at a movie theater or amusement park - visually induced roll (VIR).

Prev: Student Investigations | Next: Visual Changes

I. Changes in the Visual Components of Balance During Space Flight: Vestibulo-Ocular Reflex (VOR), Nystagmus, and Visually Induced Roll (VIR)

When a person is moving around, changing directions rapidly, or leaning sideways, forward, or backward, it would be impossible for that person to maintain a stable image on the retina of the eye unless some kind of an automatic control mechanism was in place to stabilize the eyes. By now, particularly if you participated in Student Investigation 2, you know that this automatic control mechanism is known as the **vestibulo-ocular reflex (VOR)**.

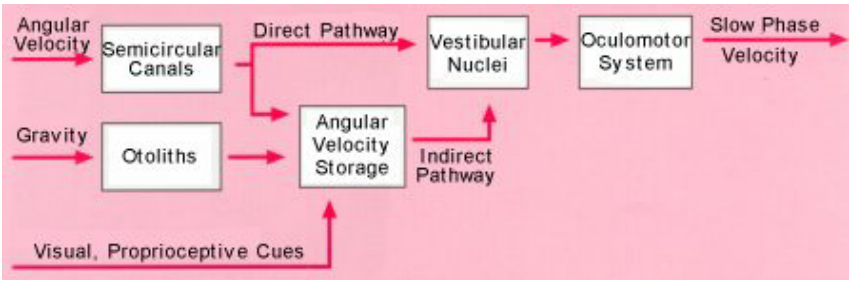
In addition, the eyes would be of little use in detecting an image unless they remained "fixed" on each object long to gain a clear image. Fortunately, each time the visual field moves or your head moves, signals primarily from the semicircular canals cause the eyes to rotate opposite to the direction of the head. This eye movement pattern, called **nystagmus**, is characterized by a series of successive compensatory movements of the eye, and it provides evidence that the VOR is at work. Nystagmus is the eye's attempt to hold on to an image and to transition to a new image in shifted stages. This allows an image to remain on the retina slightly longer. As the head continues to rotate, the eyes continue to rapidly and involuntarily oscillate back and forth, reestablishing a stable image each step of the way.

There is another source of evidence that indicates the power of the VOR, our sensations of **visually induced roll (VIR)**. VIR is when the body actually attempts a corrective shift in the opposite direction of the rotating visual field to compensate for the sensation of rolling. Your body then feels a **false sensation of self motion** due to the rotating field. This kind of sensation is used to advantage in the design of flight simulators, large- screen movies, and in amusement park exhibits or rides in which the sensation of movement is created or enhanced by visual surround motion.

Dr. Young's experiment involved preflight, inflight, postflight measurements to understand how VOR, nystagmus, and VIR functions might be affected by microgravity. He hypothesized that, in the process of adapting to weightlessness, **the influence of the non-vestibular cues will be magnified**. Therefore, he expected to see enhanced visual involvement in the body's process of establishing some sense of equilibrium. Of course, if particular visual processes require gravity to function "Earth-normally," then those visual processes would not be enhanced in space, and, in fact, may produce distortion and confusion. Let's see how the experiments were carried out and what Dr. Young found.

The measurement of VOR is **indirect**. One cannot simply go to a distinct VOR organ somewhere in the body or in the head and place an electrode on it and measure this reflex. As you know, various indicators, such as counterrolling and nystagmus, provide functional information about how the VOR is operating. A specific variable that Dr. Young measured to understand how the VOR system changed in space was the astronauts' **perception of rotation** and **how long it lasts**. This perception results in part from a set of integrated vestibular, visual, proprioceptive, and tactile spatial orientation sensory information **that has been "stored" in the central nervous system**. This is known as our **angular velocity storage** capability (Figure 18). There is no particular little box in the head, in which this information is actually stored, but the signals that relate to movement history are stored and remembered by the body.

Figure 18. Angular velocity storage capacilities. [6]



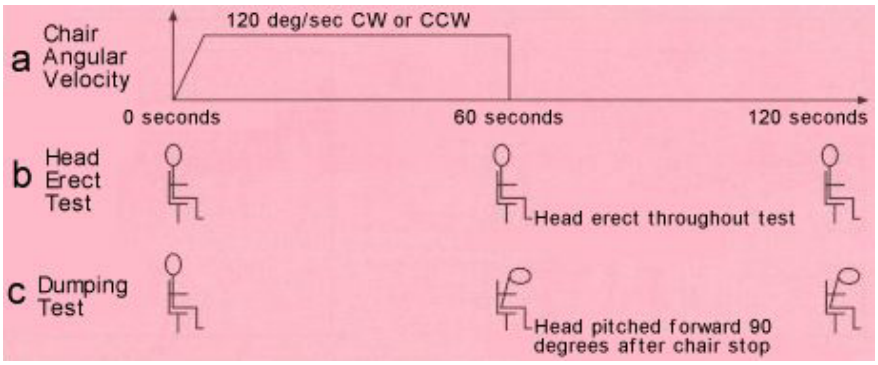
These stored signals allow a continual flow of information that enables us to predict future movements based on the way we perceive or "feel" our orientation at any given moment. The amount of time that the information can be stored is characterized by a dominant **time constant that is unique for every movement** and that is dependent on a variety of factors, including:

- vertical and horizontal semicircular canal activation;
- otolith input;
- input from the visual system;
- activity from the proprioceptive/motor system;
- the speed of rotation;
- past conditioning from repetitive movements.

Therefore, it is important when determining whether changes have occurred in the VOR to determine its dominant or **long time constant**. The long time constant can be determined by measuring the time it takes for the eye motion to decline or decay After stopping a prolonged rotation. This is called the **slow phase eye velocity (SPY)** response, and the amount of time it takes to decay fits time constant) after movement reflects the overall angular velocity storage capability. This basic data is necessary for the evaluation of the VOR. Dr. Young collected some inflight data on SPY and the VOR time constant to provide an interesting comparison with similar preflight data.

In the measurement of VOR, subjects are spun on a rotating chair and they follow a protocol similar to one that you participated in for Student Investigation 1 . Each experiment session consisted of a series of successive rotation tests of two basic types, referred to as either "head erect" or "dumping" tests (Figure 19). The chair was rotated exactly the same way for both tests. Does this sound familiar so far?

Figure 19. "Head erect" or "dumping" tests.[6]



The chair was accelerated to an angular velocity of 120° per second in a clockwise (CW) or a counterclockwise (CCW) direction, and then brought quickly to a stop After one minute. The direction of chair rotation was alternated in each successive test so the astronauts would not begin to adapt to the rotations and to be sure that any inherent differences between left and right didn't influence the results. The subject's head stayed centered on the rotation axis in both tests during the rotation. In the dumping test, however, the subject actively pitched the head forward upon instruction from the test operator, immediately after the chair stopped, bending mostly at the neck and shoulders. The subject maintained the head in the 90 degree, nose down position for at least 50 seconds After the chair stopped. In the head erect test, the subject maintained an upright position until the end of the test (Figure 19)

The subject's **electro-oculogram (EOG)** was recorded for the entire experimental period. This provided a measurement of how long after the rotation the eye continued to make its nystagmus movements, indicating the decay of the slow phase eye velocity (SPV). From this data, the VOR time constant could be calculated. Also, a video camera recorded head movement and the subjects wore a head-mounted angular accelerometer so that all of the data could be integrated to enable one to understand which movements were connected to which responses. Preflight, inflight, and postfllight data were collected on four subjects. During the nine day shuttle mission, inflight data was collected either on flight day 4 or 5 (FD-4 or FD-5). Figure 20 illustrates the combined preflight and inflight slow phase velocity (SPY) data for four subjects. The results of both the head erect test and the nystagmus dumping test are shown. In addition, the VOR time constant values calculated from the SPV data are also shown in Figure 20 and summarized in Table 2.

