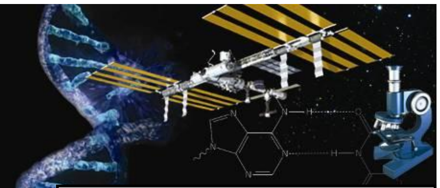
MATH AND SCIENCE @ WORK

AP* BIOLOGY Educator Edition



PHYSIOLOGY OF THE CIRCULATORY SYSTEM

TI-Nspire™ Lab Activity

This lab may replace or reinforce AP Biology Lab 10: Physiology of the Circulatory System. The Math and Science @ Work Free-Response problem, Microgravity Effects on Human Physiology: Circulatory System, may be used in conjunction with this lab.

Instructional Objectives

Students will

- develop an understanding of human blood pressure;
- gather and analyze heart rate data under various conditions;
- enter, graph, and analyze data using a TI-Nspire handheld; and
- evaluate heart rate dissimilarities between endothermic and ectothermic animals.

Teacher Preparation

- Distribute the TI-Nspire file, *Circulatory_System.tns* to the students' handhelds.
- Have stopwatches or clock with sweep-secondhand available for students.

Class Time Required

This lab requires 80-100 minutes.

- Introduction: 10-15 minutes
  - Read and discuss the background section with the class before students work on the problem.
- Student Work Time: 60-75 minutes
- Post Discussion: 10 minutes

AP Biology Framework Alignment

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.

- **Enduring understanding 2.C:** Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.

Grade Level
10-12

Key Topic
Circulatory System; Comparative Physiology

Teacher Prep Time
10 minutes

Lab Time
80-100 minutes

Materials/Equipment
- TI-Nspire Learning Handhelds
- TI-Nspire file, *Circulatory_System.tns*
- Stopwatches or clocks with sweep-secondhand
- Stairs

AP Biology Framework Alignment
Essential Knowledge:
2.C.1, 2.C.2, 2.D.3, 2.E.1, 2.E.2, 2.E.3

NSES Science Standards
- Science in Personal and Social Perspectives
- Life Science

2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

2.C.2: Organisms respond to changes in their external environments.

- **Enduring understanding 2.D:** Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.

2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis

- **Enduring understanding 2.E:** Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.

2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

2.E.2: Timing and coordination of physiological events are regulated by multiple mechanisms.

2.E.3: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.

NSES Science Standards

Science in Personal and Social Perspectives

- Personal and community health

Life Science

- Matter, energy, and organization in living systems

Background

This lab activity is part of a series of activities that apply Math and Science @ Work in one of NASA's scientific laboratories.

The International Space Station (ISS) is a research laboratory being assembled in low Earth orbit by five international partners. Construction of the ISS began in 1998 and is scheduled for completion in 2011. Crews aboard the ISS conduct experiments in biology, chemistry, physics, medicine, and physiology, as well as astronomical and meteorological observations. The microgravity environment of space makes the ISS a unique laboratory for the testing of spacecraft systems that will be required for future exploration missions beyond low Earth orbit.

Figure 1: The ISS orbiting the Earth as observed by Space Shuttle Discovery on March 26, 2009

The ISS travels in orbit around the Earth at an average speed of 27,743.8 km/h (17,239.2 mph) completing 15.7 orbits per day. An international crew, of typically six members, resides on the ISS for approximately six months. As they orbit the Earth, the crew experiences close to zero gravity. Shifting from Earth's gravity to microgravity causes changes in an astronaut's body. One of these changes can be seen in the circulatory system.

The circulatory system is responsible for carrying oxygen, carbon dioxide, nutrients, hormones and many other substances throughout the body. The body's cells rely on the circulatory system for a continuous supply of essential materials and waste removal. The heart is the driving force behind the workings of the circulatory system. The ventricles are the pumping chambers of the heart that push blood out of the heart with tremendous force then refill with blood. This process continues nonstop for many decades – billions of times during your lifetime.

Figure 2: A picture of astronaut Sunita Williams on Earth (left) is contrasted with a picture of her in microgravity (right).

