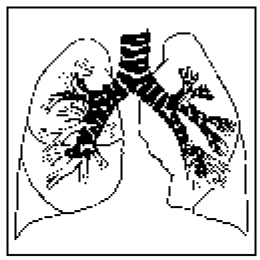
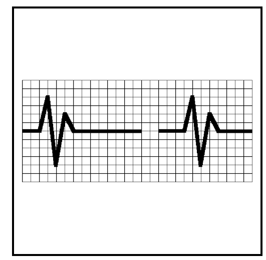
Physiology of Fitness

High School Level

The American Physiological Society






Developed by the San Diego, California Local Outreach Team

This classroom unit was developed as part of
the American Physiological Society's
Frontiers in Physiology project
by a Local Outreach Team
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Teacher's Guide

Introduction

This unit covers aspects of cardiovascular and respiratory physiology that are important in exercise and fitness. It is designed to provide students with a scientific basis for understanding "fitness" — especially why it varies between individuals, and how one can improve their fitness. The unit can be used as an integrative review of these topics, or selected activities could be used to introduce some of the topics. It was designed by a team of high school teachers and research physiologists to be useful for "Health" or "Physical Education" classes, as well as "AP Biology" or "Anatomy and Physiology" classes. However, it assumes a basic knowledge of the cardiovascular and respiratory systems as a prerequisite.

The unit utilizes the Learning Cycle approach (Karplus & Thier, 1967; Lawson, 1988), where various modules can be used to *engage* students in thinking about the topic(s); offer them opportunities to *explore* via hands-on and inquiry approach activities; *explain* their findings and how they relate to the concepts included in the unit; *elaborate* on the concepts; and *evaluate* students' understanding of the unit concepts.

The modules are designed to teach the students general physiological principles that are based on physical principles applied to living systems, and are suitable for coordinated science classes, linking physical and biological principles. An important educational objective of the unit is that students should be able to apply the general principles they learn for one organ system to a different system.

Suggestions for Teachers are provided for each module and provide the information necessary to teach the units. The Background Information section is designed to supplement the information available in any good physiology textbook used in high school or lower division college courses. **Boldfaced** terms typically can be found in the index of your textbook or other references, to help identify relevant sections of the text. The relationship of the *Physiology of Fitness* unit to the *National Science Education Standards* for content and teaching is outlined on the following page.

This unit was developed as part of an American Physiological Society program designed to form partnerships between scientists and teachers. Therefore, the units also can be used in consultation with research scientists, such as a university faculty member or pharmaceutical company researcher. The Education Officer of the American Physiological Society can assist you in making connections with physiologists in your area (301-530-7132; educatio@aps.faseb.org).

References

Karplus, R. & Thier, H.D. (1967). *A new look at elementary school science*. Chicago: Rand McNally.
Lawson, A.E. (1988). A better way to teach biology. *American Biology Teacher, 50 (5)*, p. 266-289.

Background Information

Themes and required student background

With the exception of Module #1, these modules assume that students already have been introduced to the basic structure of the cardiovascular system, including the pumping of the heart and the distribution function of the blood vessels and capillaries. One of the common themes throughout these modules is the application of physical laws to biological

Relationship of Physiology of Fitness Unit to National Science Education Standards for Content and Teaching

Selected Content Standards	*Physiology of Fitness*
Grades 5-8	
Structure and function in living systems	*
Regulation and behavior	*
Personal health	*
Risks and benefits	*
History and nature of science	*
Grades 9-12	
Matter, energy, and organization of living systems	*
Behavior (responses to stimuli)	*
Personal and community health	*
History and nature of science	*

Unit Activities	Pedagogy		
	Hands-On	Inquiry	Authentic Assessment
#1: What Do You Know About the Effects of Exercise?			*
#2: What Effects Does Exercise Have on YOU?	*		*
#3: How Does Exercise Affect the Cardiovascular System?	*	*	*
#4: The Elvis Experiment Papers	*	*	*
#5: Cardiovascular System and Exercise — What Do You Know?			*

systems. The “names” of the laws are only necessary to emphasize their historical roots in the physical sciences, or if the students have already learned the laws in another context. The students should be encouraged to understand that these same principles apply to flow of other “fluids” like water and gases, and even electrons, as well as biological systems. However, they should also note the difference between, for example, resistance in physiological systems and physical resistances like an electrical resistor. Unlike an electrical resistor, physiological resistance can be adjusted by reflexes and local mechanisms sensitive to metabolites.

The cardiovascular system — transport and mechanisms

The cardiovascular system is the integral link between oxygen transport, delivery, and utilization and is essential for life in all animal species. In people, the heart plays an important role in moving blood, loaded with oxygen, which is then consumed during cellular respiration. The response to exercise offers an unequaled opportunity to observe and learn about the physiological principles of oxygen transport and utilization. In this module, students can observe the effects of exercise on heart rate, cardiac output, blood pressure, and respiration.

Oxygen transport

Oxygen is “the fuel of life,” and it is necessary in increased amounts for increased activities like exercise. An important function of the cardiovascular system is to supply oxygen to metabolically active tissues like exercising muscle, thinking brains, kidneys that are actively pumping salts and waste products into and out of the blood, and even the heart muscle itself. Oxygen delivery by blood is greatly enhanced by the molecule, **hemoglobin**. Oxygen is carried in blood as the physically dissolved gas, and in chemical combination with hemoglobin. If we had no hemoglobin, we would need a cardiac output of almost 1000 liters/minute (versus a normal maximum of approximately 30 liters/minute) to deliver enough physically dissolved oxygen to support high rates of exercise!

The shape of the oxygen-hemoglobin equilibrium curve (blood O_2 dissociation curve) is advantageous for delivering oxygen to tissues. The arterial-venous O_2 difference can be greatly increased by only small decreases in arterial PO_2 (partial pressure, on the abscissa of an O_2 dissociation curve). It is advantageous to keep venous PO_2 high because it is the **partial pressure** of O_2 that drives **diffusive transport** of O_2 out of capillaries and into tissues. (Note: Fick’s first law of diffusion describes such diffusive transport in **tissue gas exchange**...and it’s the same Fick!)

The heart as a pump

Many physiological transport systems involve muscular pumps, for example, cardiac muscle in the heart, skeletal muscles of respiration, and smooth muscle in the stomach and intestine. The amount of materials these pumps can move depends upon 1) the pressure gradients they can generate to pump materials; and 2) the resistances they must overcome in blood vessels, airways, etc. In Module #4, students can test their theories about the relationships between flow, pressure, and resistance with a physical model.

The pumping of blood by the heart is known as **convective transport**, and the Fick Principle is used to quantify oxygen consumption. Basically, the Fick Principle states that the amount of oxygen consumed by active tissues is the difference between the amount of oxygen entering the tissues in arterial blood, and the amount of oxygen leaving the tissues in venous blood. It is actually the principle of the conservation of mass, or **mass balance**, applied to convective physiological transport systems. (see Modules #2 and #3). The important variables in this equation are the cardiac output (pump output) and arterial-venous O_2 concentration difference (input-output difference).

Most physiological pumps like the heart can increase their rate of delivery (or output) by increasing the frequency of contractions or the volume of contractions. In the cardiovascular system, cardiac output is dependent upon two variables, heart rate and stroke volume:

Cardiac output = (heart rate) (stroke volume)

A typical resting cardiac output is 6 liters/minute in humans and a typical resting heart rate is 50-70 beats/minute.

Therefore, a typical stroke volume would be:

6 liters/min = 70 beats/min (stroke volume)
stroke volume = .08 liters/beat (or 80 ml/beat)

Cardiac output may increase more or less than the increase in **heart rate**, because **stroke volume** may increase more or less. In exercise, for example, stroke volume increases progressively until about 60% of the maximum rate of oxygen utilization (or VO_2 max), and then further increases in cardiac output are achieved mainly by increased heart rate.

The flow of blood

The flow of blood through the blood vessels is analogous to the flow of current in an electrical system and follows the same principle, as described by Ohm's Law:

In an electrical system: Voltage = (current)(resistance)
In a hydraulic system: Pressure difference = (flow)(resistance)

Several factors contribute to the resistance to flow in a system, including the radius of the tube, the length of the tube, and the viscosity of the fluid. These relationships are summarized as **Poiseuille's Law**:

$$\text{Flow} = \frac{\text{P (pressure difference)(tube radius)}^4}{\text{8 (tube length)(fluid viscosity)}}$$

In Modules #2 and #3, students will use Poiseuille's law, along with Fick's Principle (see below) to predict how flow, pressure, and resistance are influenced by exercise.

Fick's Principle: Oxygen Uptake = (Cardiac Output)(Difference in O_2 Concentration between Vein and Artery)

Through the extension activity in Module #2, students can predict changes in blood pressure after exercise. Actual pressure will increase much less than this prediction, however, because peripheral vascular resistance **decreases** upon exercise. This is due to the flow of blood through capillaries that were unperfused or intermittently flowing when the person was at rest.