Table 2. A summary of VOR time constants for Subjects M, N, P, and T. Preflight and inflight data are shown for both the head erect test (T_e) and the dumping test (T_d).[6]

Subject	Preflight T_e (seconds)	Preflight T_d (seconds)	Inflight T_e (seconds)	Inflight T_d (seconds)
M	14.0	7.6	15.9	14.7
N	19.3	11.0	20.4	21.2
P	15.8	9.1	35	16.7
T	30.3	16.0	17.8	13.4
Mean ± SD	19.9 ± 7.3	16.0 ± 5.1	22.3 ± 8.7	16.5 ± 3.4

The first thing to look at in Table 2 is the difference in time constants between the values for the head erect data and the dumping data. In the gravitational environment of Earth, the time constant for the slow phase eye velocity I(PV) decay with the head tilted face down (Td) is a little more than half, or 55%, of the time constant that is obtained with the head erect test (Te). If you will compare the **preflight time constant values for both tests**, Dr. Oman's data also seems to show the dumping time (preflight Td) is a little more than half of the head erect time (preflight Te). However, by comparing the **inflight time constants for both tests**, you can see that for most subjects, the dumping time constant (inflight T_d) did not change much from the head erect time constant (inflight T_e). This is an important finding. This shows that nystagmus dumping does not occur to the same extent in space as it does here on Earth. This suggests that **nystagmus dumping** must be dependent on gravity to some extent since, by the removal of gravity, it is changed.

The data in Table 2 suggests another important finding. Since the inflight time constants for both the head erect test and the dumping test are similar for subjects M, N. and to some extent T, this indicates that the subject's angular velocity storage capability **may not be reduced inflight**. As explained previously, this indicates that their VOR is probably maintaining most of its function in space. This finding is surprising since the angular velocity storage capability is found to be greatly reduced during similar tests on the KC-135 parabolic flight airplane.

The important thing to remember here is that the inflight data was not **collected until the fourth or fifth day in space**. Do you think the results would have been different if data had been collected earlier in the mission, say on the first or second day in space? The earliest parts of the mission are the time when the brain and sensory organs are most confused and when the astronauts are most ill. In fact, some internal reorganization and reprogramming may have already occurred in the astronaut's sensory and balance system by the time the data was collected. Even so, it is interesting that the nystagmus dumping phenomena did not work in space the same way it does on Earth.

Let's now look at the technique and results for Dr. Young's investigation of **visually induced roll (VIR)**. Recall that this occurs as you observe a rotating visual field and your body feels a **false sensation of rotational motion** due to that rotating field. VIR is measured by having the astronaut place his head inside a "rotating dome" whose interior is covered with dots that serve as a visual stimulus Figure 21. This moving visual field rotates at a constant velocity of 30, 45, or 60 degrees/second. The astronaut watches the visual field rotate for 20 seconds at a time with a 10 second pause between each view. A sensation of self-rotation is felt by the crew member.

Figure 21. As the astronaut observes a rotating visual field, his body feels a false sense of rotational motion.

Before placing one's head in the dome, a **soft contact lens**, marked with a "starburst" pattern to serve as eye landmarks for postflight data analysis, is inserted and wetted with distilled water so that it will temporarily stick to the lens of the cornea. As the dome rotates, the crew member moves a **joystick** to indicate the perception of self-motion. Rolling eye movements and body position are also recorded by split-screen, closed-circuit television. Neck movements, produced when the crew member attempted to "correct" for the perceived roll, were recorded using gauges that measure neck strain (Figure 15). These gauges were attached to a biteboard that was built onto the flight model of the rotating dome and that the astronauts would bite to keep their head stable while they either floated or while their body was secured to the floor with bungee cords. During the preflight and postflight tests, the biteboard was eliminated since, on Earth, the astronauts could stand up. Various measurements were recorded during the experiment, including the extent of **swaying** off center that the astronauts experienced while looking at the rotating visual field of the rotating dome. **The more the astronauts sway, the greater the level of their instability**. The interesting data shown in Figure 22 illustrates the **postural sway** results for two crewmembers, Subject M and Subject T.

Postflight Postural Instability

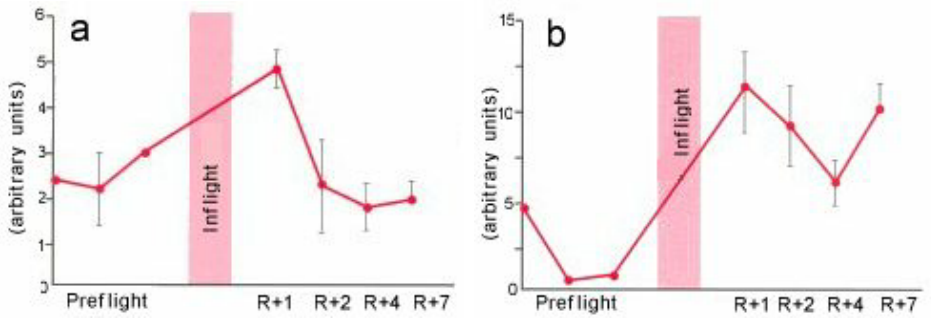


Figure 22. (a) Postflight postural instability, in response to the rotating dome without biteboard stabilization, was evident for the entire postflight week of testing for Subject M. (b) The day after return from space was the most unstable for Subject T, but postural stability resumed to normal levels within a day or two. (R = recovery, which refers to having landed back on Earth.)

By comparing the level of sway **before flight** and **after flight**, you can see that both astronauts exhibited great instability upon their return to Earth. Subject T seemed to return close to normal soon after returning from space, but Subject M took longer to recover, and After a week, was still experiencing significant swaying It must be remembered that the data presented are from **only two subjects**. Therefore, it is very difficult to draw any general conclusion about the disorientation that astronauts experience upon their return home. Also, many other variables were measured during Dr. Young's investigation of VIR and the **integrated picture** that is produced by considering all the data is necessary for a full explanation about what is happening. This data does suggest, however, that exposure to weightlessness causes the astronauts to rely more on their visual cues since many of their confirming vestibular signals are absent in space. Upon returning, the astronaut's balance systems are initially unstable while the brain and vestibular organs are "reprogrammed" to understand and interpret the gravitational stimulus that is present on Earth. During this reprogramming time, astronauts shift their body's reliance away from visually dominated cues back to the utilization of a fully operating VOR.

The good news is that, upon their return home, astronauts **do** eventually recover their "Earth-normal" sensory and balance function completely. However, a few astronauts have even experienced a very brief "readaptation sickness" when they return home, since the brain must once again recall or relearn how it and the other sensory organs used to work together before the space flight mission took place. Of course, it is not clear whether their sickness is due to the readaptation process or to the overwhelming excitement they feel for having completed a space mission and returned home to their families! We've learned in this section how the visual components of the sensory and balance system serve as indicators for a changed vestibulo-ocular reflex (VOR) in space. We have also seen the level of instability that at least two astronauts experienced because of space flight. All that we have seen seems to suggest that, in space, humans tend to shift their emphasis from vestibular cues to visual cues. In fact, the alteration of the visual-vestibular interaction caused by the loss of gravity is considered one of the possible causes of space motion sickness.

Let's now review Dr. Young's results from a set of experiments designed to understand how space flight affects our awareness of our body's position and posture.

Prev: Introduction | Next: Awareness of Position

II. Awareness of Position and Posture

Astronauts who flew on the Skylab missions of the early 1970s have reported in various personal communications that, during space flight, with eyes closed or with the lights out, they lost the sense of where everything was in relation to them. There are three possible explanations for why the astronauts might have felt this way.

1. It may be that the central nervous system requires some sense of "upness" or "downness" before it can begin the complex task of assembling an image of the body's surroundings. The lack of "up" and "down" in space may cause a loss of our **external spatial map** (loss of our image of the outside world), which could create disorientation.
2. The second possibility is that the proprioceptive mechanisms in our joints, tendons, and muscles do not work properly, and that one cannot move one's limbs accurately when one cannot see them in weightlessness. This would demonstrate a loss of our **internal spatial map** (loss of our own normal body image), and again, this could cause disorientation.
3. The third possibility is that one loses the sense of one's body image, i.e., the sense of relationship of the body's various parts to one another, and therefore cannot relate the external surroundings to the location or movement of the body. This would demonstrate the lack of **both** an **external spatial map** and an **internal spatial map**, and together this could also cause disorientation.

If these three possibilities could be tested individually, we could come much closer to understanding why astronauts seem to "lose themselves" when their eyes are closed.

