

THE SCIENCE OF THE
HEART AND
CIRCULATION



Challenge: Microgravity

by

Barbara Z. Tharp, M.S.

Deanne B. Erdmann, M.S.

Marsha L. Matyas, Ph.D.

Ronald L. McNeil, Dr.P.H.

Nancy P. Moreno, Ph.D.

RESOURCES

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Authors: Barbara Z. Tharp, M.S., Deanne B. Erdmann, M.S., Marsha L. Matyas, Ph.D., Ronald L. McNeel, Dr.P.H., and Nancy P. Moreno, Ph.D.

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1 Baylor Plaza, NA-425, Houston, Texas 77030-3498
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CENTER FOR EDUCATIONAL OUTREACH

Baylor College of Medicine, 1 Baylor Plaza, BCM411, Houston, Texas 77030
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TEAMING WITH BENEFITS

by Jeffrey P. Sutton, M.D., Ph.D., Director, National Space Biomedical Research Institute (NSBRI)

Space is a challenging environment for the human body. With long-duration missions, the physical and psychological stresses and risks to astronauts are significant. Finding answers to these health concerns is at the heart of the National Space Biomedical Research Institute's program. In turn, the Institute's research is helping to enhance medical care on Earth.

The NSBRI, a unique partnership between NASA and the academic and industrial communities, is advancing biomedical research with the goal of ensuring a safe and productive long-term human presence in space. By developing new approaches and countermeasures to prevent, minimize and reverse critical risks to health, the Institute plays an essential, enabling role for NASA. The NSBRI bridges the research, technological and clinical expertise of the biomedical community with the scientific, engineering and operational expertise of NASA.

With nearly 60 science, technology and education projects, the NSBRI engages investigators at leading institutions across the nation to conduct goal-directed, peer-reviewed research in a team approach. Key working relationships have been established with end users, including astronauts and flight surgeons at Johnson Space Center, NASA scientists and engineers, other federal agencies, industry and international partners. The value of these



Dr. Jeffrey P. Sutton

collaborations and revolutionary research advances that result from them is enormous and unprecedented, with substantial benefits for both the space program and the American people.

Through our strategic plan, the NSBRI takes a leadership role in countermeasure development and space life sciences education. The results-oriented research and development program is integrated and implemented using focused teams, with scientific and management directives that are innovative and dynamic. An active Board of Directors, External Advisory Council, Board of Scientific Counselors, User Panel, Industry Forum and academic Consortium

help guide the Institute in achieving its goals and objectives.

It will become necessary to perform more investigations in the unique environment of space. The vision of using extended exposure to microgravity as a laboratory for discovery and exploration builds upon the legacy of NASA and our quest to push the frontier of human understanding about nature and ourselves.

The NSBRI is maturing in an era of unparalleled scientific and technological advancement and opportunity. We are excited by the challenges confronting us, and by our collective ability to enhance human health and well-being in space, and on Earth.



NSBRI RESEARCH AREAS

CARDIOVASCULAR PROBLEMS

The amount of blood in the body is reduced when astronauts are in microgravity. The heart grows smaller and weaker, which makes astronauts feel dizzy and weak when they return to Earth. Heart failure and diabetes, experienced by many people on Earth, lead to similar problems.

HUMAN FACTORS AND PERFORMANCE

Many factors can impact an astronaut's ability to work well in space or on the lunar surface. NSBRI is studying ways to improve daily living and keep crew-members healthy, productive and safe during exploration missions. Efforts focus on reducing performance errors, improving nutrition, examining ways to improve sleep and scheduling of work shifts, and studying how specific types of lighting in the craft and habitat can improve alertness and performance.

MUSCLE AND BONE LOSS

When muscles and bones do not have to work against gravity, they weaken and begin to waste away. Special exercises and other strategies to help astronauts' bones and muscles stay strong in space also may help older and bedridden people, who experience similar problems on Earth, as well as people whose work requires intense physical exertion, like firefighters and construction workers.