On Earth, gravity affects how blood and other fluids flow in the body. Gravity pulls most of the body fluid to parts of the body that are below the heart. Natural muscular tension in the legs helps pump body fluids to the upper body. In space, the force of gravity is absent, but muscular tension continues to exert a force that moves the fluids toward the head. This fluid shift that astronauts experience while in space is characterized by nasal congestion, swelling in the face, and bulging blood vessels in the neck. This is a similar sensation as one would experience by hanging upside down here on Earth. While in space, these symptoms decrease somewhat after about three days, but are noticeable during the entire duration of a spaceflight mission.

A change in appearance is not the only side-effect of this fluid shift. Research has shown that spaceflight can have a dramatic effect on the human cardiovascular system. Even brief periods of exposure to reduced gravity environments can result in cardiovascular anomalies. One anomaly is a reduction in total blood volume. Up to 20% of circulating blood volume can be excreted by the kidneys as well as through the skin and lungs during the first 24-36 hours in space. When spaceflight crewmembers return to Earth's gravity, symptoms such as difficulty standing, low blood pressure, and even fainting have been observed. The risk of some of these symptoms is reduced by fluid loading just before landing and by wearing G-suits during landing. A G-suit is a specially designed suit that applies pressure to the abdomen and legs to restrict the draining of blood from the brain during periods of high acceleration.

Lab Procedure

On your TI-Nspire handheld, open the file, *Circulatory System*. Read the provided information and answer the Pre-Lab questions that follow (TI-Nspire pages 1.1-1.15). You will then be ready to start the Lab Activity (TI-Nspire pages 2.1-2.21). Work with a lab partner through the activity and answer the questions. Following the lab activity, proceed to the Lab Extension (TI-Nspire pages 3.1-3.9) and the Lab Analysis (TI-Nspire pages 4.1- 4.3).

Solution Key

Throughout this activity, students are provided information and questions within the TI-Nspire document, *Circulatory_System.tns.* A solution key, *Circulatory_System_Solutions.tns*, is also provided for the instructor to review with student using TI-Nspire software.

Mission (TI-Nspire pages 1.1-1.5)

Researchers are working hard to develop methods to reduce or reverse cardiovascular irregularities associated with exposure to microgravity. At the present time, exercise, balanced nutrition and hydration help to balance crew members' cardiovascular function while in space. Immediately after landing, medical doctors (called flight surgeons) supervise rehydration and management of motion sickness. Both are usually resolved within hours of landing. The flight surgeons also supervise reconditioning of the crew members for up to one month post landing. Reconditioning includes cardiovascular, neurovestibular, skeletal muscle and bone re-calcification. After the one-month rehabilitation period, flight surgeons can usually clear the crew member to return to all normal activities including diving, flying and other astronaut training. However, each crewmember is considered on a case-by-case basis. Once they are cleared for full activity, they may be reassigned to another flight which usually requires about one year of training before launch. Note that studies have shown that full bone density recovery may take six months up to three years.

Following this lab activity, you will better understand how the circulatory system works on Earth. Throughout the activity, consider how this would be different in microgravity, lunar gravity (16.5% of Earth's gravity) and Martian gravity (38% of Earth's gravity). As NASA's space exploration programs move forward, researchers must consider how the human body will adapt in different conditions and for different lengths of time. In order for humans to have a more permanent presence in space, precautions will need to be taken to ensure the health of the astronauts. You will be asked to hypothesize how the human circulatory system will be affected on long duration missions and in environments with gravitational forces different from Earth. You will also be asked to propose countermeasures that could be used to maintain cardiovascular health.

Pre-Lab Questions (TI-Nspire pages 1.7-1.16)

The force with which the ventricles push out blood is called *systolic pressure*. The force that the blood exerts on the walls of the arteries when the ventricles relax is called *diastolic pressure*. Together, these two pressures represent the numbers in a blood pressure (BP) measurement, written as

$$\frac{\textit{systolic pressure}}{\textit{diastolic pressure}}.$$

1.8 The pulmonary artery takes blood from the right ventricle to which body organs?

Lungs

1.9 The aorta, which is the largest artery in your body, takes blood from the left ventricle. What is the destination of this blood?