Past experiments related to understanding how an astronaut's **awareness of position** changes during space flight have shown that our knowledge of limb and body position may be altered in space. Astronauts have had difficulty positioning their legs precisely under themselves during "drop tests" in space. Others have shown an interesting difficulty in maintaining a body position **perpendicular to the vehicle floor** (an "upright posture") in the absence of vision and while secured by the feet only (Figure 23). Finally, other astronauts have shown great difficulty estimating the angle of their knees and elbows when tested repeatedly in space. Dr. Young and his team of researchers carried out an Awareness of Position experiment that was designed to measure the astronaut's ability to point accurately at memorized targets in the absence of vision. They found some interesting results that may help us answer the question of whether our external or internal spatial maps have been affected in space. Let's first examine how the experiment was carried out and then we will examine some of the results.

Figure 23. An astronaut asked to stand "straight up".

The test procedure consisted of three parts. Each part was designed so that the two possible perception losses (that of the internal spatial map and the external spatial map) could be tested separately to see which one dominated the response. The three parts of the experiment are described as follows. All sequences were carried out preflight, inflight, and postflight.

Figure 24. The Awareness of Position experiment.

1. In the first part, the subjects pointed to **five remembered target positions** on a target screen with their eyes closed. Target pointing accuracy was demonstrated with a hand held light pointer, recorded both on videotape and by the observer (Figure 24). Each point began with the hand close to the chest. The arm was then extended, directing the beam of the light pointer at the (unseen) target. The observer recorded the actual position of the light beam on a data sheet, and the subject brought the hand back to a position close to the chest in preparation for the next point. This was repeated 25 times. This part examined the accuracy and the strength of the astronaut's external spatial map.
2. For the second part, the subject continued to keep the eyes closed and touched various parts of the body with the right index finger. This was done to test the accuracy of the internal spatial map.
3. The third and final part began with the subject opening the eyes and memorizing the target positions again. Pointing was carried out in the same fashion as in the first part of the experiment, with the significant difference that the eyes were closed only during the actual pointing maneuver of the arm Unlike the first part of the experiment, this allowed the subject to maintain an accurate image of the external world during testing. Since it provided no feedback as to how the astronauts perceived their own body position, this test allowed for an evaluation of the astronaut's **internal spatial map** perception.

Figure 25. The target screen and the coordinated system.

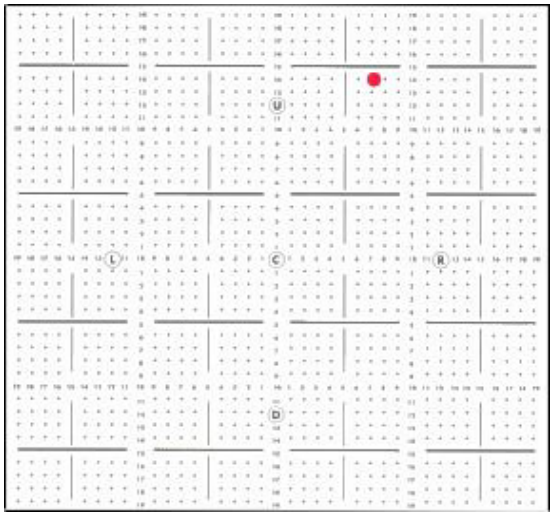
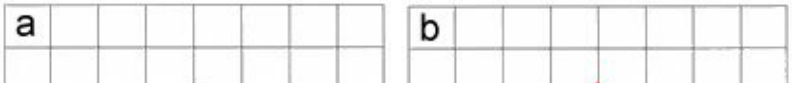


Figure 25 shows the five targets (labelled C, U. D, L, and R referring to center, up, down, left and right) and the **coordinate system** printed on the target screen. This coordinate system was important to provide detailed information about the location of each point for analysis. For instance, the specific locater information for the red dot on Figure 25 is the coordinate (7,14) in the upper right quadrant. The divisions on the screen are in inches.

Figure 26 shows the pointing results from one astronaut, Subject P. for the two **preflight** tests. The first one was performed with the eyes closed continually, and the second one, with the eyes open between each point. It is quite clear that a frequent updating of one's mental image of the outside world can improve performance even on the ground.

Figure 26. Subject P's preflight test results.



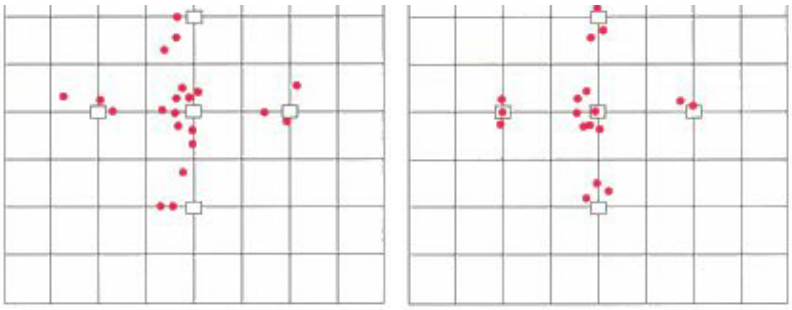
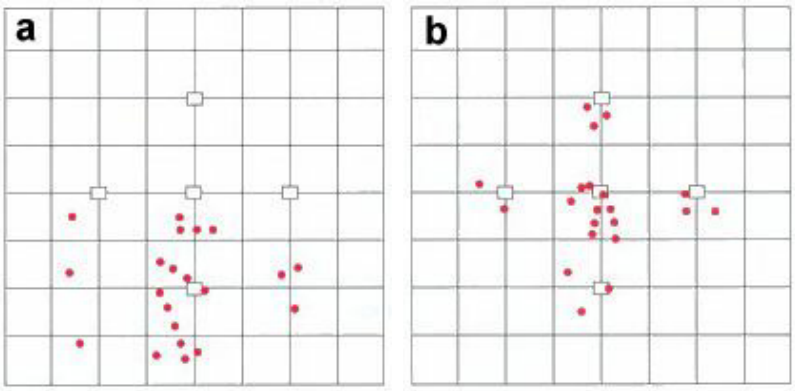


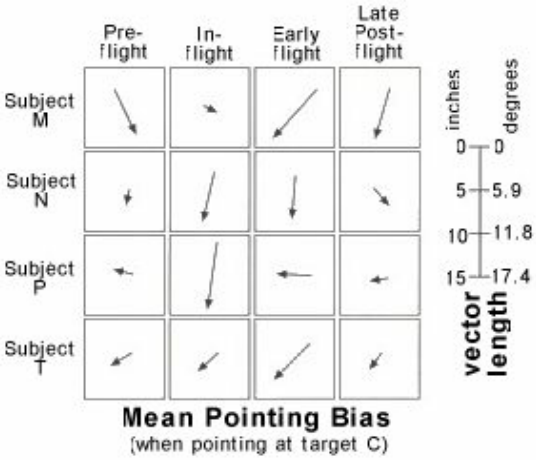
Figure 27 shows how the same subject performed **inflight**. Once again, the first results, shown in Figure 27a, are with the eyes continually closed and the second results, shown in Figure 27b, are with the eyes open between each point. As you can see, in weightlessness, the subject exhibited a very pronounced downward pointing bias, and this was true for all five targets, C, U. D, L, and R. In fact, there were attempts to point at target D that fell **below the target screen**; these are not shown here. The data from Figure 27b shows a marked improvement when the astronaut was able to see the external world between each point, although in this particular example, performance in space was not quite as good as on the ground.

Figure 27. Subject P's inflight test results.



Finally, the **mean pointing bias** (mean = an average value, bias = an inclination or tendency toward a certain direction) for all four subjects, before, during, and following flights is illustrated in Figure 28. Each arrow represents the **combined and averaged data** from all of the pointing events that were performed by each subject. Two subjects (N and P) who were able to point very accurately on Earth demonstrated greatly reduced performance inflight, with a pronounced tendency to point towards the floor. All subjects made greater errors postflight than preflight, but in similar directions. Recovery to the preflight level of performance was nearly complete by seven days after landing.

Figure 28. The mean pointing bias for all four subjects.