Interestingly, vascular resistance may actually **increase** in some vascular beds during exercise, for example, in the gut. This is homeostatic in terms of diverting blood away from a function such as digestion, that is not needed in a "fight or flight" response, and is an example of reflex control by the autonomic nervous system. See the table below for a summary of some of the cardiovascular changes which occur with exercise:

During mild exercise, the following changes will occur:		
Increases in...	Skeletal muscle blood flow	175% increase
	Mean arterial pressure	15% increase
	Systolic arterial pressure	50% increase
	Cardiac output	120% increase
	Heart rate	100% increase
	Stroke volume	20% increase
Decreases in...	Total peripheral resistance	50% decrease
No change in...	Diastolic arterial pressure	No change
	End-diastolic ventricular volume	No change

Adapted from Vander, A.J., Sherman, J.H., & Luciano, D.S. (1994). *Human Physiology: The Mechanisms of Body Function*. New York: McGraw-Hill, pg. 464.

Medical focus

Heart disease will decrease exercise capacity, that is VO_2 (Max), because it decreases the efficiency of the pump. A **heart attack** may damage cardiac muscle so stroke volume is diminished. However, cardiovascular disease frequently starts in the peripheral circulation, for example with **atherosclerosis**, or clogging of the arteries with cholesterol and fat. This serves to increase resistance to flow through the arteries. The effects of such changes in vascular resistance on blood pressure, and the efficiency of cardiac pumping, are explored in Module #4. Chronic increases in vascular resistance, termed **hypertension**, can cause **heart failure**.

Interestingly, the heart may actually **hypertrophy** (become larger) in an attempt to pump through vessels with greater resistance, but it actually becomes less efficient and, ultimately, fails from such enlargement. A weak heart cannot effectively pump blood so blood “backs-up” in the circuit, and venous pressure increases. This can lead to leakage of fluid out of capillary pores into the lungs or peripheral tissues (**edema**). It also stretches the heart and increases sarcomere length of the striated cardiac muscle, and can cause **congestive heart failure**. Less effective overlap of the **actin-myosin cross-bridges** decreases contractile function. High salt intake can cause fluid retention and increase blood volume, which can further stretch the heart.

In Module #4, students also explore the effect of **viscosity** on resistance. The most common cause of increased blood viscosity is an increased **hematocrit**. Increased production of red blood cells (**erythropoiesis**) occurs in response to low levels of oxygen in the blood. This occurs in normal subjects during **acclimatization** to high altitude, and in patients with lung diseases, often from smoking. It is also one of the adverse side effects of **blood doping** — attempts by athletes to increase their hematocrit by various methods.

Variability — Biological and experimental

Finally, some of the experiments here (such as Module #2) can be used to describe the contribution of biological variability between different individuals, and experimental variability due to imperfect measurement techniques, to different results from different lab groups. Biological variability includes gender differences, genetic differences, and differences due to training. This is the kind of difference you look for when you grade tests on a Normal curve. Experimental variability can occur, for example, when different periods of time are used to count heart rate. Consider what would happen if you only counted heart rate for the average duration of a single beat - sometimes you’d get a beat, but others you may not, and your calculated heart rate could vary from 0 per min to the true value (usually 50 to 70 beats per min)! The longer the period of data collection the more likely we are to obtain an accurate measurement. A normal shaped curve usually describes random variation of experimental nature, too. This is known as the Gaussian curve, named after the astronomer and mathematician, Gauss. He noticed that the coordinates of stars he observed on sequential nights seemed to fit a normal shaped curve and he explained this as a result of imperfections in his telescope sighting methods.

Suggestions For Teachers

Module #1 *(Engage)*
What Do You Know About the Effects of Exercise?

Purpose
Engage students in exploring the effects of exercise on human physiology

Objectives
1. Engage students in making observations about how strenuous exercise affects respiration, heart rate, and blood flow.
2. Allow students to connect their own experiences in the effects of exercise on their cardiovascular and respiratory systems to the observations they make.
3. Assess students' current understanding and possible misconceptions about the effects of exercise on the cardiovascular and respiratory systems via analysis of initial KWL responses.

Materials and Methods
- copy of the My Health Lifestyle Inventory for each student
- VCR and monitor
- clips from television, movies, interviews, etc. of persons at rest and persons engaged in heavy exercise (preferably aerobic exercise such as long-distance running, not short-term, anaerobic exercise such as the 100 meter dash — good possibilities would be clips from the most recent Olympics, a school track meet or training session, or a movie with sports competition, such as a basketball game)
- KWL ("What I Know, What I Want to Know, What I Learned") chart materials for groups of 3-4 students (poster board, Post-It® notes, markers or pens...see Student Handout)

Procedure
1. Ask students to complete the My Health Lifestyle Inventory as pre-homework at the beginning of the unit and to hold the Inventory for Module #5 (evaluate). We do not recommend collecting the inventory since it includes personal questions about the student. Encourage students to answer the questions honestly.
2. To initially engage students in the unit, they will make some observations about differences they can see and/or hear between persons at rest and persons engaged in strenuous exercise. After you tell students to make observations, show a 1-3 minute video clip of persons at rest and then a 1-3 minute video clip of persons engaged in strenuous exercise. We have found that this works especially well if the clips are shown the first time without sound, students are asked to write down some of their observations, and then show the clips again with sound to see if they can make any additional observations.
3. Divide students into groups of 3-4 to generate the KWL chart described on the student handout. They should put their names on the back of the board. The KWL can be used as an initial assessment tool to determine students' understanding about cardiovascular and respiratory responses to exercise and is an excellent way to identify students' misconceptions and their questions. Posters can be hung on bulletin boards so students can refer to them throughout the unit. NOTE: Concept maps can be substituted for the KWL chart.

Safety Issues
None.

Suggestions for Assessment

Use the KWL charts to check for student misconceptions and to provide a baseline assessment of student understanding of the unit concepts.

References and Resources

Karplus, R. & Thier, H.D. (1967). *A new look at elementary school science*. Chicago: Rand McNally.
Lawson, A.E. (1988). *A better way to teach biology*. American Biology Teacher, 50(5), 266-289.
U.S. Department of Health and Human Services. (1981). *Healthstyle: A Self-test*. DHHS Publication No. (PHS) 81-0155. Washington, DC: U.S. Department of Health and Human Services, Public Health Service.

Student Activity Sheet

Module #1
What Do You Know About the Effects of Exercise?

Materials

- pen/pencil
- poster board (1 sheet per group)
- Post-It® notes

Procedure

- Using the poster board and stick-on notes, work with your group to develop a "KWL" chart (complete the first 2 columns **only**) describing what you know about how exercise affects the cardiovascular and respiratory systems (heart, blood, blood vessels, lungs, etc.), and what you would like to know. See the example below:

How Exercise Affects My Heart, Blood, Blood Vessels, and Lungs		
What I Know	What I Want to Know	What I Learned

My Health Lifestyle Inventory

Directions

Complete each section of the inventory. Circle the number that corresponds to the answer that BEST describes your behavior. Then add the numbers you have circled to determine your score for that section. Write the score on the line provided at the end of each section. The highest score you can get for each section is 10.

	Almost Always	Sometimes	Almost Never
I. Cigarette Smoking, Drugs, and Alcohol If you never smoke or use drugs or alcohol, enter a score of 10 for this section and go to Section II.			
1. I avoid smoking cigarettes.	2	1	0
2. I smoke only low tar and nicotine cigarettes (if you do not smoke, mark "2").	2	1	0
3. I avoid drinking alcoholic beverages.	2	1	0
4. I avoid using alcohol or other drugs (especially illegal drugs) as a way of handling stressful situations or the problems in my life.	2	1	0
5. I read and follow the label directions when using prescribed and over-the-counter drugs.	2	1	0
CIGARETTE SMOKING, DRUGS, AND ALCOHOL SCORE			
II. Eating Habits			
1. I eat a variety of foods each day, such as fruits and vegetables, whole grain breads and cereals, lean meats, dairy products, dry peas, and beans.	4	1	0
2. I limit the amount of fat, saturated fat, and cholesterol I eat.	2	1	0
3. I limit the amount of salt I eat by cooking with only small amounts, not adding salt at the table, and avoiding salty snacks.	2	1	0
4. I avoid eating too much sugar (especially frequent snacks of sticky candy or soft drinks).	2	1	0
EATING HABITS SCORE			
III. Exercise and Fitness			
1. I maintain a desired weight.	3	1	0
2. I do vigorous exercises for 15-30 minutes at least 3 times a week (such as running, walking, swimming, or aerobics).	3	1	0
3. I do exercises that enhance my muscle tone for 15-30 minutes at least 3 times a week (such as yoga).	2	1	0
4. I use part of my leisure time to participate in individual, family, or team activities that increase my level of fitness.	2	1	0
EXERCISE AND FITNESS SCORE			
IV. Stress Control			
1. I have a job, attend school, or do other work that I enjoy.	2	1	0
2. I find it easy to relax and express my feelings freely.	2	1	0
3. I recognize early, and prepare for, events or situations likely to be stressful for me.	2	1	0
4. I have close friends, relatives, or others whom I can talk to about personal matters and call on for help when needed.	2	1	0
5. I participate in group activities (such as church and community organizations) or hobbies that I enjoy.	2	1	0
STRESS CONTROL SCORE			
V. Safety and Health			
1. I wear a seat belt while riding in a car.	2	1	0
2. I avoid riding with anyone under the influence of alcohol and other drugs.	2	1	0
3. I only ride with persons who obey traffic rules and the speed limit when driving.	2	1	0
4. I am careful when using potentially harmful products or substances (such as household cleaners, poisons, and electrical devices).	2	1	0
5. I get at least 7-8 hours of sleep a night.	2	1	0
SAFETYANDHEALTHSCORE			

What Your Scores Mean to You

Section Scores of 9 and 10 - Excellent! Your answers show that you are aware of the importance of this area to your health. More importantly, you are putting your knowledge to work for you by practicing good health habits. As long as you continue to do so, this area should not pose a serious health risk. It's likely that you are setting an example for your family and friends to follow. Since you got a very high score on this part of the test, you may want to consider other areas where your scores indicate room for improvement.