NEUROBEHAVIORAL AND STRESS FACTORS

To ensure astronaut readiness for spaceflight, preflight prevention programs are being developed to avoid as many risks as possible to individual and

group behavioral health during flight and post flight. People on Earth can benefit from relevant assessment tests, monitoring and intervention.

RADIATION EFFECTS AND CANCER

Exploration missions will expose astronauts to greater levels and more varied types of radiation. Radiation exposure can lead to many health problems, including acute effects such as nausea, vomiting, fatigue, skin injury and changes to white blood cell counts and the immune system. Longer-term effects include damage to the eyes, gastrointestinal system, lungs and central nervous system, and increased cancer risk. Learning how to keep astronauts safe from radiation may improve cancer treatments for people on Earth.

SENSORIMOTOR AND BALANCE ISSUES

During their first days in space, astronauts can become dizzy and nauseous. Eventually they adjust, but once they return to Earth, they have a hard time walking and standing upright. Finding ways to counteract these effects could benefit millions of Americans with balance disorders.

SMART MEDICAL SYSTEMS AND TECHNOLOGY

Since astronauts on long-duration missions will not be able to return quickly to Earth, new methods of remote medical diagnosis and treatment are necessary. These systems must be small, low-power, noninvasive and versatile. Portable medical care systems that monitor, diagnose and treat major illness and trauma during flight will have immediate benefits to medical care on Earth.

For current, in-depth information on NSBRI's cutting-edge research and innovative technologies, visit <http://www.nsbri.org>.

OVERVIEW

The circulatory system is able to adjust to different external conditions. On Earth, gravity causes blood to pool in our lower legs. But in space, beyond the pull of Earth's gravity, blood distributes itself evenly throughout the body. The body adjusts to this condition by decreasing the total volume of blood, which can cause problems, such as low blood pressure and fainting, when a person returns to Earth.

Students will use water balloons to simulate the effects of gravity and microgravity on fluid distribution in the body.



ACTIVITY



CHALLENGE: MICROGRAVITY

If students have been reading the Astroblogs, they already know quite a lot about the challenges faced by the circulatory system when humans travel into a microgravity environment. Living in microgravity changes both the heart and the blood.

On Earth, blood is pulled downward by gravity and tends to pool in the lower half of the body. In microgravity, blood is no longer pulled toward the feet, or in any particular direction. Without the effects

of gravity, the distribution of blood in the body changes, with less blood than normal in the legs and more blood than normal in the upper body. Therefore, astronauts in space get skinny "chicken legs" and puffy faces, and often feel stuffiness in their ears and noses. Suddenly, the heart is not moving five liters of blood (the amount in most adults) against the strong pull of gravity. Because it does not have to work as hard, the heart becomes slightly smaller and weaker while in space.

In microgravity, the body senses the extra blood in the upper body and interprets it as too much fluid (over-hydration). This signals the kidneys to remove water from the blood and dispose of it as urine. Astronauts lose as much as 20% of their blood volume during a space mission. Other sensors in the body then discern that there are too many red blood cells for the amount of blood circulating, so the body reduces the amount of red blood cells to match the plasma. This reduction in red blood cells is called "space anemia." After only one day in space or in orbit, astronauts have a lower blood volume. However, their ratio of red blood cells to plasma is similar to that experienced on Earth.

SCIENCE EDUCATION CONTENT STANDARDS*

GRADES 5–8

LIFE SCIENCE

Structure and function of living systems

- Living systems at all levels of organization demonstrate the complementary nature of structure and function. Important levels of organization for structure and function include cells, organs, tissues, organ systems, whole organisms and ecosystems.
- Regulation of an organism's internal environment involves sensing the internal environment and changing physiological activities to keep conditions within the range required to survive.

SCIENCE, HEALTH & MATH SKILLS

- Creating a model
- Comparing and contrasting
- Questioning

* National Research Council. 1996. National Science Education Standards. Washington, D.C., National Academies Press.