These results provide evidence that the primary factor causing the pointing errors and the perceptional changes is the loss of the **external spatial map** since performance was lower when the astronauts did not view the world around them between pointing maneuvers. These data also suggest that, in the absence of vision, the maintenance of a stable external spatial map is highly dependent on the presence of normal gravitational forces. We know this because the astronauts were able to point more accurately when performing the preflight tests. The pattern and time it took for the astronauts to recover after landing also suggest that this phenomenon may be normally influenced by the otolith organs.

In this section, we reviewed some interesting results about how space flight affects our perception of our own bodies relative to the world around us. Using these results, Dr. Young and other researchers have begun to develop an understanding of how our perceptions and senses are influenced by gravity. Such an understanding will help clarify what is happening to the astronaut's sensory and balance systems during space flight and may provide the necessary information for researchers to determine how to deal effectively with space motion sickness. You see, when the astronauts become sick in space, not only is it extremely uncomfortable for them, but it also compromises the mission objectives. If the astronauts are sick, they can't perform the multitude of important experiments that we send them up to do. And if they have to take motion sickness medication, as many of them do, the medication alters their physiology. Therefore, any physiological data collected on medicated astronauts will not represent the "normal" state but, instead, a "medicated" state.

The good news is that space motion sickness is a **temporary affliction**. The most severe symptoms usually last no longer than about the first three days after arriving in space and may require medication. As time moves on the symptoms become "manageable" without medication. If you think about it, three days is not very long for the balance system to completely relearn how to interpret sensory information and to respond with appropriate body movements. But three days out of a one" or two-week shuttle mission is too much time to waste. Therefore, it is a major goal of researchers like Dr. Young to characterize the physiological changes related to vestibular function and develop **countermeasures** for space motion sickness.

To study space motion sickness in more detail, crew members wore an **accelerometer/recording unit (ARU)** to measure and record all head movements and they used a voice recorder to record verbal comments. If they experienced space sickness, the crew members recorded any **symptoms** of

space motion sickness and their **time of occurrence**. This provided Dr. Oman with a chronological (time) history of the onset and continuation of specific symptoms.[7] By comparing accelerometer data and reports of symptoms, Dr. Oman was able to link specific and **provocative** (something that causes feelings of any kind) head movements with periods of discomfort.[8] By understanding which head movements create the worst feelings of sickness, steps can be taken to help the astronauts develop ways of avoiding such movements early inflight, thereby reducing the magnitude of this problem.

The role of **visual cues** in causing space sickness was also studied by eliminating or reducing head movements in order to determine the extent to which the eye movements themselves were responsible for causing sickness. This was accomplished by having the subjects wear a collar that restricts head movements in order to find out whether wearing such a collar reduces the occurrence of space sickness symptoms. This experiment gave Dr. Young an indication of the degree to which different signals are participating in the sickness response. All of the research being done to understand how the sensory and balance systems operate in space will help researchers here on Earth understand better how the various sensory signals operate together in an **integrated fashion**. This is because a laboratory in space is the only place that we can eliminate sensory signals related to gravity for days at a time. **It is only by eliminating a signal that one can truly obtain an understanding of how important it is.** You know the old saying, "you don't know what you have until you lose it!" Well, that saying is true in this case.

Speaking of **integrated**, let's pay one last visit to our familiar **integrated physiology flow chart** (Figure 29). Since we have constantly been reminded in every chapter of this book that **all of the systems in the body work together**, it is truly fitting that we covered the cardiovascular system in the first major chapter of this book and the nervous system as the last chapter. Together, they represent the two powerful communication networks that **allow**all of the different parts and pieces of the body to work together, through the flow of nerve impulses and the flow of blood.

Prev: Visual Changes

SPEAKING OF SPACE

Your assignment for the final Speaking of Space activity is very different from the previous Speaking of Space activities. The present activity centers around the **integrated physiology flow chart** shown in Figure 29. The flow chart shows 26 differen t physiological changes that occur in the astronauts in space. Certainly these are not the only changes that occur in space and, in fact, while carrying out this exercise you may come up with a few more. Depending on how many chapters you have covered in class, you should be more or less familiar with the various elements of this chart. If you're not now, you will be soon!

For this activity, your class will develop a presentation to describe the individual changes that appear in Figure 29, along with a description of **how they are connected**. The name of your class presentatio n might be "Integrated Physiology in Space." The class should break into seven groups to cover the following seven **topics** (the chapter reference is indicated for each one):

- an introductory description of the entire flow chart, naming each of the body changes but emphasizing and describing the environmental changes that appear in the white boxes (the Introduction chapter);
- the cardiovascular/cardiopulmonary changes (Focus 2);
- the hematology (blood) changes (Focus 3);
- the fluid/electrolyte/hormone changes (Focus 4);
- the muscle changes (Focus 5);
- the bone changes (Focus 6);
- the neurosensory/vestibular changes (Focus 7).

Certain groups will be smaller than others, depending on how many "boxes" appear on the flow chart for each topic. Each group should divide the job up so that **each person in the group** can plan for and describe a particular component of the topic in your group's presentation. The entire presentation by each group should consist of individual presentations from each person, but at the same time, the individual presentations should be **connected** so that you can lead the audience through a descri ption of your entire topic.

The main point is to provide a description of how these various body systems change in space and how these changes are **integrated together**.

Therefore, each group should also include in their presentation an explanation of **how their topic is related to other group's topics**.

Here are a few guidelines to help you plan a complete and effective presentation.

1. **You should design your presentation as if your audience has never heard the information before**. This means that you must first provide enough background so that your audience will understand the significance of your topic. That is, you should e xplain why the study of your topic was important. Keep the audience foremost in your mind as you design your presentation and always make it as easy as possible to understand.
2. You must present information about:
    - what the changes are;
    - how they are different from Earth physiology;
    - how the physiological changes in your topic are related;
    - how the physiological changes in your topic relate to changes in other topics;
    - generally how the changes were measured;
    - what the significance of the changes are;
    - how the information may be able to help us understand the body or treat health problems here on Earth.
3. **Use visual aids to present illustrations, graphs, or tables of values.** If you choose to produce a graph, include a title, the units of measurement on each axis, a legend, and make it as clear as possible. For tables, also include a title and un its of measurement.

After each presentation, there should be a short question and answer (Q&A) period so that the audience has the chance to ask relevant, thoughtful questions. Rely on your team members to help you answer the questions.

Good luck!

Prev: Space Flight Investigations | Next: Conclusion

Conclusion

Well, this is it! Not many people in the world have been exposed to information and lessons about how space **affects** the human body as you have. In fact, after participating in all of the various activities and chapters in this book, **you now possess more knowledge about "Human Physiology in Space" than even most researchers and physicians in this world.** That's pretty exciting. We hope that you have enjoyed learning about the biology, chemistry, physics (and, yes, even the mathematics) of Earth and space physiology. Maybe you will be involved in the next generation of experiments that fly in space. Who knows? There is plenty of science left to do, plenty of questions to answer about the world around us, and plenty of mysteries to unravel about the human body. So think about it!

Prev: Speaking of Space | Next: Review Questions

REVIEW QUESTIONS

Earth Physiology

1. Describe the general anatomical features of the brain.

2. Describe the anatomy of the spinal cord.

3. Describe the nerve structures coming from the brain and spinal cord and name the parts of the body that are served by them.

4. Three classes of neurons make up the communication system of the body. All parts of the body are connected to this communication system. Name the three classes, their function and how the body's communication system works.

5. In what locations of the body do the signals that neurons transmit originate? Describe the different origination sites.

6. Neurons, when destroyed, are not replaced by the body. Explain how neurons are protected and preserved in the brain, the spinal cord and the rest of the body.

7. Why can you stand or whirl around without falling down?

8. When a motor signal travels to a muscle site and reaches a gap, what is the name of this gap and what events occur so that the signal can travel across the gap to activate the muscle?

Space Physiology

1. The neurovestibular system is responsible for the balance mechanisms in the body. Why does this system not function the same way in space to provide the needed support to the balance mechanisms?

2. Explain the term nystagmus.

3. What sensory organ is considered the "window" to the vestibular system? Name two ocular methods that can be used to measure vestibular function. (Hint: The hint is in the question!)

4. Select one of Dr.Young's hypotheses and, using any of the data sets in this chapter, provide an argument that supports or refutes the hypothesis.

