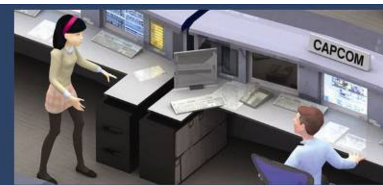
MATH AND SCIENCE @ WORK

AP* BIOLOGY Educator Edition



MICROGRAVITY EFFECTS ON HUMAN PHYSIOLOGY: CIRCULATORY SYSTEM

Instructional Objectives

Students will:

- analyze the effects of external stimuli on the physiological processes of the body;
- apply the concept of form and function to an unfamiliar situation;
- review and recall specific content knowledge for the circulatory system as it relates to blood pressure and cardiac output;
- examine form and function of the heart as muscle tissue rather than an organ;
- examine the effects of gravity on the evolution of form and function in the human circulatory system;
- find the connection between space biology and related medical pathologies on Earth; and
- recognize the risks and hazards associated with space science and the human body.

Degree of Difficulty

For the average AP Biology student, this problem is at a moderate level of difficulty. If AP Biology Lab 10 and the human circulatory system have been covered in class, an average student should be able to make a connection between microgravity and its effects on body fluids and enhanced muscle atrophy.

Class Time Required

This problem requires 35-50 minutes.

- Introduction: 5-10 minutes
- Student Work Time: 20-25 minutes
- Post Discussion: 10-15 minutes

Grade Level
10-12

Key Topic
Physiology of the Circulatory System, Application of Lab 10

Degree of Difficulty
Moderate

Teacher Prep Time
30 minutes

Class Time Required
35-50 minutes

Technology
None

AP Course Topics
Organisms and Populations:
- Structure and Function of Plants and Animals

NSES
Science Standards
- Unifying Concepts and Processes
- Science as Inquiry
- Life Science
- Science and Technology
- History and Nature of Science

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's Space Shuttle Mission Control Center.

Since its conception in 1981, NASA has used the space shuttle for human transport, the construction of the International Space Station (ISS), and to research the effects of space on the human body. One of the keys to the success of the Space Shuttle Program is the Space Shuttle Mission Control Center (MCC). The Space Shuttle MCC at NASA Johnson Space Center uses some of the most sophisticated technology and communication equipment in the world to monitor and control the space shuttle flights.

Within the Space Shuttle MCC, teams of highly qualified engineers, scientists, doctors, and technicians, known as flight controllers, monitor the systems and activities aboard the space shuttle. They work together as a powerful team, spending many hours performing critical simulations as they prepare to support preflight, ascent, flight, and re-entry of the space shuttle and the crew. The flight controllers provide the knowledge and expertise needed to support normal operations and any unexpected events.

One of the flight control positions in the MCC is the Surgeon. Surgeons have an extensive role in the crews' health and well-being during training, pre-flight, mission, and post-landing. Each astronaut is selected and trained for a very specific skill set. Their inability to perform due to health reasons can be very costly to the mission and hazardous to the whole crew. Therefore, flight surgeons work very closely with astronauts throughout their training and monitor their health from the MCC during flight.

Figure 1: Astronaut Edward T. Lu exercises on the Treadmill Vibration Isolation System (TVIS) on the International Space Station (ISS).

Figure 2: Catherine (Cady) Coleman is performing a remotely guided echocardiogram on a test subject utilizing the Integrated Cardiovascular protocols.

Shifting from an environment with gravity to one of microgravity causes changes in an astronaut's body. Structural and functional changes of the cardiovascular system in microgravity are known medical issues associated with human space flight. Even though short-duration flights pose no major problems with post-flight functional and structural recovery, understanding these physiological changes are of great importance when planning for challenging extravehicular activities and longer duration missions.

AP Course Topics

Organisms and Populations

- Structure and Function of Plants and Animals
  - Structural, physiological, and behavioral adaptations
  - Response to the environment

NSES Science Standards

Unifying Concepts and Processes

- Systems, order, and organization
- Evidence, models, and explanations
- Change, constancy, and measurements
- Evolutions and equilibrium
- Form and function

Science as Inquiry

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

Life Science

- Biological evolution
- Matter, energy, and organization in living systems

Science and Technology

- Understanding about science and technology

History and Nature of Science

- Science as a human endeavor

Problem

In spaceflight, shortly after reaching orbit, astronauts experience much lower gravity than on Earth. This is known as microgravity. Therefore, the average physical exertion of astronauts on board the space shuttle and the ISS is reduced compared to pre-flight, with the exception of challenging extravehicular activities such as a space walk. An astronaut's circulatory system, which is accustomed to working against gravity, receives a different set of signals and stimuli in microgravity and adapts to the new environment. The heart does not need to work as hard to send blood to the upper body as it does when it working against gravity. This causes blood volume to increase in the upper body.

Table 1 demonstrates a comparison of percent changes obtained from pre-flight and post-flight taken on 17 male astronauts, with an age range of 34-48 years. Thirteen subjects had flown on short-duration flights of 4-17 days versus four subjects that had flown long-term missions of 129-144 days.

Table 1: Percent Changes from Pre-Flight to Landing of Echocardiographic Parameters (Mean ± SE)**

	Short-duration *n* = 13 Δ % (Mean ± SE)	Long-duration *n* = 4 Δ % (Mean ± SE)
Systolic Blood Pressure (mm Hg)	6.69 ± 2.47	8.93 ± 3.12
Diastolic Blood Pressure (mm Hg)	6.64 ± 4.12	16.60 ± 3.90
Stroke Volume+ (mL)	- 5.00 ± 0.03	- 17.40 ± 0.05
Cardiac Output * (L/min)	- 2.30 ± 0.07	- 12.20 ± 0.09

+Stroke volume is the amount of blood that is pumped by the left ventricle in one contraction.