Section Scores of 6 to 8 - Good. Your health practices in this area are good, but there is room for improvement. Look again at the items you answered with a "Sometimes" or "Almost Never." What changes can you make to improve your score? Even a small change can often help you achieve better health.

Section Scores of 3 to 5 - Your health risks are showing! Would you like more information about the risks you are facing and about why it is important for you to change these behaviors? Perhaps you need help in deciding how to successfully make the changes you desire.

Scores of 1 to 2 - Obviously, you were concerned enough about your health to take the test, but your answers show that you may be taking serious unnecessary risks with your health. Perhaps you are not aware of the risks and what to do about them. You can easily get the information and help you need to improve, if you wish.

Adapted from *Healthstyle: A self-test.* DHHS Publication No. (PHS) 81-50155. Washington, DC: U.S. Department of Health and Human Services, Public Health Service.

Suggestions for Teachers

Module #2 *(Explore)*
What Effects Does Exercise Have on YOU?

Purpose
To explore the responses of the heart and blood pressure to exercise.

Objectives
1. To learn how to take a pulse and blood pressure reading
2. To learn how heart rate responds to exercise
3. To learn how blood pressure responds to exercise

Materials
- 16" high bench or step
- blood pressure cuff (sphygmomanometer)
- stethoscope
- graph paper, poster board, or overhead transparencies to make heart rate and blood pressure graphs

Procedure
1. Students should work in groups of three.
2. Practice taking your or a colleague's pulse before the lesson (see Diagram #1).
3. Practice taking a colleague's blood pressure before the lesson (see Diagram #2).
4. You will find that it is easier for students to take pulse and blood pressure readings if all groups start and stop the step test at the same time...the room must be quiet while readings are being taken.
5. You may modify the step test to fit your particular situation. For example, we have done the step test on choir risers, bleachers, and building steps. If the step test is not feasible, an alternate exercise could be substituted. However, if you do not use the step test, student numbers are not as accurate for the extension activity in Module #3.

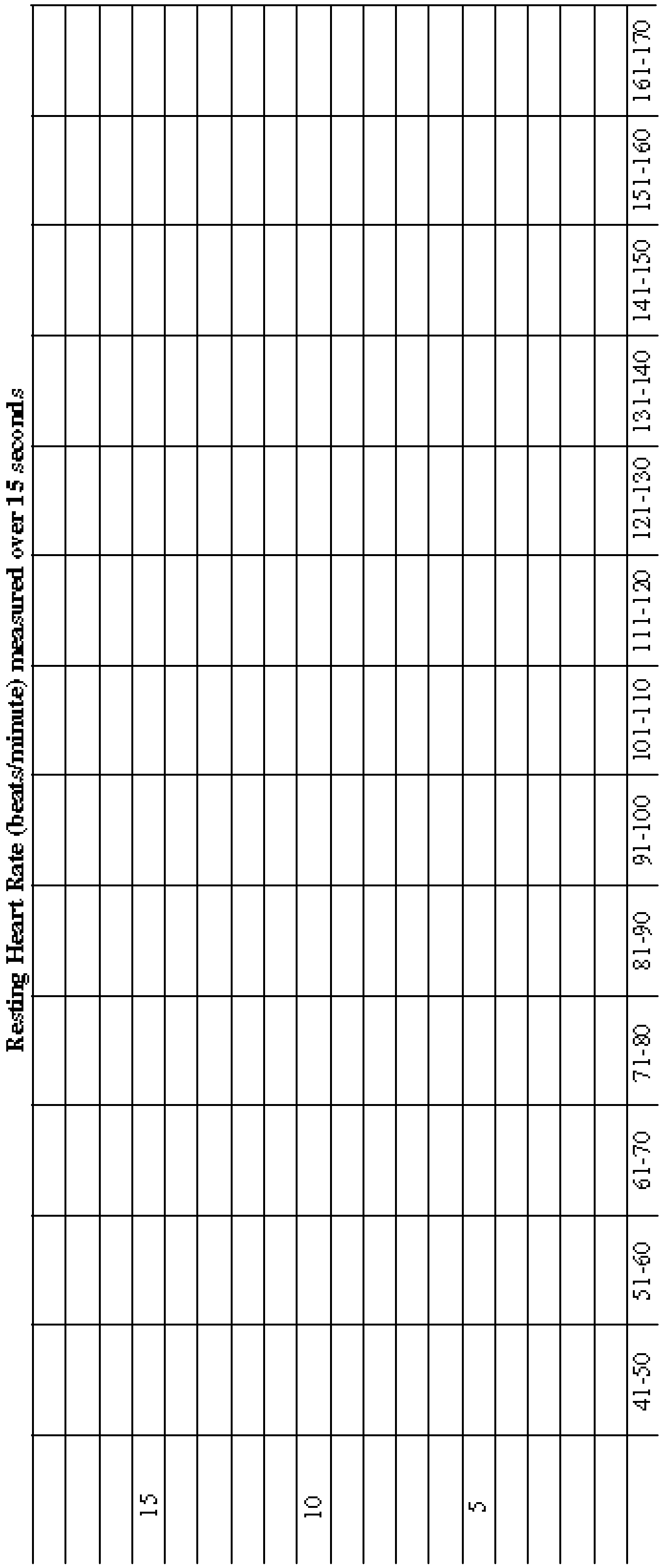
Safety
Students should NOT take the pulse at the carotid artery in the neck. You may want to get parental permission slips for students participating in the step test. This is a relatively strenuous activity in which all students may be unwilling or unable to participate. The more athletic students in your class should have no difficulty with the activity. Be sure to have at least one student in each group designated as a "spotter" in case the step tester stumbles.

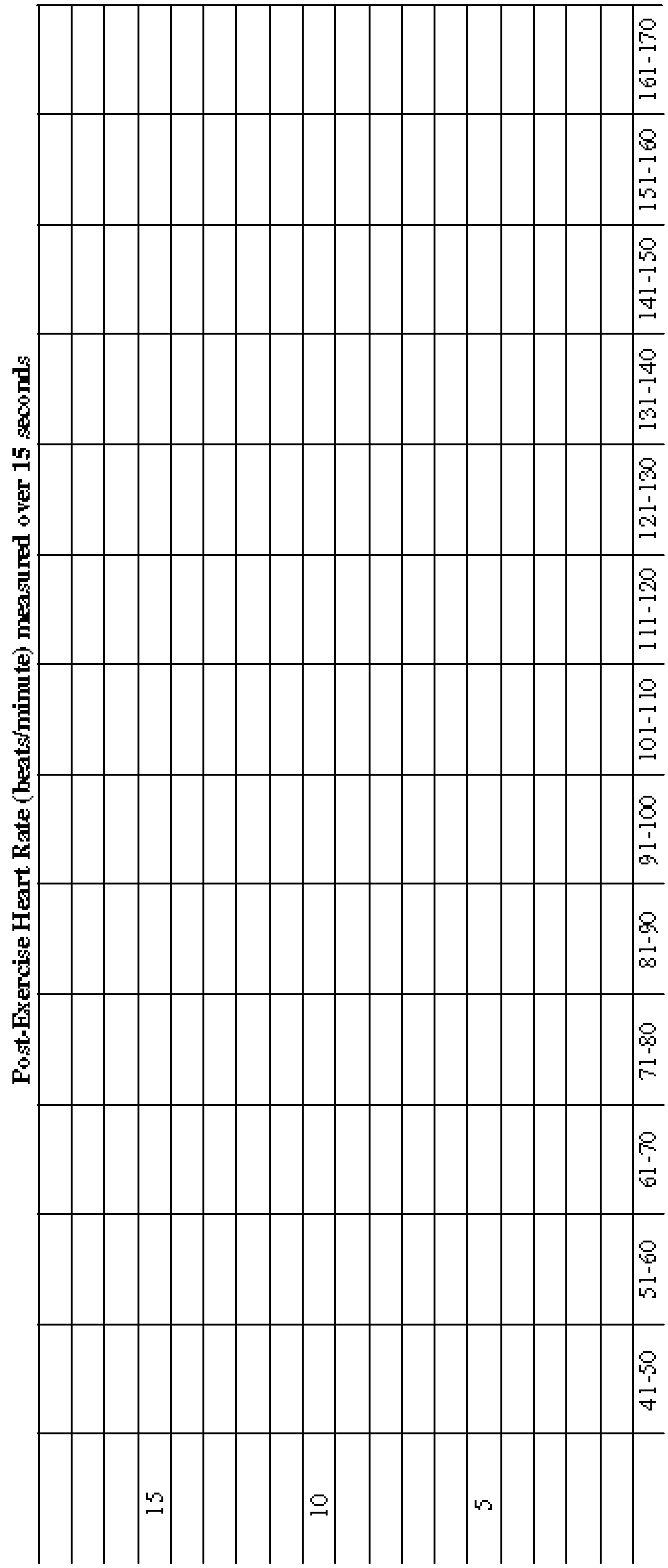
Suggestions for Assessment
Groups can turn in the answers to their analysis questions or can write a complete laboratory report.