5.
   A. When the astronauts return to Earth, they go through a period of disorientation. Is this similar to what happens when they first go into space? Explain.
   B. Physiologically, what does their body do to overcome this disorientation?

6. What do the astronauts do while in space to reduce the magnitude of space sickness?

CRITICAL THINKING

1. If you wished to run to a pizza restaurant to smell the pizza, explain what parts of your nervous system would be involved in your running and smelling and describe their function.

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REFERENCES

Certain parts of the text were excerpted and adapted from the following publications and other references:

For the section describing Earth Physiology:

1. Fox Sl (1987). Human Physiology, 2nd ed. William C Brown Publishers, Dubuque, Iowa.
2. Guyton AC (1986). Textbook of Medical Physiology, 7th ed. WB Saunders Company, Philadelphia, PA.
3. Nourse AE (1964) The Body. Life Science Laboratory, Time Incorporated, New York.
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6. Personal communications with Dr. Laurence Young and Dr. Charles Oman (August 1994), Massachusetts Institute of Technology, Cambridge, Massachusetts.

For the section describing the space flight results and as influence for numerous figures and tables:

1. Churchland P.S. (1986). Neurophilosophy Toward a Unified Science of the Mind-Brain. The MIT Press, London, England.
2. Young L.R. (1984). Handbook of Physiology - The Nervous System. Vol. 3, Part 2, Oxford University Press, Inc.
3. Young L.R., Oman C.M., Merfeld D., Watt D., Roy S. DeLuca C, Balkwill D., Christie J. Groleau N. Jackson D.K., Law G. Modestino S. Mayer W (1993). Spatial orientation and posture during and following weightlessness: human experiments on Spacelab Life Sciences 1. J. Vest. Res..
4. Young L.R. (1993). Final Report for E072: Vestibular Experiments in Spacelab Life Sciences 1. MIT Man-Vehicle Laboratory, Cambridge, Massachusetts.
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6. Oman, C.M. and Balkwill, M.D. (1993). Horizontal angular VOR, nystagmus dumping, and sentation duration in Spacelab SLS-1 crew members. Journal of Vestibular Research, Vol 3, pp. 315-330.
7. Oman, C.M., Lichtenberg, B.K., Money, K.E. & McCoy, R.K. "MIT/Canadian vestibular experiments on the Spacelab-1 mission: 4. Space motion sickness: symptoms, stimuli, and predictability", Experimental Brain Research. 64: 316-334, 1986.
8. Oman, C.M. & Shubentsov, I. "Space sickness symptom severity correlates with average head acceleration", in Mechanisms and Control of Emesis, eds., Bianchi, A.L., Grelot, L., Miller, A.D., & Kink, G.L., Colloque INSERM/John Libbey Eurotext Ltd. 233: 185-194, 1992. Presented at the conference: New vistas on mechanisms and control of emesis, Marseille, France, September 4-7, 1992.

Prev: Review Questions

Figure 2. The 72 pairs of cranial nerves originate deep within the brain and the 31 pairs of spinal nerves originate from the spinal cord. The nerves travel throughout the body, reaching every millimeter of body tissue.

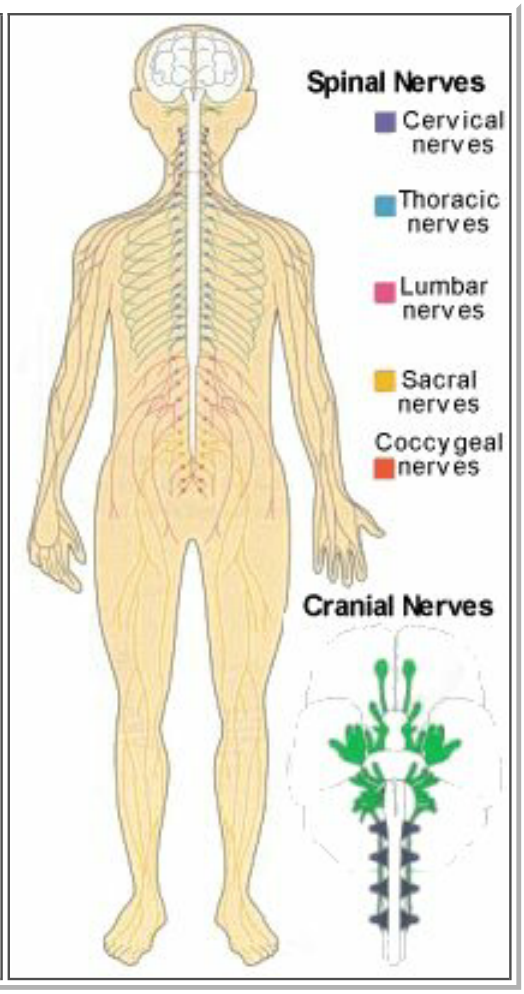

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Figure 3. A typical motor neuron.

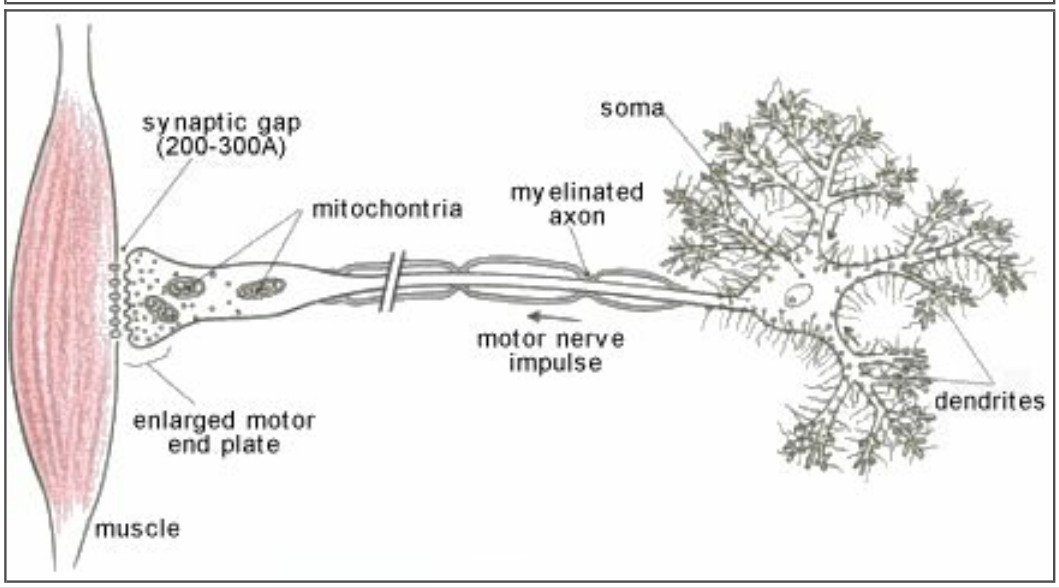

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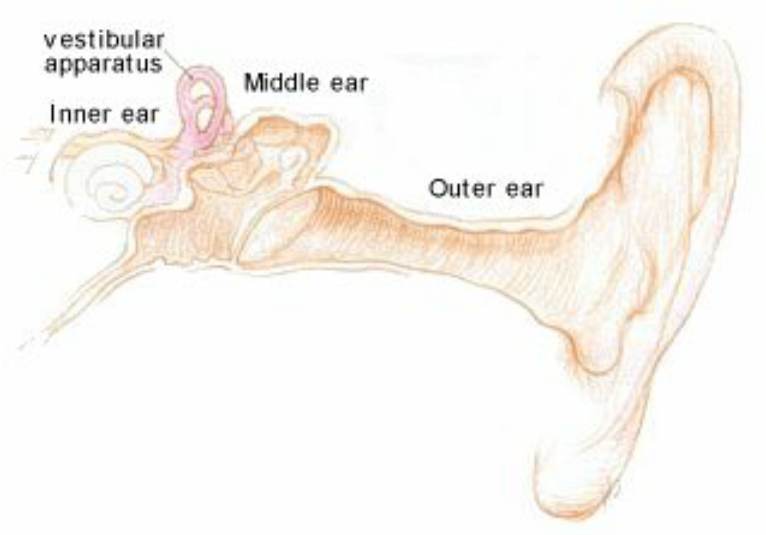
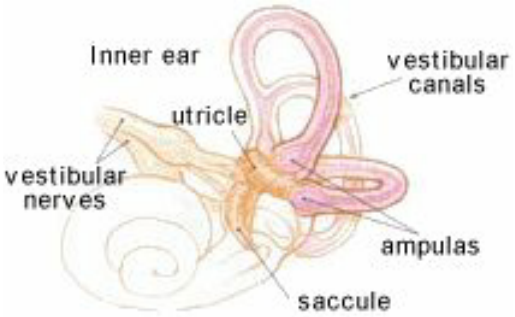
Figure 4: The vectibular organs are located in the inner ear portion of the ear canal. The three semicircular canals detect rotational head movement and the otolith organs (located in the utricle and saccule) detect linear head movement.