The entire body, except the lungs

1.10 Which of the two values in a BP reading is always greater?

Systolic pressure

1.11 What is a "sphygmomanometer"?

A device that measures blood pressure

1.12 An example of a BP reading is 120/70. What does this reading represent?

In this example, 120 mm HG is the maximum pressure exerted when the heart contracts and 70 mm HG is the minimum pressure in the arteries when the heart is at rest.

1.13 In which of the following locations would you expect the diastolic pressure to be the highest?

In your aorta, near the heart

You may know someone who has been diagnosed with "high blood pressure" (HBP), or hypertension. In general, a person who has a BP reading greater than 140/90 is considered to have HBP. A BP reading less than 120/80 is considered to be "normal". There are many variables to consider, however, so these values should be used only as benchmarks.

1.15 What do you think are some contributing factors to a person having HBP?

Sedentary lifestyle, overweight, high salt intake, stress, poor diet, family history

1.16 What are some ways that a person with HBP could lower his/her blood pressure?

Exercise, lose weight, reduce salt intake, improve diet, take medication

Lab Activity & Questions (TI-Nspire pages 2.1-2.18)

Lab Objectives

- Develop an understanding of human blood pressure.
- Gather and analyze your heart rate data under various conditions.
- Enter, graph and analyze data.
- Evaluate heart rate dissimilarities between endothermic and ectothermic animals.

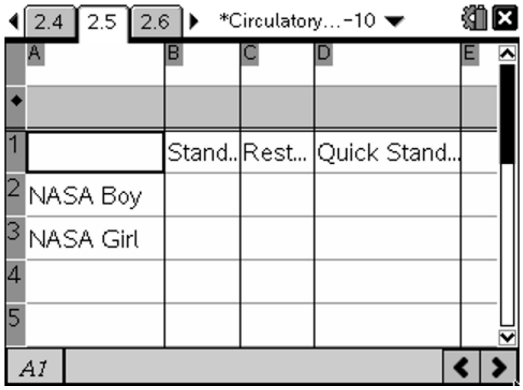
Materials/Equipment needed

- TI-Nspire Learning Handheld
- Stopwatch or clock with a sweep-secondhand
- Stairs

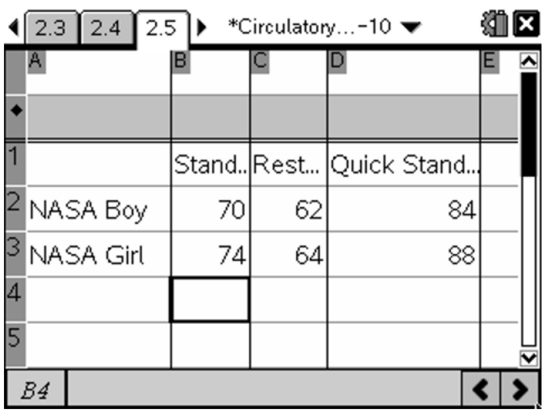
Finding your pulse:

You will be finding your radial pulse throughout this lab. To do this, face either hand palm up and use the index and middle finger from your other hand to locate your pulse. Your radial artery is on the thumb's side (or outside) of your wrist when the palm of your hand is facing you. Place your fingers half way between the tendons that run down the center of your forearm and the edge of your arm, on the thumb side, right at your wrist. You should feel a strong pulse here.

- Go to the spreadsheet on the next page. Enter your name in cell A2 and your lab partner’s name in cell A3.



- Stand upright for one to two minutes. Find your heart rate in beats per minute (BPM) by taking your radial pulse. Count the beats while your partner times 30 seconds on the stop watch or clock. Multiply this number by two to find your BPM and record in cell B2.
- Switch roles and have your partner find his/her heart rate. Record it in cell B3.
- Lie down on a lab table or the floor for one to two minutes until you are totally relaxed.
- Find your heart rate as you did before and record it in cell C2. Remain lying down.
- Rest for one to two minutes, then stand up quickly and immediately take your pulse. Record your BPM in cell D2.
- Switch roles and gather data for your partner recording in row 3.



2.9 Explain why your heart rate is lower when you are at rest.

Your muscles don't need as much oxygen when you are not moving as much.