Post-Assessment Reminder

To conclude this unit, have students complete the post-assessment and present their final concept maps, as described in the activity, "Pre- and Post-assessment."



Final AstroBlog!

An AstroBlog entry for this activity can be found on page 5.



What is Blood?

Blood is a mixture of cells and a pale yellow liquid, called plasma, in which red blood cells (carrying oxygen), white blood cells (infection fighters) and platelets (clotting agents) float. In addition, plasma transports vitamins and nutrients, proteins, enzymes, hormones, cholesterol, and carbon dioxide, among other things like sugar and electrolytes (sodium, potassium and calcium). Even with all of these components, plasma still is made up of almost 90% water!

The cardiovascular system adapts well to microgravity, but what happens when an astronaut returns to Earth and “normal” gravity? By the time a spacecraft or orbiter begins reentry into the Earth’s atmosphere, astronauts have fewer red blood cells, their hearts have not been working as hard as they do in normal gravity, and their blood volume is lower than normal. These changes occurred over several days (or even longer), but reentry into normal Earth gravity happens quickly. This abrupt change creates important challenges for the circulatory system. And it can be dangerous for astronauts, because they must function effectively during reentry and landing.

In the previous activity, students learned about high and low blood pressure (hypertension and hypotension, respectively). One consequence of low blood pressure is reduced blood flow to the brain. Upon returning to Earth’s gravity, astronauts sometimes experience a specific type of low blood pressure, called orthostatic hypotension, which you also may have experienced if you’ve ever stood up quickly after being seated on a chair. You get a little dizzy because gravity pulls the blood in your body down toward your feet. For a moment, your blood pressure falls slightly, and you feel dizzy. The dizziness goes away as your heart speeds up and stroke volume increases.

This same experience of orthostatic hypotension can happen to astronauts returning from space. Upon reentry, the pull of the gravity increases and blood is pulled back toward the lower body, as it is on Earth. However, since an astronaut’s total blood volume has decreased while in space, the effect is quite a bit stronger than when a person stands up from a chair. Astronauts can become very dizzy, or even lose consciousness during reentry. This condition can last for several days after returning to Earth, until the changes in the astronaut’s circulatory

system reverse themselves and the body’s overall blood volume returns to a normal level. Scientists are working to develop short-acting medications to help prevent the effects of orthostatic hypotension and allow astronauts to function normally during landings.

Many biomedical researchers and astronauts also are conducting experiments to determine the impacts of longer-term spaceflight on astronauts’ circulatory systems. For example, would an exercise routine be sufficient to prevent long-term changes in heart strength and size, blood volume, and the number of circulating red blood cells? Researchers are working to answer these questions. Their work also may produce better treatments for people on Earth who are bedridden for long periods of time, or who have diseases of the heart or circulatory system.

TIME

60 minutes

MATERIALS

Each group will need:

- Highlighters
- Oblong-shaped balloon
- Paper towels
- Tub half-filled with water (large enough to float a filled balloon)
- Group concept map (ongoing)

Each student will need:

- Copy of student sheet

SAFETY

It is a good idea for students to wash their hands with soap and water before and after any science activity. Make sure any spilled water is cleaned up promptly.

SETUP & MANAGEMENT

Depending on time and the ages of your students, you may want to fill water balloons in advance, instead of having students fill the balloons during class.

Have students work in teams of four.