References and Resources
McArdle, W.D., Katch, F.I., & Katch, V.L. (1991). *Exercise Physiology (3rd edition)*. New York: Lea & Fedger.

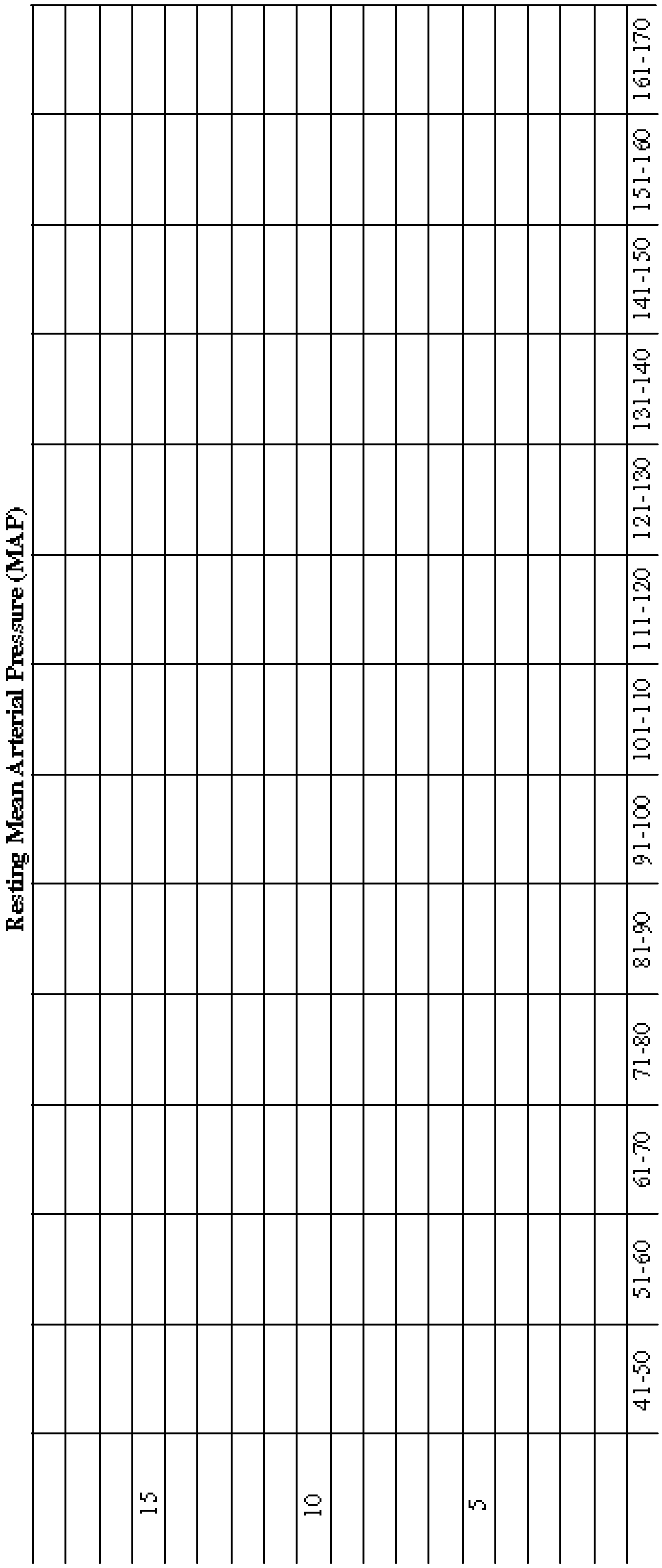
Vander, A.J., Sherman, J.H., & Luciano, D.S. (1994). *Human Physiology: The Mechanisms of Body Function (6th edition)*. New York: McGraw-Hill, Inc.

Transparency Master 2.1





Transparency Master 2.2



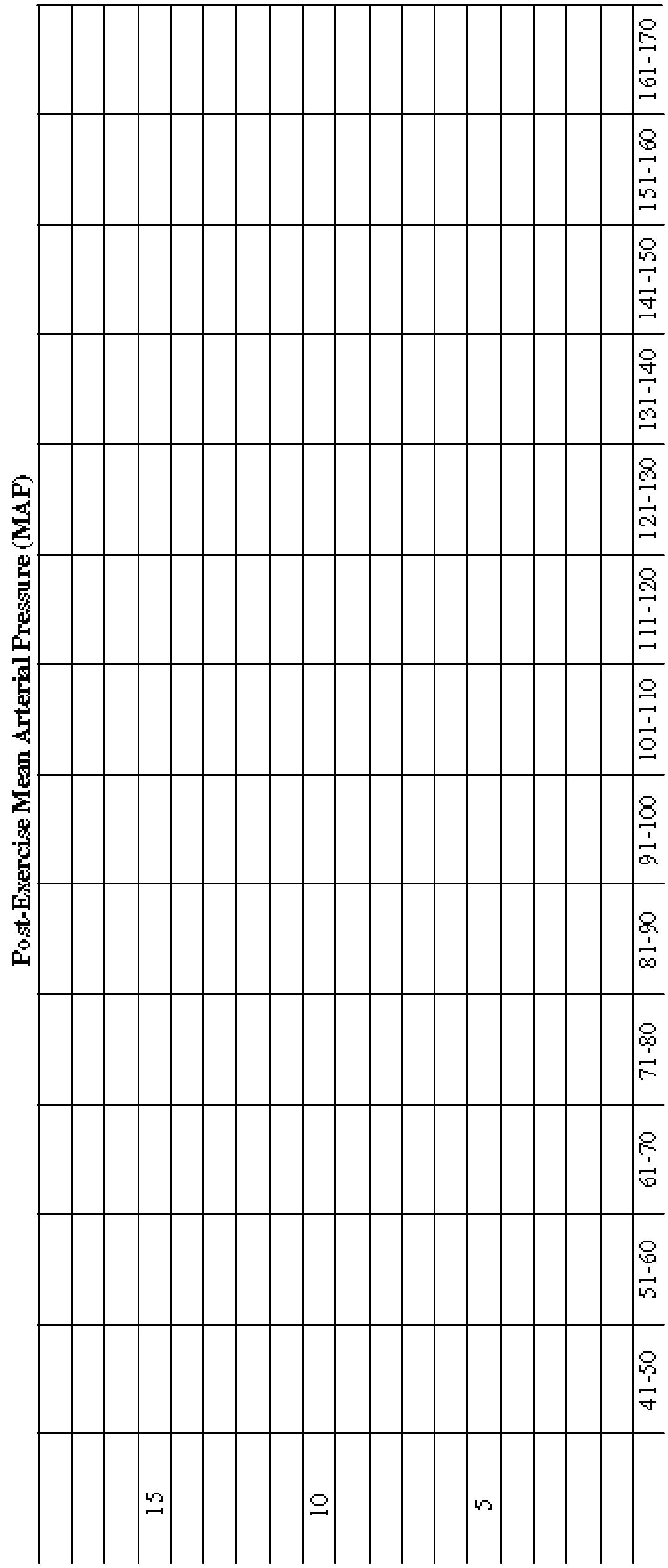
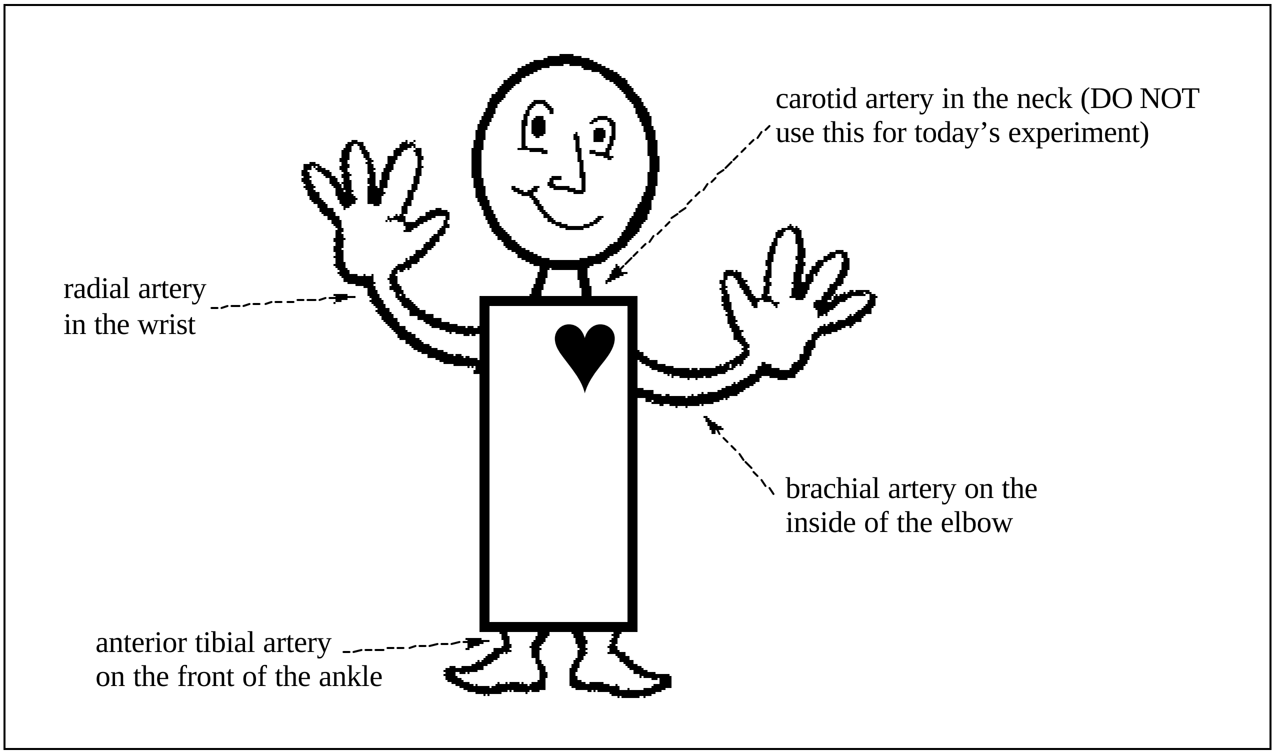