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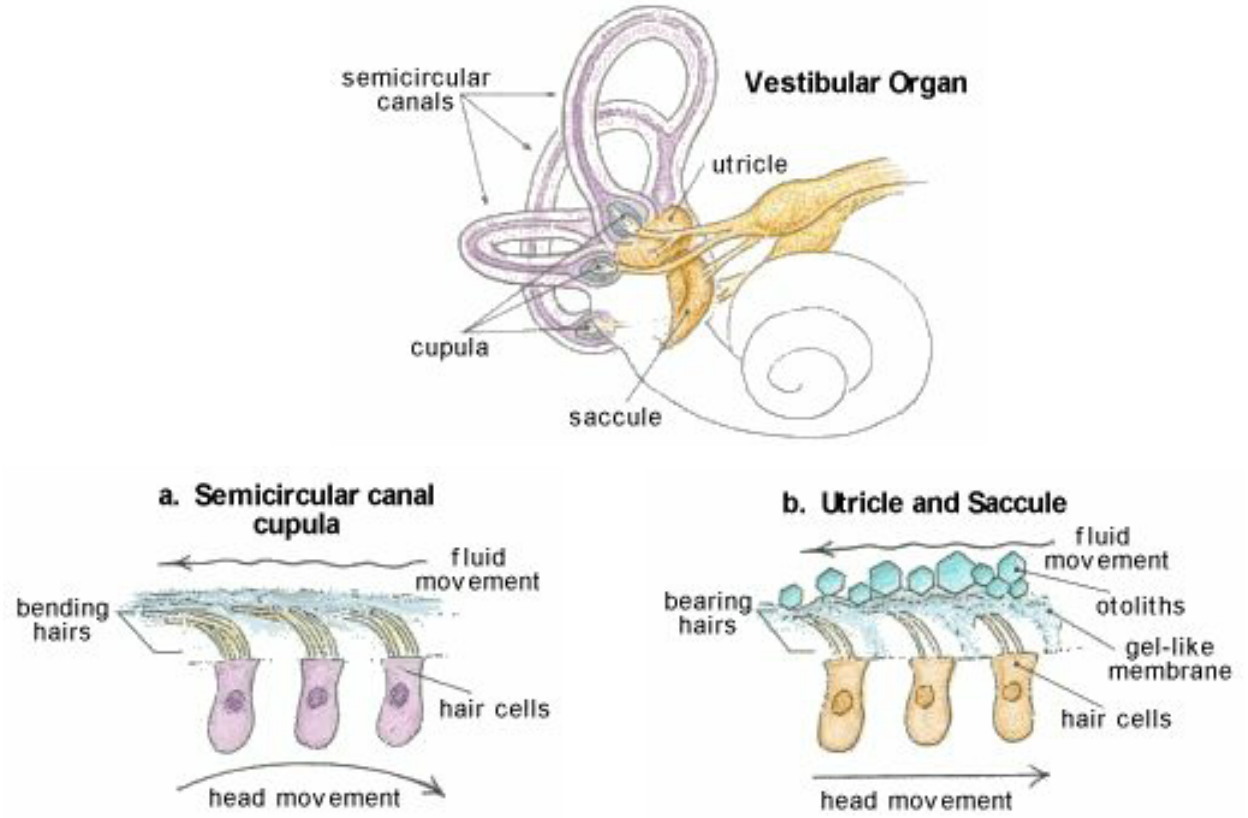

Figure 5. a) The fluid in the semicircular canals bends the receptor hairs of the cupula in response to rotational head movement. b) The otoliths are embedded in a gel-like substance and, in response to linear head movements, the otoliths move and bend the receptor hairs.

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Figure 6. A person walking on a tightwire relies on his senses of sight and touch, as well as the many signals that come from his inner ear balance system and his muscles. The integration sites for such information are the reticular formation located in the brain stem and the cerebellum. Our awareness, sensations, and responses are initiated in the motor and sensory cortex regions of the brain, indicated as color bands along the cerebral cortex.	

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Figure 7. The sensory and balance system within the body operates with a variety of input and output signals that control our body's movement.

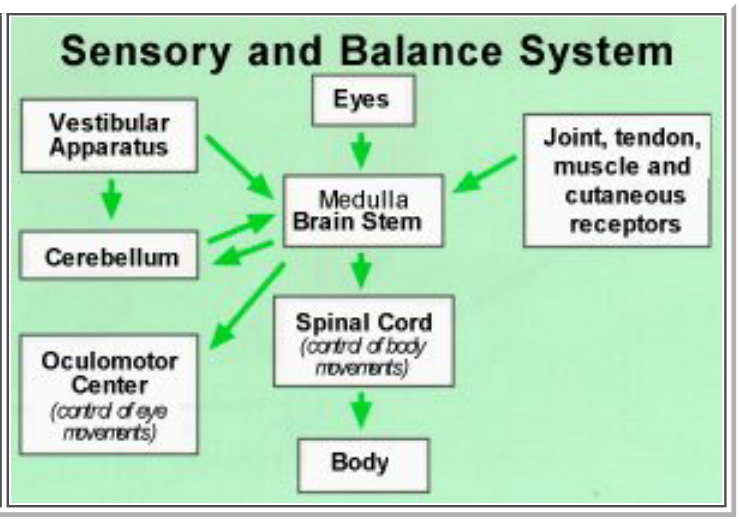

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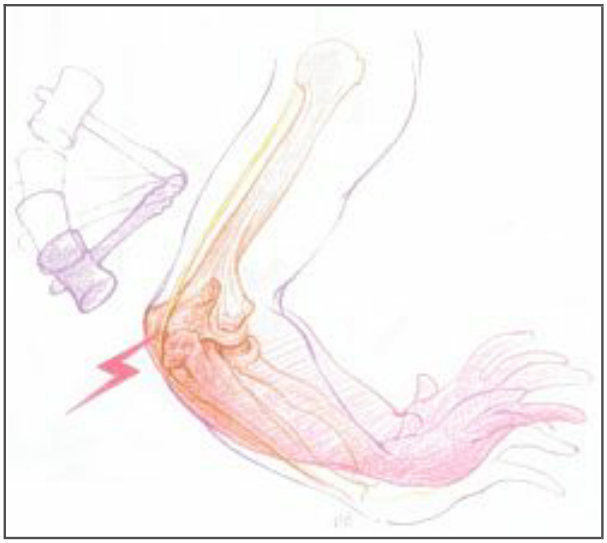
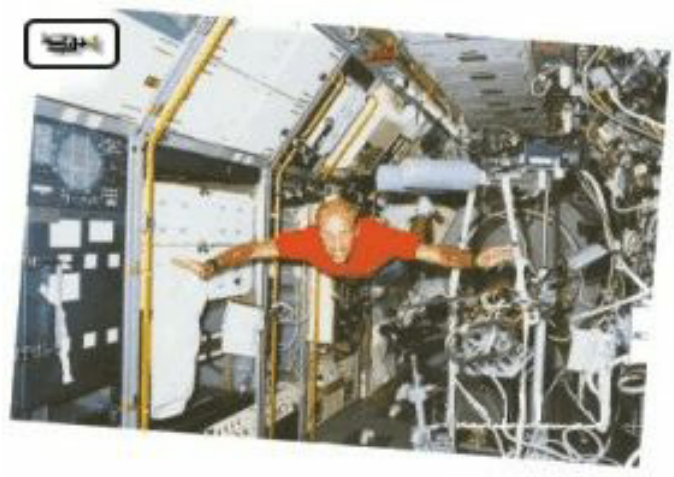
Figure 8. The "funny bone" does not originate in the bone at all. The ulnar nerve is unprotected in one small spot in the elbow and when it is hit hard, a strong electrical impulse is felt.	