**Cardiac Output is the stroke volume multiplied by the heart rate.*

****** Martin, David S., South, Donna A., Wood, Margie L., Bungo, Michael W., Meck, Janice V. Comparison of Echocardiographic Changes After Short- and Long-Duration Spaceflight. *Aviation, Space, and Environmental Medicine*. June 2002; 73-6: 532-536.

A. Describe arterial pressure changes during a single heart beat of a fit human on Earth.

B. Consider the data in Table 1 and explain how the circulatory system of a fit astronaut is affected by the muscle atrophy and fluid shift (from lower to upper body) as a result of microgravity. Explain why this could be a serious issue on long-duration flights.

   Note: In Table 1, blood pressure is not presented in the usual format of systolic/diastolic. Each data set in Table 1 is presented as the percent change of the values measured before and immediately after flight.

C. To stay healthy and productive in space and after astronauts return to earth, they follow certain procedures, strategies, medications, exercise routines, etc. known as countermeasures. What are some potential countermeasures the Surgeon might suggest to help minimize the effects of microgravity on the circulatory system, specifically for long-duration flights or on board the ISS?

D. How might these microgravity studies and results be applied to the treatment or prevention of circulatory diseases on Earth?

Solution Key (One Approach)

A. Describe arterial pressure changes during a single heart beat of a fit human on Earth.

   During systole, ventricles contract to pump a volume of blood through the body which increases the volume of blood in the arteries and therefore also increases the pressure in the arteries. During diastole, the heart relaxes and fills with blood; therefore, the volume of blood and the pressure in the arteries decreases.

   Note to teacher: You may wish to further explain that blood pressure is the pressure the heart generates to overcome resistance of the blood vessels in the body. Vasoconstriction, or vasodilation of blood vessels (arteries and veins) downstream of the heart, determines how hard the heart has to work. Arteries can constrict or dilate to change the pressure independent of the pressure generated by the heart. This is a complex closed loop system.

B. Consider the data in Table 1 and explain how the circulatory system of a fit astronaut is affected by the muscle atrophy and fluid shift (from lower to upper body) as a result of microgravity. Explain why this could be a serious issue on long-duration flights.

Note: In Table 1 blood pressure is not presented in the usual format of systolic/diastolic. Each data set in Table 1 is presented as the percent change of the values measured before and immediately after flight.

A microgravity environment leads to changes in fluid distribution, muscle loading, and altered signaling pathways. Some basic changes include alterations in blood pressure and the quantity of blood that is pumped by the heart with each beat. The human heart is designed to force blood to the body, and the most difficult organ to perfuse is the brain since it is above the heart. In space your heart does not have to work against gravity to pump blood to your brain and blood accumulates in the upper body because gravity is not there to pull it toward your feet. Your body takes advantage of this lack of work and begins to be less efficient as demonstrated by the lower stroke volume. The heart generates slightly higher systolic and diastolic pressures because large muscle groups (like the legs) are inactive and do not demand blood, resulting in vasoconstriction. Also, since the heart is less efficient some blood remains in the heart after each contraction which slightly increases the pressure during the relaxation phase known as diastole. Taken together, the amount of blood that is being pumped out of the heart (stroke volume) will change. As the flight duration increases, these changes become slightly more dramatic, and may affect an astronaut's other physiological functions. There could even be permanent changes in the way organs and blood vessels behave.

C. To stay healthy and productive in space and after astronauts return to earth, they follow certain procedures, strategies, medications, exercise routines, etc. known as countermeasures. What are some potential countermeasures the Surgeon might suggest to help minimize the effects of microgravity on the circulatory system, specifically for long-duration flights or on board the ISS?

Resistance training (weight lifting) and cardiovascular (aerobic) exercise to minimize muscle atrophy and cardiovascular de-conditioning are very important countermeasures.

D. How might these microgravity studies and results be applied to the treatment or prevention of circulatory diseases on Earth?

Lack of activity and a sedentary lifestyle may lead to the same problems that astronauts face in microgravity. As the heart becomes less efficient, other physiological functions of the body are affected. Long term sedentary lifestyle may lead to permanent changes that may increase risks of certain cardiac diseases.

Note to teacher: You may wish to introduce your students to the way that the effects of microgravity on cardiovascular system are studied on Earth. Bed rest studies have proven to be a useful and reliable method to mimic some of the effects of microgravity on cardiovascular system. Read more about these studies by following the link below: http://hacd.jsc.nasa.gov/projects/flight_analogs.cfm.

Scoring Guide

Suggested 10 points total to be given.

There is 1 additional point possible; however, students should not receive more than 10 total points for the question, or more than the allotted points per question.

Question		Distribution of points
A	*3 points*	1 point for using systole and diastole 1 point **each** for identifying each separate pathway
B	*4 points*	1 point for the role of microgravity in fluid shift 1 point for the role of microgravity in muscle loading and change 1 point for signaling pathway changes 1 point for comparison between long- and short-duration flight *1 additional point if all data points in the graph have been addressed*
C	*2 points*	1 point for addressing fluids 1 point for addressing muscle
D	*1 point*	1 point for addressing the effects of sedentary lifestyle on cardiovascular system and making the connection to the problems astronauts face in microgravity

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Instructors.

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