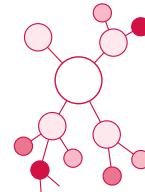
Continued



PROCEDURE

1. Give each group of students a long balloon. Instruct students to fill the balloon with water at a faucet and tie a knot at the top. This task is best accomplished by two students working together.
2. Ask, *Do you think the shape of the water balloon will remain constant?* Tell students that they will investigate the shape of the balloon under different conditions: lying horizontally on a flat surface, held vertically, and suspended in water. Student groups should discuss and predict the shape of the balloon under each condition.
3. Have students place their water balloons on a flat surface. Each student should observe and draw the balloon's shape as it lies on the table.
4. Next, have one student from each group hold the balloon up by the knot. Instruct students to observe and draw the balloon again.
5. Finally, have students place their balloons in the tubs of water, and then observe and draw the balloon's shape again. Under each of their three drawings, have students write a brief description comparing and contrasting each shape, and explaining why the shapes are different.
6. Ask, *Why does the balloon change shape?* [Walls of the balloon stretch in response to pressure exerted by the water inside the balloon. The force of gravity pulls the water toward the lowest part of the balloon when it is lying on a table or held by the knot. This does not appear to happen when the balloon is in water.] Discuss the ways in which a water environment might mimic conditions in space, where gravity does not have an effect (microgravity). [The water balloon suspended in water is similar to an astronaut suspended in air within the space shuttle. The density of the water balloon is the same as the density of the water surrounding it, so gravity does not pull on the water balloon any more than it does on the rest of the water in the tub. In a sense, the water surrounding the balloon counteracts the pull of gravity on the balloon itself.]
7. Ask, *In what way could you compare the human body to the balloon? Is there liquid water inside the human body? What percent of a human's body weight is water? [55–65%]*
8. Hold the balloon vertically. Ask, *If this were a human body, where would the blood pool? Does blood flow down in the body like water does in the balloon?* Explain that the fluid (blood) in a human body does travel downward through the blood vessels. Under normal conditions, blood is forced back to the heart by:
 - a) continuous flow of blood through the body,
 - b) constriction of the muscles in the walls of the blood vessels,
 - c) contraction of muscles surrounding the veins, and
 - d) "one-way" valves inside many veins that allow blood to move in only one direction—back to the heart.
9. Ask, *How might the body function differently in space? What would happen if the water were not pulled downward by gravity?* Remind students of the appearance of the balloon when it floated in the water.
10. Distribute the student sheet. Have students read and highlight important facts from the article.
11. Have students individually complete the "3-2-1" activity (see sidebar, right). When they have finished, let individual students share responses within their groups.
12. As a class, have students discuss possible answers to the questions generated by the activity. Assign groups of students to research questions that are not resolved, and have them present their findings to the class in any format they choose.
13. Ask students if they have anything to add to the concept maps they have compiled over the course of the unit.

Finalize Concept Maps



3-2-1 Activity

Have students respond individually to the following prompts in their lab notebooks or on a sheet of paper.

3 Things you learned

2 Things that surprised you

1 Question you have

Post-assessment

Conduct a final unit assessment with students using the activity, "Pre- and Post-assessment."



WHEN SPACE . . .

MAKES YOU DIZZY

It's terrible to feel dizzy when you're trying to land a spaceship, yet that's what happens to some astronauts. Their legs become heavy and their heads feel light, even as the planet below expands to fill the windshield. It's an unwelcome side effect of returning home from orbit . . .

Researchers have learned that dizziness experienced by returning astronauts is caused, in part, by orthostatic hypotension—"in other words, a temporary drop in blood pressure," explains NASA Chief Medical Officer, Rich Williams. On Earth, you can feel orthostatic hypotension by standing or sitting up too fast. Gravity has much the same effect on astronauts returning from a long spell in space: blood rushes down toward their feet and the space travelers become, literally, lightheaded.

Each person responds differently. Some astronauts are hardly affected, while others feel very dizzy. About 20% of short-duration and 83% of long-duration space travelers experience some symptoms during reentry or after they land.

"Cosmonauts who spent a long time onboard Mir commonly had to be carried away in stretchers when they came home," recalls Williams. Fortunately, their Soyuz return capsules did not require a pilot to land, so it didn't matter much. Shuttle pilots, on the other hand, must perform complex reentry procedures. To them, it matters a great deal.