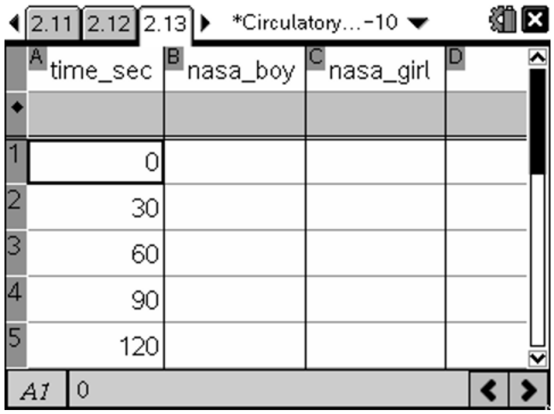
2.10 Why might you feel dizzy when you stand up quickly from a lying down position?

Blood rushes "down", away from your head, leaving you light-headed.

2.11 Why does your heart rate increase right after you stand up from a lying down position?

Gravity pushes blood to your lower body, and your heart needs to pump faster to return it to your upper body.

For this last piece of data collection, you will use a new spreadsheet, which can be found on the next page (2.13). Type your names at the top of columns B and C (in the cells that contain the letters B and C). You have created columns of data which are variables that can be graphed.



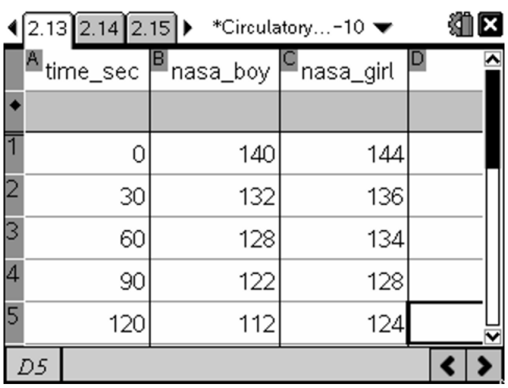
	A time_sec	B nasa_boy	C nasa_girl	D
◆				
1	0			
2	30			
3	60			
4	90			
5	120			

Do a step-test for 30 seconds. Step up with one foot followed by the other. Then down with one foot followed by the other. Repeat, maintaining a steady and consistent pace by using a four beat cycle saying, "up, up, down, down."

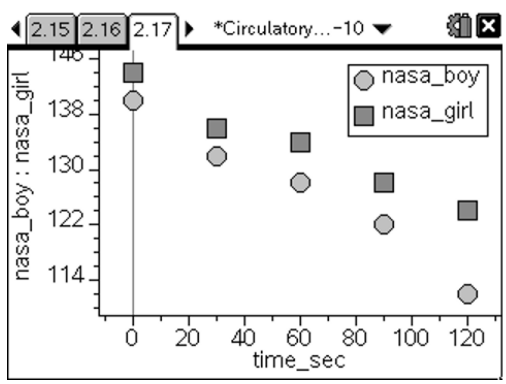
Find your heart rate five times following the step-test: immediately after you finish, after 30 seconds of rest, after 60 seconds of rest, after 90 seconds of rest and after 120 seconds of rest.

You may want to record this data on paper initially, then transfer the heart rates to the table on page 2.12 with your data in column A and your partner's in column B.

On the following page (2.17), you will find a Data and Statistics page. Move your cursor to the horizontal axis and add "time" as the independent variable. Now move your cursor to the middle of the vertical axis and select your name. Keep your cursor there, press **ctrl**, **menu**, select **Add Y Variable** and then select your partner's name. You should now see both sets of data plotted.



	A time_sec	B nasa_boy	C nasa_girl	D
◆				
1	0	140	144	
2	30	132	136	
3	60	128	134	
4	90	122	128	
5	120	112	124	



2.18 Describe the trend you see in the data for both you and your partner.

Answers will vary.

2.19 Why does your heart rate increase during exercise?

Your muscles need more oxygen and need to get rid of carbon dioxide.