Diagram 1, Part 1

How To Measure Your Pulse or Heart Rate

Method:
1. Feel with your fingertips of your index and middle fingers for your pulse point until you detect pulsations.
2. Keep yourself as still as possible while you are taking your heart rate.



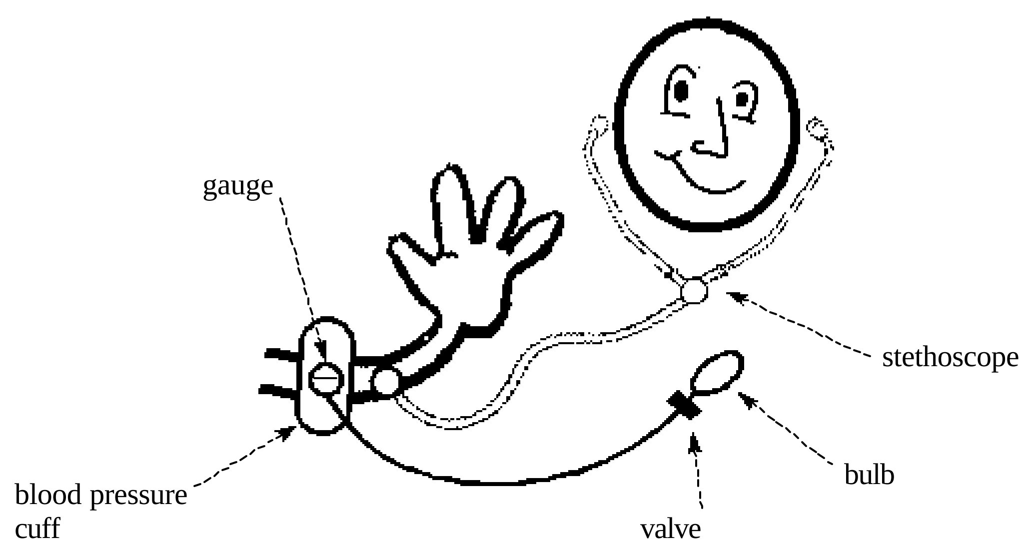
3. Count the number of heartbeats you feel in the time period on your data chart. Record the results.
4. Try repeating steps 1-3, measuring your heart rate at a different pulse point.

Adapted from Runyan, P. K.. (1997). Factors affecting blood pressure and heart rate. *Works in Progress 1997*, Bethesda, MD: The American Physiological Society.

Diagram 1, Part 2

How To Measure Your Blood Pressure

Method:
1. Student patient should extend arm on table with palm up.
2. Place blood pressure cuff above the bend in the arm. The cuff should be snug but yet have enough room to insert two fingers.



3. Check to see if valve is open or closed. It should be closed.
4. Place stethoscope eartips into ears.
5. Position stethoscope on arm to hear pulse.
6. Pump pressure up to 180 mm.
7. Release valve slowly.
8. The first pulse sound you hear as you release the valve is the **systolic pressure**. Have the student patient put his/her finger on the number of the first sound to mark the spot.
9. Continue to release the valve slowly. Approximately 40 mm down from the first sound, you will hear the second sound. The second sound you hear is the **diastolic pressure**.
10. Record the systolic and the diastolic pressure on the data chart.

Adapted from Runyan, P. K.. (1997). Factors affecting blood pressure and heart rate. *Works in Progress 1997*, Bethesda, MD: The American Physiological Society.

Student Activity Sheet

Module #2
What Effects Does Exercise Have on YOU?

Background Information
The cardiovascular system is the important link between the transport of oxygen from the lungs to other parts of the body, its delivery to tissues, and its use in those tissues. It is essential for life in ALL animal species. In humans, the heart plays an important role in moving blood, loaded with oxygen, which is then consumed during cellular respiration. The response to exercise offers an excellent opportunity to observe and learn about the physiological principles of oxygen transport and utilization. In this laboratory, you will be able to study the response of the heart and/or blood pressure to exercise.

Materials
- stopwatch or metronome
- 16” high bench or step
- blood pressure cuff (sphygmomanometer)
- stethoscope

Procedure
1. Do these activities in groups of three students. One student should volunteer to be the first experimental “subject.”
2. The “subject” should stand quietly at rest for a minute or two before you measure his/her pulse. Find your partner’s radial pulse (on the thumb side of the inner wrist) and count it for the times directed below. Then use the multiplication factor to calculate the number of beats per minute. If you have difficulty finding the pulse in the wrist, try the other arm and or the ankles. DO NOT take the pulse from arteries in the neck area. You should also measure your resting respiration rate (breaths/min.)

Count pulse for:	Record the count	Multiply by:	Heart beats per minute	Breaths per minute
60 seconds		x 1 =		
30 seconds		x 2 =		
15 seconds		x 4 =		
10 seconds		x 6 =		
6 seconds		x 10 =		

3. While still standing, measure the “subject’s” blood pressure using the stethoscope and blood pressure cuff. You should measure both the systolic and diastolic pressures. The systolic pressure is the pressure inside the artery when the heart is contracting and the diastolic pressure is the pressure inside the artery when the heart is refilling with blood. Record your findings below and calculate the subject’s Mean Arterial Pressure (MAP), using the following formula:

Mean Arterial Pressure = Diastolic Pressure + 1/3 (Systolic Pressure - Diastolic Pressure)
or
MAP = DP + 1/3(SP-DP)

4. Add your data to the charts which your teacher has provided and to the chart below:

Measurements taken:	15 second heart rate (x 4)	Systolic pressure	Diastolic pressure	Mean arterial pressure	Breaths per minute
At rest					
After exercise					

5. Now that you are good at finding and recording the pulse rate and blood pressure, you can perform the Physical Fitness Step Test which is used to predict a person's maximum O_2 uptake and observe acute physiological changes due to exercise. The subject should do the Step Test in the following way:

a) The subject steps at a rate of 22 steps per minute (female) or 24 steps per minute (males) for 3 minutes total. The other team members should "spot" for the subject in case he/she stumbles during the test.

b) After exercise, the subject remains standing. Wait 5 seconds (find the pulse during this time) and then begin counting a 15 second heart rate count at the radial artery (as you did before). Be prepared to count quickly since the rate will be faster than before! At the same time, the other team member should take the subject's blood pressure (on the arm opposite to the one where you are measuring the pulse).

c) Calculate the MAP after exercise using the following formula:

MAP = DP + 1/3(SP-DP)

d) Record your findings on the table above and calculate the ratio of the heart rate during exercise to the heart rate at rest (from the measurements you made in step #2 above) and the ratio of the MAP during exercise to the MAP at rest.

Analysis

1. What happens to the resting heart rate (in beats per minute) depending upon how long you take your measurements? Why could you get different answers for different measurement times?

2. Not everyone has the same resting heart rate. Add your data to a histogram of resting heart rate for everyone in the class. What might explain the variability in heart rate between individuals?