Orthostatic hypotension can strike Earth-dwellers for many reasons. Weak hearts might not pump enough

blood, for example. Certain medications, or even a hot shower, can dilate blood vessels and cause blood pressure to drop. Women—especially pregnant women—are more likely to suffer from it than men. "Some patients with this condition are afraid to leave home or even get out of bed," writes neurologist Phillip Low of the Mayo Clinic.

What Is G-force?

G-force refers to the force that an accelerating object "feels." The term refers to the backward push you feel when you are going uphill on roller coaster, or when you are in plane that is taking off. An object at rest on Earth's surface experiences a g-force of 1, which corresponds to the effect of Earth's gravity. When astronauts return to Earth, they experience strong g-forces as they accelerate back toward the surface of the planet.

Astronauts experience orthostatic hypotension because of the way human bodies respond to gravity. On Earth, gravity pulls blood toward the lower body. But in space—either in free-fall or far from a source of gravity—blood that normally pools in the legs collects in the upper body instead. That's why astronauts have puffy-looking faces and spindly "chicken legs."

Astronauts don't feel orthostatic hypotension while they're traveling through space. But they do begin to feel it during reentry (when g-forces mimic gravity) and after landing. Blood returns to the lower body and blood pressure to the head is suddenly reduced. Hence the dizziness, which can continue for a while after landing.

It's a classic case of "use it or lose it." Veins in human legs contain tiny muscles that contract when the veins fill with blood. Their function is to send blood "uphill" toward the heart and thereby maintain blood pressure. But in space, there is no "uphill," so those tiny muscles in the veins are used less—a normal adaptation to weightlessness.

During reentry, those muscles are needed again, but they have temporarily "forgotten" how to contract. They fail to push blood back toward the heart and brain. "This effect is more severe after prolonged space-flights," notes heart researcher Richard Cohen.

For many years, astronauts have tried to counteract orthostatic hypotension by drinking lots of salt water, which increases the volume of bodily fluids. (There is a general loss of body fluids during space missions.) Astronauts also wear "G-suits"—rubberized full-body suits that can be inflated with air, which squeezes the extremities and raises blood pressure. These suits are similar to what fighter pilots wear, and for the same purpose of counteracting "g" force.

Such countermeasures are only partially effective. "Almost all returning astronauts experience changes in gait and balance," continues Williams. (Gait is the way someone moves on foot.) Nevertheless, "most are able to walk around just fine. A small number experience orthostatic changes that render them quite dizzy." Scientists are looking for other ways to reduce dizziness problems for astronauts. Their research is likely to help people on Earth as well.



Adapted from "When Space Makes You Dizzy," Science@NASA. An audio file of the original article is available at http://science.nasa.gov/headlines/y2002/25mar_dizzy.htm.

AN ASTRONAUT'S POINT OF VIEW

ASTROBLOGS

Create a “blog-wall” in your classroom to stimulate students’ thinking and encourage students to express their ideas in writing. Periodically, post a copy of one of the AstroBlog entries below to spark students’ interest. Suggested use with specific activities is noted with each entry.



ASTROBLOGS

Blood pressure is an important issue for astronauts, especially during take off and landing.

When we blast off from Earth, our hearts have to push the blood against Earth's gravity. Then, as we move into orbit and the microgravity of space, our bodies' control systems tell the circulatory system to adjust. This causes our blood pressure to drop.

When we return home, we have a bigger problem. As we approach Earth, the pull of gravity increases. This makes the heart work harder to move the blood to all parts of

the body, including the brain. If the heart doesn't respond quickly enough, we can get light headed, and even faint. Not cool, especially when you're flying a spacecraft at several thousand miles per hour!

Not all astronauts get light headed during reentry, and it's hard to predict who will react this way. I hope that when we land from this mission, I will be clear-headed all the way down. I'm not flying the shuttle, but I want to see the whole landing process. Besides, if I pass out, I might drool inside my helmet. That would be embarrassing!