2.20 What other physiological changes do you notice during exercise?

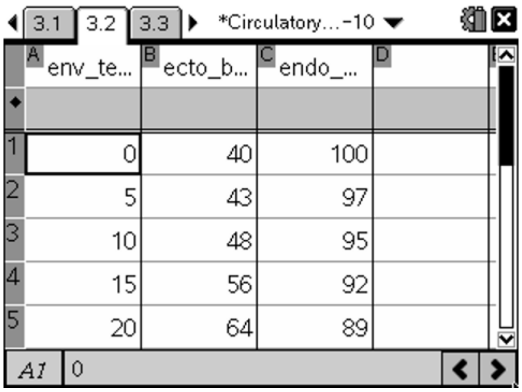
Increased breathing rate, flushed skin, perspiration, muscle fatigue, etc.

2.21 What factors could contribute to a lower heart rate during exercise and a faster recovery after exercise?

Level of fitness, intensity of the exercise, etc.

Lab Extension: Endothermic vs. Ectothermic Heart Rates (TI-Nspire pages 3.1-3.9)

The next page shows sample heart rates (beats per minute or BPM) for two different organisms at increasing environmental temperatures. Column A shows the temperature in °C. Column B shows BPM for an ectotherm, or "cold-blooded" animal, and Column C for an endotherm, or "warm-blooded" animal. Examine the data and then move to the page following the spreadsheet (3.3).



	A env_te...	B ecto_b...	C endo_...	D
◆				
1	0	40	100	
2	5	43	97	
3	10	48	95	
4	15	56	92	
5	20	64	89	

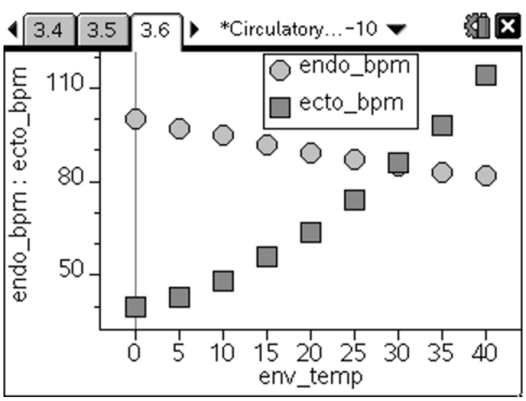
3.3 With respect to the environmental temperature, what trends do you see with the heart rates of the two animals?

Ectotherm: temp goes up, BPM goes up; Endotherm: temp goes up, BPM goes down.

3.4 Explain the trends.

Ectotherms' body temperatures depend directly on the environmental temperature. Endotherms' body temperatures stay relatively constant, but must increase in cold temperatures to offset heat loss.

Now graph the data on the Data and Statistics page that follows (3.6). Decide which variable is independent and which one is dependent. Plot both the ectotherm and endotherm data.



3.7 Based on your graph, are ectotherms or endotherms more affected by changes in the environmental temperature?

Ectotherms

3.8 Based on the data and the graph, when do you think ectotherms would need to eat more food?

Summer

3.9 When would endotherms need to eat more?

Winter

Lab Analysis (TI-Nspire pages 4.1-4.3)

As NASA looks into the future of spaceflight and human exploration, doctors and researchers continue to search for ways to reduce the health risks associated with spaceflight. As NASA continues to explore different environments with different gravitational forces, having solutions to the concerns that arise is vital to ensuring a healthy crew and a successful mission.

4.2 Hypothesize how the human circulatory system would be affected during long duration missions on the Moon (16.5% of Earth's gravity) and Mars (38% of Earth's gravity).

Since there is more gravity felt on the Moon and on Mars than in microgravity, these missions will have a proportionally smaller effect on the cardiovascular response including cardiac workload. Martian gravity would have less of an effect than lunar gravity.

4.3 Propose two countermeasures or interventions that could be used to maintain cardiovascular health on the missions referred to on page 4.2.

Answers will vary, but could include exercise and nutrition.

Primary countermeasures currently used by astronauts on orbit are cardio and resistance exercises performed daily. Studies are being done to look at intermittent artificial gravity using a human-rated short arm centrifuge. Lower body negative pressure suits which simulate some of the physiological effects of Earth gravity are also being tested.

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 Biology instructors.

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