Return to Earth Physiology.

Figure 10. Floating in microgravity is a new experience for the body. Our senses of touch and sight take on new responsibilities in space and our vestibular otolith signals take on new meanings.



Return to Space Physiology.

Figure 15. An astronaut perfoming the rotating dome experiment to determine any changes in rotational perceptions during space flight.

Figure 16. An astronaut perfomrs the Awareness of Position task using a pointer. This experiment measures if any changes occur in pointing accuracy and control of limb position due to space flight.

Figure 17. An astronaut performs the "drop experiment" to measure the leg reflex (otolith-spinal reflex) that causes him to catch himself when sensing a fall. In sapce, bungee cords are used to pull him "down".

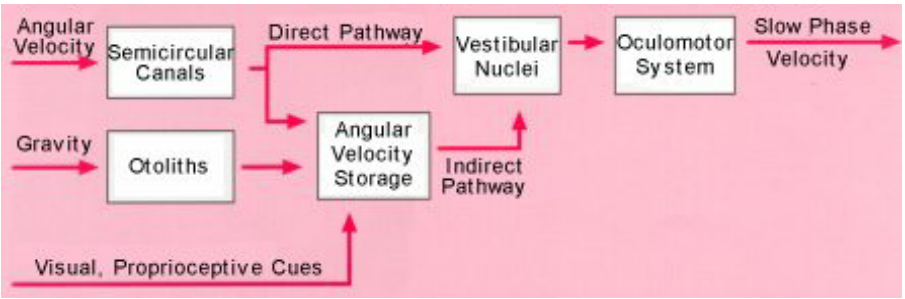


Figure 18. Integrated sensory information can be stored by the body temporarily during movement. This angular velocity storage capability, as its called, can be evaluated by measuring the sow phase velocity which is the amount of time it takes for eye mot ion to stop after particular head movements.

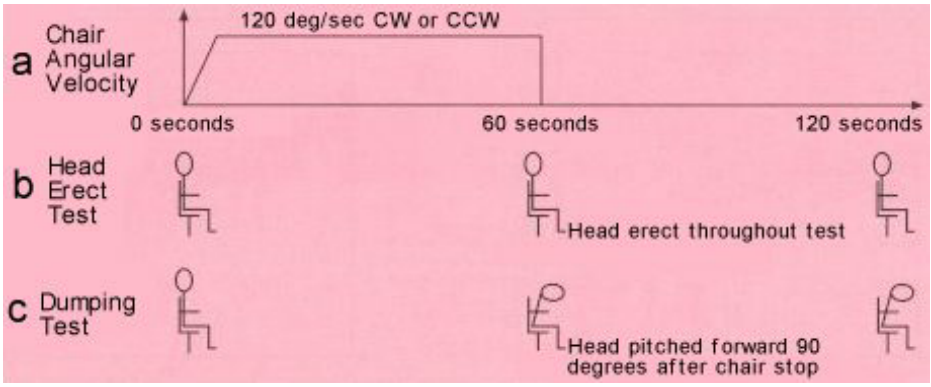


Figure 19. (a) The chair was spun for 60 seconds at a constant velocity and then stopped abruptly. (b) In the first test, the subject maintained a head erect position while being spun and for aminute after the chair was stopped. (c) In the second test, th e subject pictched the head forward after the chair was stopped and mainained that position for about a minute until the end of the test.

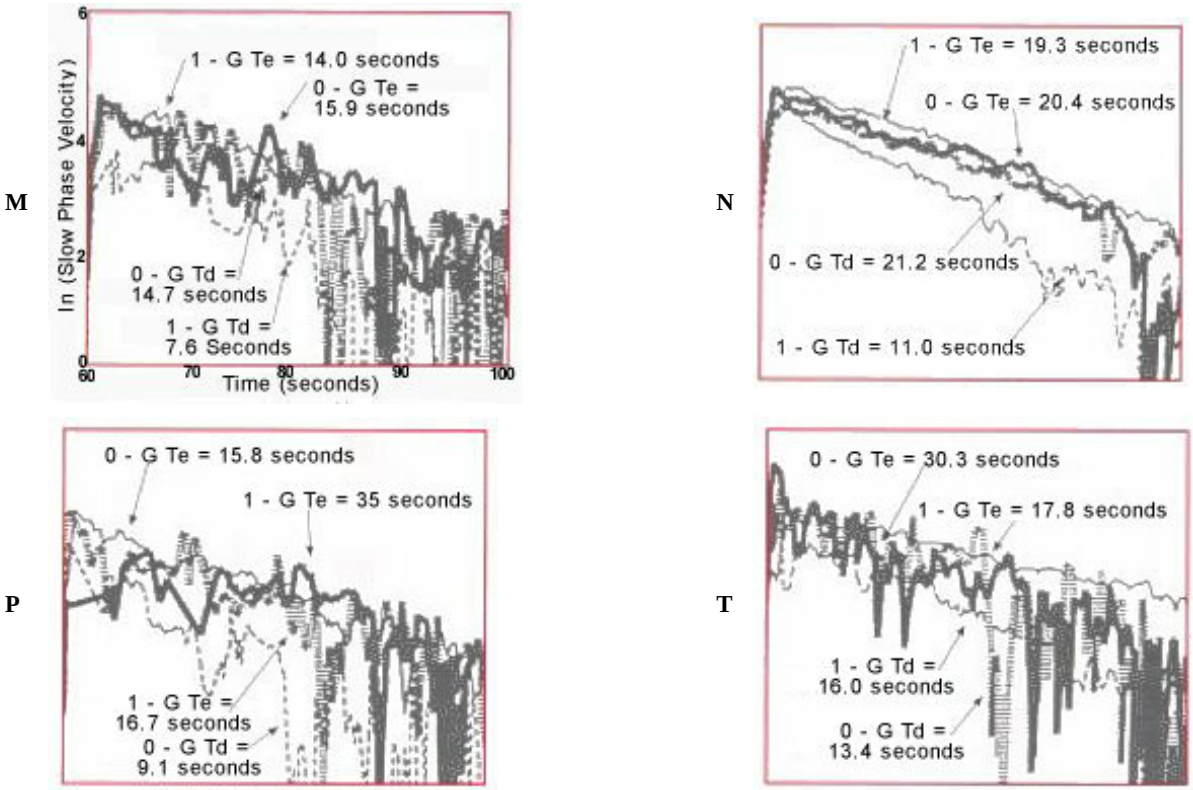


Figure 20. Preflight and inflight individual slop pahse velocity (SPV) data and vestibulo-ocular reflex (VOR) time constant values for Subjects M, N, P, and T. Both the head erect tests and the dumping tests are indicated. All data that is shown was coll ected during the post-rotatory period.

Figure 23. This astronaut, whose feet were secured to the floor, was asked to stand "straight up" to test his postural perception in space. As you can see, he was unable to judge his postural position particularly with his eyes closed.

Figure 24. For the Awareness of Position experiment, the subject was seated on the floor leaning back against a supporting surface and was aiming the light pointer at one of the targets. The reference screen was attached to the wall 49 inches from the ba ck support Inflight, the subject used a Velcro starp maintain this position.

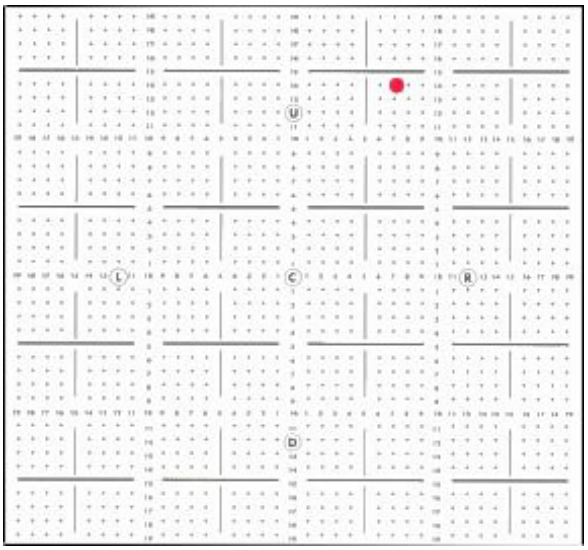


Figure 25. The target screen contains five targets labelled center (C), up (U), down (D), left (L), and right (R), as well as a full coordinate system to identify specific location of all points. The red dot is located at coordinate (7,14) in the upper ri ght quadrant.