3. Cardiac output is the amount of blood moved by the heart. Cardiac output depends on both the rate the heart is beating and the volume of blood the heart moves with each beat (that is, the stroke volume). If a normal cardiac output is 5 liters/minute (when the person is at rest), use your resting heart rate to find out the stroke volume:

Cardiac output = (heart rate)(stroke volume)
5 liters/minute = (heart rate)(stroke volume)

What is your stroke volume? ___________________

4. What happens to the heart rate when you exercise? Why do you think it is important for this to occur?

5. Divide your post-exercise heart rate by your resting heart rate. How many times faster was your heart beating after exercise? (Example: If your resting heart rate=72 and your post-exercise heart rate=154, then: 154/72=2.1...or your heart was beating more than 2 times as fast after exercise).

6. If stroke volume remains constant (doesn't change), calculate your cardiac output after exercise. (Hint: Use the stroke volume you calculated in question #3 above). Remember:

$$\text{Cardiac output} = (\text{heart rate})(\text{stroke volume})$$

What is your cardiac output after exercise? ___________________

7. What happens to the Mean Arterial Pressure (MAP) when you exercise? Why do you think it is important for this to occur?

8. What happened to the systolic pressure when you exercised? What happened to the diastolic pressure when you exercised? How might you explain this difference?

9. As you look at your data, what other questions come to mind about how the cardiovascular system responds to exercise? Write your questions down...we'll be exploring your findings further in the next activity.

Go a little further!

Extension questions on flow, pressure, and resistance:

The flow of a liquid between two points in a tube (such as the flow of blood through an artery or vein) is related to the pressure difference between the points (delta P) and the resistance to flow. This can be represented as:

$$\textbf{Flow} = \frac{\textbf{Pressure Difference}}{\textbf{Resistance}}$$

Therefore, flow increases as the pressure difference increases and as resistance decreases. For our cardiovascular system, flow is **cardiac output** (in liters/minute) and the pressure difference is the **mean arterial pressure (MAP).**

Question 1:

If we assume that resistance (R) is constant, what would you predict would be your MAP <u>after</u> exercise?

Example:

If your resting heart rate is 70 beats/minute your heart rate after exercise is 130 beats/minute, and your resting MAP is 120 mmHg, then:

$Flow_{rest}$ = 5 liters/minute (see question #3)
$Flow_{exercise}$ = 11 liters/minute
ΔP_{rest} = 120 mmHg

Remember that:

$$\textbf{Resistance} = \frac{\textbf{Pressure Difference}}{\textbf{Flow}}$$

If we assume that resistance stays constant whether or not we exercise, we can use the data from our example this way:

$$\frac{\Delta P_{exercise}}{Flow_{exercise}} = R = \frac{\Delta P_{rest}}{Flow_{rest}}$$

$$\frac{\Delta P_{exercise}}{Flow_{exercise}} = \frac{\Delta P_{rest}}{Flow_{rest}}$$

$$\frac{\Delta P_{exercise}}{11 \text{ liters/min}} = \frac{120 \text{ mmHg}}{6 \text{ liters/min}}$$

$$\Delta P_{exercise} = 220 \text{ mmHg}$$

Now, try this with YOUR data. Using the cardiac output you calculated in question #6, what's your predicted MAP after exercise? __________

Finally, compare your predicted MAP to the actual MAP value you got in Module #2. Was your MAP higher or lower than you predicted?____________________

Question #2:

If your prediction did not prove true, then our assumption that the resistance was the same in both cases (rest and exercise) must be incorrect. This time, use your actual MAP (the reading you took in Module #2) to determine how vascular resistance responds during exercise. (Hint: Use the cardiac output (flow) that you calculated in question #6 along with the actual MAP you measured and the relationship between flow, resistance, and pressure difference.)

What is your conclusion? Does resistance increase or decrease during exercise?
Write at least two ideas you have of how resistance can decrease quickly in the cardiovascular system. (Remember these are hypotheses — just think about it and offer an idea).

Suggestions for Teachers

Module #3 *(Explain)*
How Does Exercise Affect the Cardiovascular System?

Purpose
Explain the relationship of exercise to the body tissues' need for oxygen and how the cardiovascular and respiratory systems respond to meet that need.

Objectives
1. To understand how increases in heart rate contribute to increases in cardiac output.
2. To estimate oxygen consumption by using Fick's Principle.

Materials
- egg carton
- bag of marbles, candies, or other small hard objects
- overhead transparencies

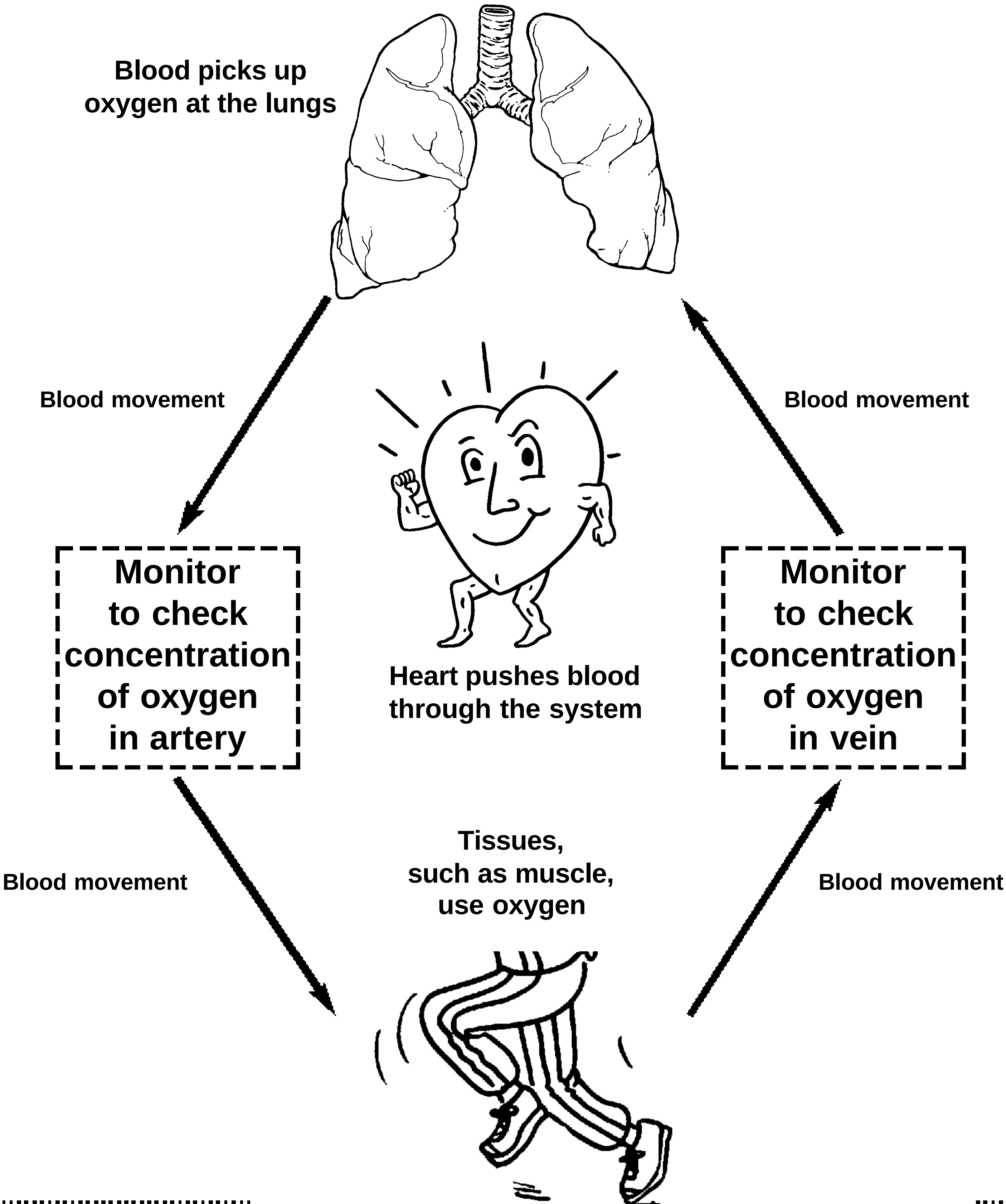
Procedure
Demonstration #1:

1. Recruit six students to assist with this demonstration. Each student has a particular role:

    Student #1 = Lungs, supplying blood with oxygen
    Student #2 = Oxygen monitor placed in an artery
    Student #3 = Muscle tissue which is using oxygen
    Student #4 = Oxygen monitor placed in a vein
    Student #5 = Blood carrying oxygen
    Student #6 = Heart - S/he drives the blood through the system.
    Marbles = Oxygen molecules

2. Position students around the room (as shown in Transparency Master 3.1)
3. Give the empty carton to Student #5.
4. Give the bowl or bag of marbles to Student #1.
5. Student #5 (Blood) begins at the Lungs (#1) and places one marble in each cup of the carton.
6. Heart (#6) pushes (gently!) the Blood toward the monitor in the Artery (#2).
7. Monitor (artery) (#2) counts the total number of marbles in the egg carton and remembers the number.
8. Heart (#6) pushes (gently!) the Blood toward Muscle Tissue (#3).
9. Muscle Tissue (#3) takes a few oxygen molecules from the egg carton and does not reveal the number. Note: S/he should only take a few the first time (1-6 pieces).
10. Heart (#6) pushes (gently!) the Blood toward the monitor in the Vein (#4).
11. Monitor (vein) (#4) counts the total number of marbles left in the egg carton and remembers the number.
12. Heart (#6) pushes (gently!) the Blood back to the Lungs (#1).
13. Blood replenishes it's supply of oxygen at the Lungs.