Figure 26. The preflight results Subject P for the cases where, (a) the eyes were kept closed contiguously, and (b) the eyes were opened between each point and kept closed only while pointing.

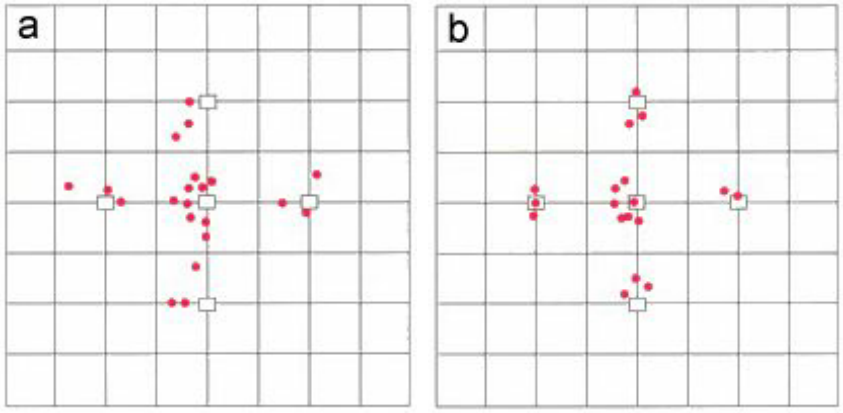
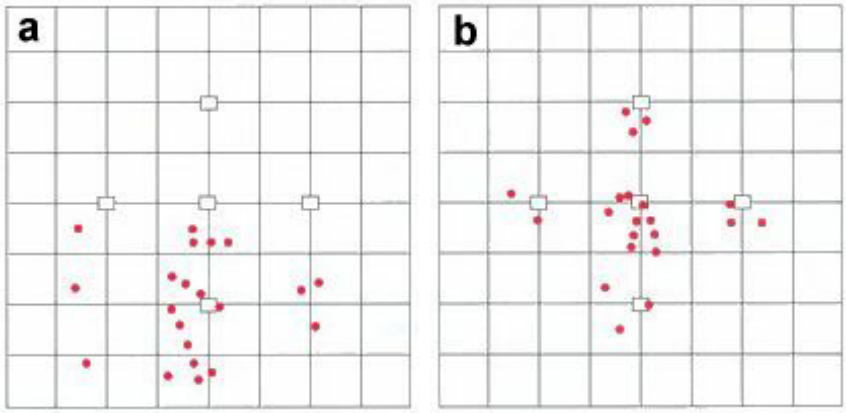


Figure 27. The inflight results for Subject P for the cases where, (a) the eyes were kept closed continuously and (b) the eyes were opened between each point and kept closed only white pointing.



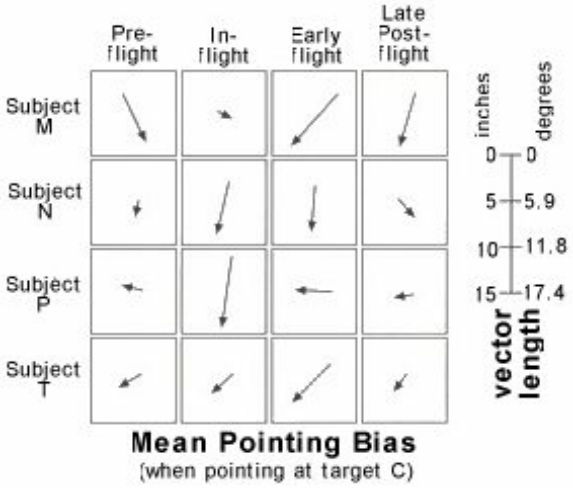
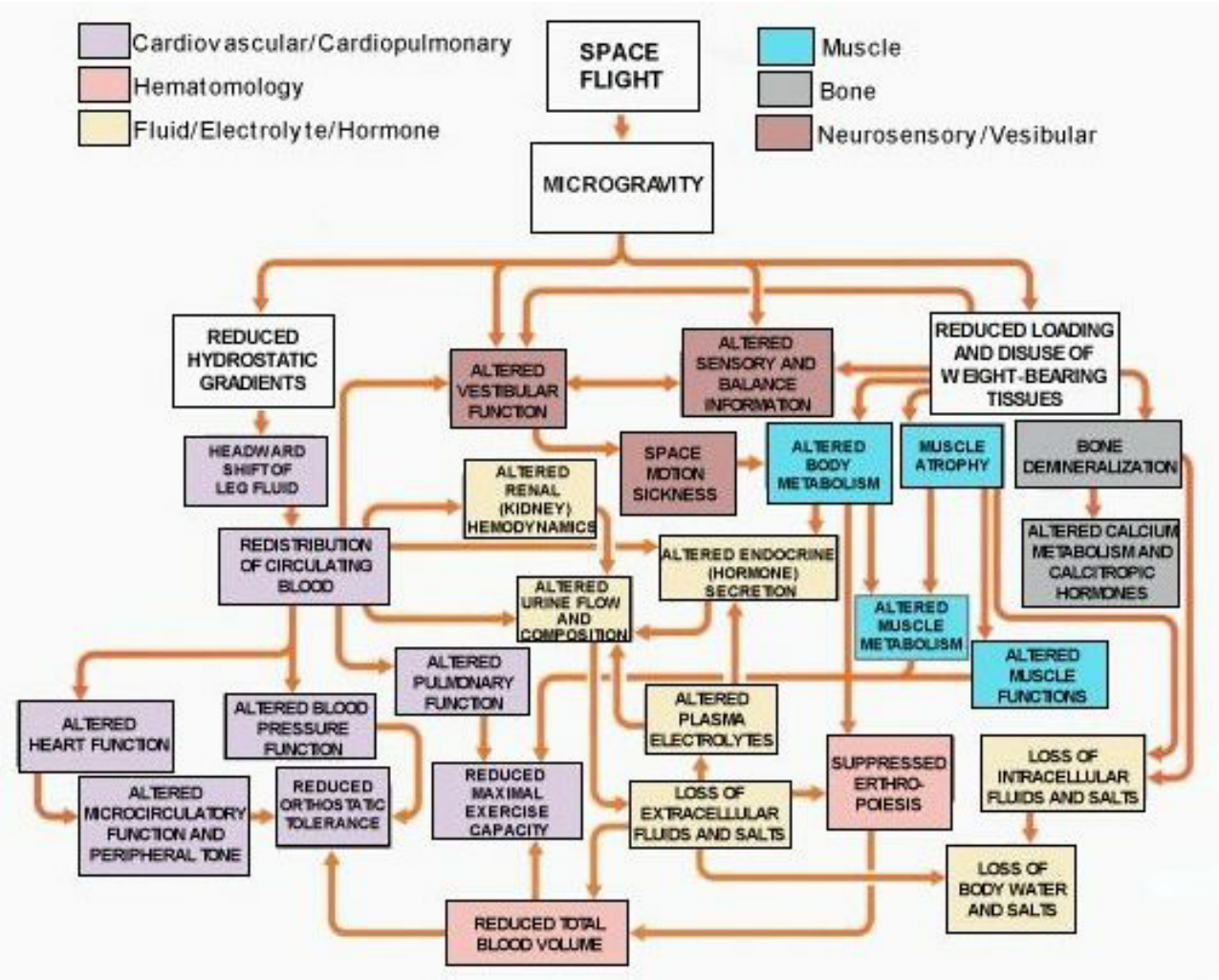


Figure 28. The mean pointing bias for each subject as determined preflight, inflight, early postflight, and late postflight.

Figure 29. The integrated nature of our body's responses to space flight. Those boxes regerring to the sensory and balance system are highlighted.



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