Transparency Master 3.1



Work through the following questions with the class:

- How many marbles were in the carton at the Artery? (Artery should report)
- How many marbles were in the carton at the Vein? (Vein should report)
- Therefore, how many marbles did the Muscle Tissue use? (Class should calculate; Muscle Tissue should confirm).

If we want to know how much oxygen is being used by the tissues, we can measure the concentration of oxygen in the artery and in the vein (normally measured in ml O_2 per 100 ml of blood) and calculate the difference. This will tell us the difference in concentration but not tell us the amount of oxygen being taken in and used by the tissue (called the “oxygen uptake”). What other information do we need? (Answer: Rate of blood flow, or “cardiac output”).

Oxygen Uptake = (Cardiac Output)(Difference in O_2 Concentration between Vein and Artery)

Example:
A typical cardiac output when a person is at rest is 6 liters of blood per minute (or in terms of milliliters, 6000 ml/min). If your difference in O_2 Concentration between Vein and Artery was 5 ml O_2/100 ml blood, then we’d calculate Oxygen Uptake this way:

Oxygen Uptake = (Cardiac Output)(Difference in O_2 Concentration between Vein and Artery)
= (6000 ml blood/min)(5 ml O_2/100 ml blood)
= (6000 ml blood/min)(5 ml O_2/100 ml blood)
= 300 ml O_2/min
= 0.3 liters O_2/min

This is the amount of oxygen being used by the tissues.

Demonstration #2: Responses to exercise

Continue with the following questions:

- If you begin to exercise (as you did in Module #2), what happens to the muscle tissues need for oxygen? (Answer: It increases).
- What are some ways that you could increase the amount of oxygen available to the tissues? (You should encourage many answers, including: 1) increase the amount of oxygen each red blood cell (RBC) carries; 2) increase the number of red blood cells in the circulatory system; 3) increase the heart rate so that more red blood cells go by the tissues in the same amount of time. 4) increase the stroke volume of the heart so that more red blood cells pass by the tissues in the same amount of time. Note: Write each idea down on the overhead transparency. Answers: 1) is not feasible...normal RBCs generally already carry their capacity of O_2; 2) actually occurs in many animals including horses and dogs...they have a reserve of RBCs in the spleen which are released during exercise for just this purpose — this does not happen in humans; 3) and 4) are the responses seen in most animals, including humans.)

Now demonstrate this process:

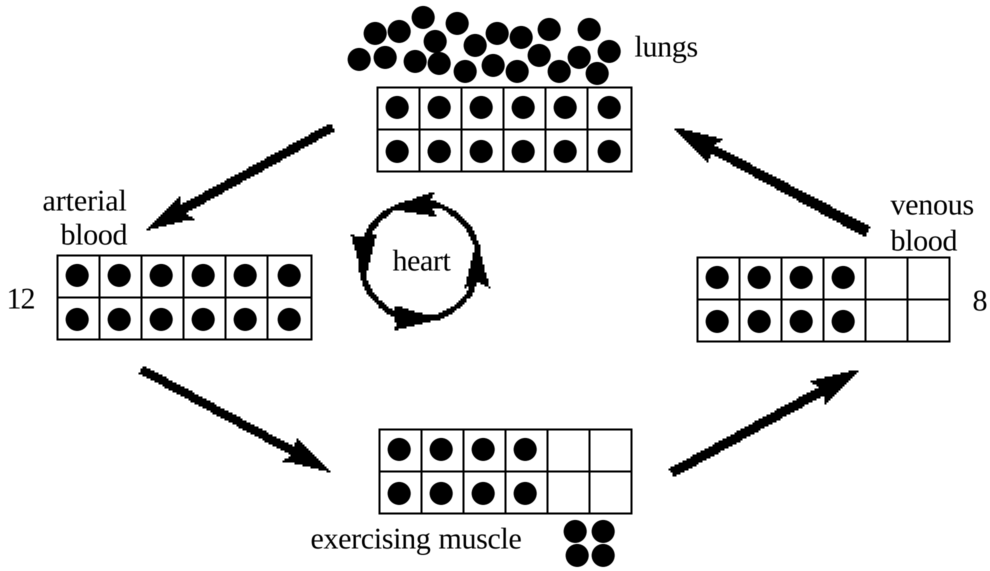
- Repeat steps 1-13 in Demonstration #1 several times, each time modeling one of the “ways” students proposed in the above question to increase the supply of oxygen to the muscle tissue. With each pass the muscle tissue should take more of the oxygen than s/he did in the first demonstration. After each demonstration, give feedback on whether the system works this way in humans or other animals. Give students opportunity to take “theatrical license” if possible, during this part of the demonstration! Use the following two overhead transparencies to review the process <u>after</u> you act it out.

Questions to Ask

- Is there a limit to this process? (Answer: Yes! Oxygen uptake has an upper limit. If you place a volunteer on a treadmill and, over time, keep increasing the slope on the treadmill (therefore, increasing the amount of work they have to do), you reach a point where their oxygen uptake can go no higher. No matter how hard the heart is working

Transparency Master 3.2

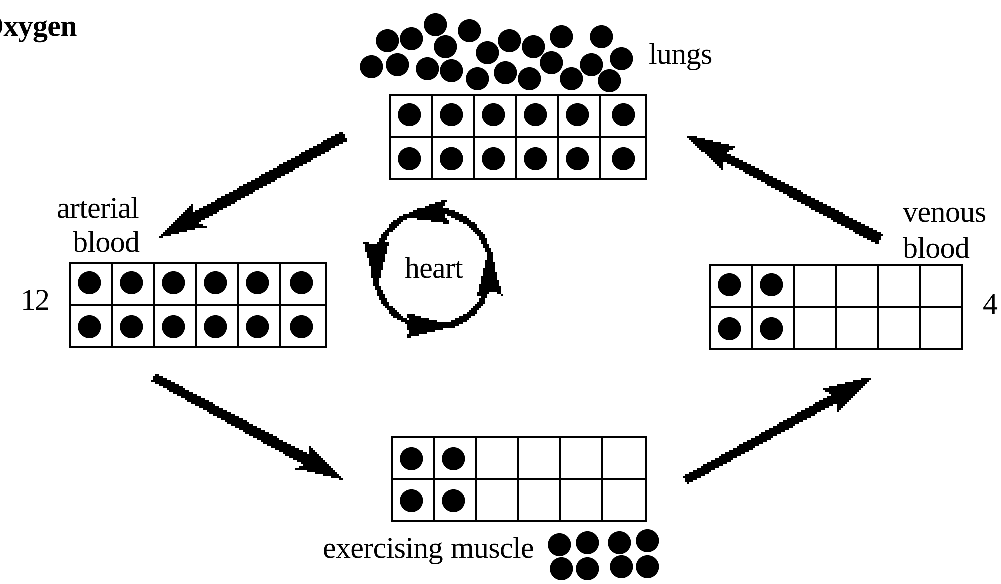
1. At Rest



Flow = 1 box per 20 seconds = 3 boxes per minute
Arterial-Venous Difference = 12-8 = 4 O_2
Oxygen consumption = 4 O_2 per 20 seconds = 12 O_2 per minute

Fick Principle: Oxygen consumption = (A-V) x Flow

2. Increase in Oxygen Extraction

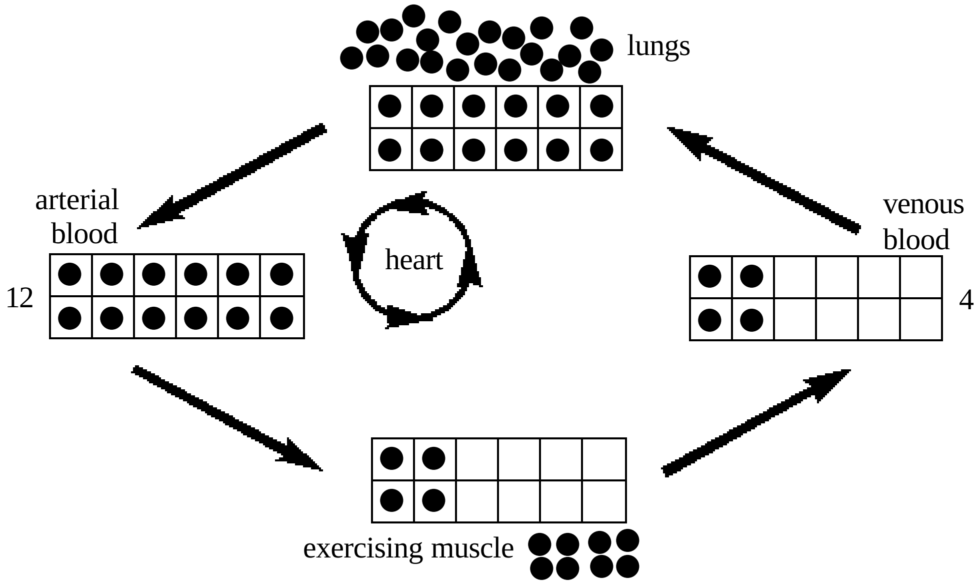


Flow = 1 box per 20 seconds = 3 boxes per minute
Arterial-Venous Difference = 12-4 = 8 O_2
Oxygen consumption = 8 O_2 per 20 seconds = 24 O_2 per minute

Diagrams courtesy of Richard W. Carruba, Brackenridge High School, San Antonio, TX, and San Antonio Local Outreach Team.

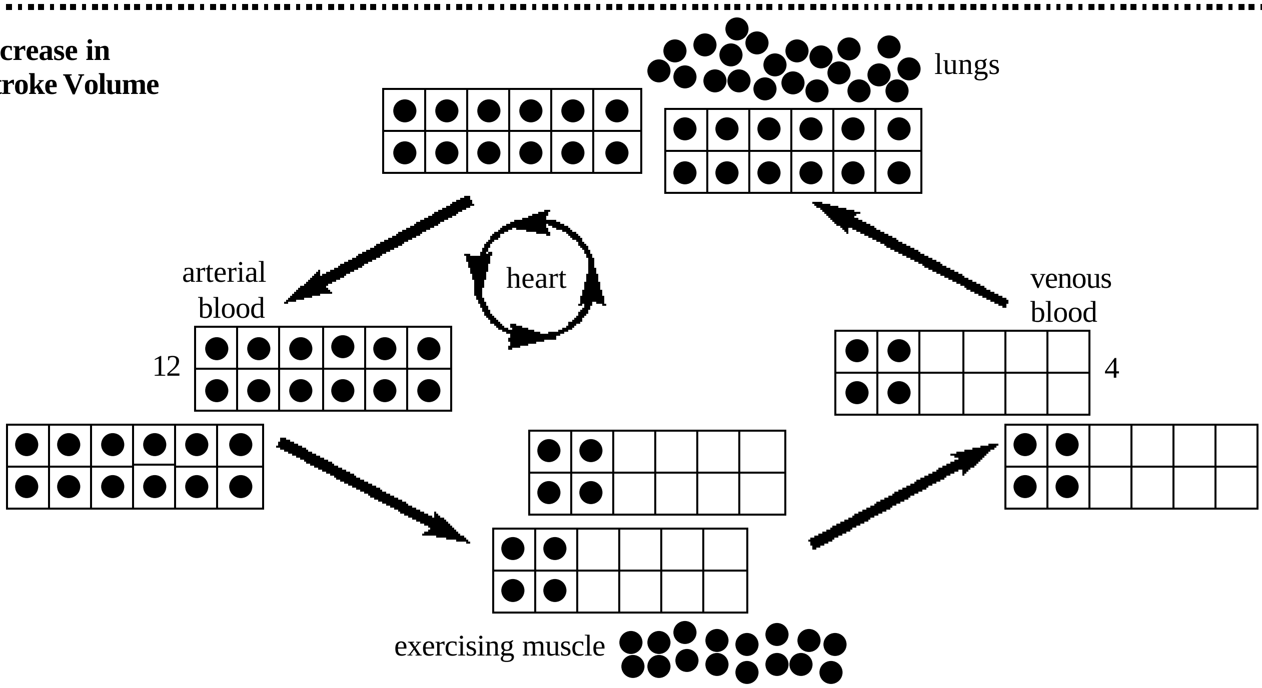
Transparency Master 3.3

3. Increase in Heart Rate



Flow = 1 box per 10 seconds = 6 boxes per minute
Arterial-Venous Difference = 12-4 = 8 O_2
Oxygen consumption = 8 O_2 per 10 seconds = 48 O_2 per minute

4. Increase in Stroke Volume



Flow = 2 boxes per 10 seconds = 12 boxes per minute
Arterial-Venous Difference = 24-8 = 16 O_2
Oxygen consumption = 16 O_2 per 10 seconds = 96 O_2 per minute

Diagrams courtesy of Richard W. Carruba, Brackenridge High School, San Antonio, TX, and San Antonio Local Outreach Team.

to get oxygen-carrying blood cells to the muscle tissue, the muscle can't absorb O_2 fast enough to supply the muscles (see Figure 2). Also, the volume of blood moved by each stroke of the heart decreases because the heart is beating so fast that the blood can't fill the heart chamber before the next contraction (beat) of the heart begins.)

Safety

Students should walk quickly during the demonstration, but not run. The "Heart" should lead or gently push the "Blood" along; jerking, dragging, or shoving are not allowed.

Suggestions for Assessment

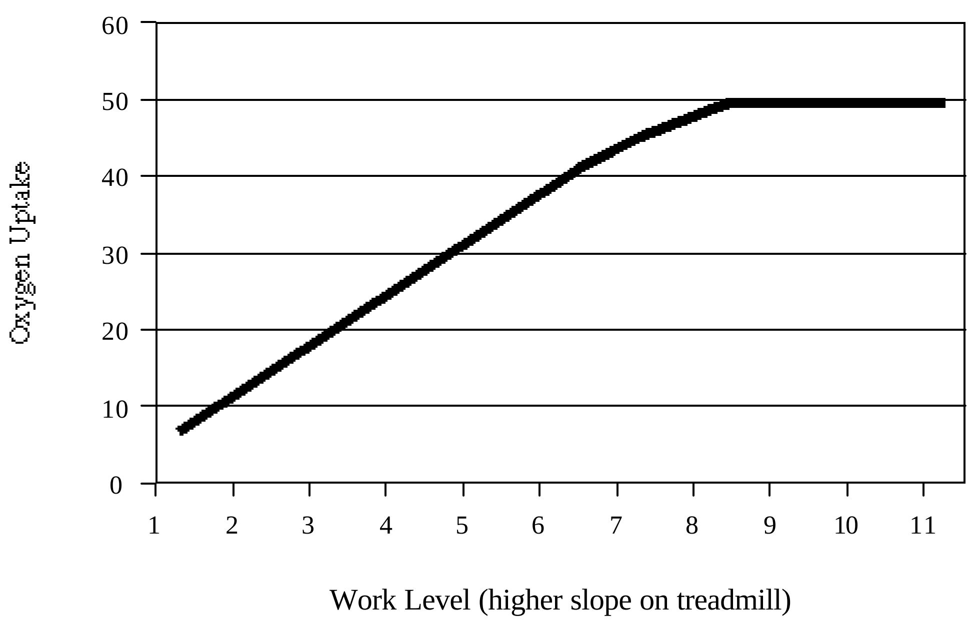
Ask students to calculate the oxygen uptake, given a set of arterial and venous measurements and a cardiac output rate provided by you. Ask students to design an experiment to determine the effects of three different types of exercise on oxygen uptake of tissues. See the extension activity on the following page.

References and Resources

Vander, A.J., Sherman, J.H., & Luciano, D.S. (1994). *Human Physiology: The Mechanisms of Body Function (6th edition)*. New York: McGraw-Hill, Inc.

Note: There is NO student handout for Module #3.

Figure 2



Go a little further!

Extension Questions:

As part of a special student team, you are designing a series of exercise physiology experiments for a future NASA shuttle mission. Some members of your team have expressed concern that, when one of the mission specialists is engaged in strenuous exercise during the experiments, the equipment that provides oxygen for the eight crew members may not be able to keep up with the need for oxygen on board the space craft. Your task is to do a preliminary estimate of the amount of oxygen needed per minute while one of the crew members is engaged in strenuous exercise.

Method: You can use the data you gathered in Module #2 to do an estimate.

1. Find your post-exercise heart rate from Module #2 data.
2. Using the chart below, find your Predicted Maximum VO_2, that is the maximum amount of oxygen being used per kilogram of body weight immediately after you stopped exercising.

What is your Max VO_2? _____________

Maximum Oxygen Consumption (Max VO_2)
Predicted from Heart Rate Measured 15 Seconds
After a 3 Minute Step Test in College Students

Post-exercise heart rate (women)	Predicted Max VO_2 (ml/kg*min)	Post-exercise heart rate (men)	Predicted Max VO_2 (ml/kg*min)
128	42.2	120	60.9
140	40.0	124	59.3
148	38.5	128	57.6
152	37.7	136	54.2
156	37.0	140	52.5
158	36.6	144	50.9
160	36.3	148	49.2
162	35.9	149	48.8
163	35.7	152	47.5
164	35.5	154	46.7
166	35.1	156	45.8
168	34.8	160	44.1
170	34.4	162	43.3
171	34.2	164	42.5
172	34.0	166	41.6
176	33.3	168	40.8
180	32.6	172	39.1
182	32.2	176	37.4
184	31.8	178	36.6
196	29.6	184	34.1

Adapted from McArdle, Pechar, Katch, and Magel. (1973). *Research Quarterly, 44*, p. 498.

3. **How much total O_2 were you using per minute?**

First, convert your body weight to kilograms. For example, if you weigh 110 pounds:

110 lb x .45 kg/lb = 49.5 kg

If your heart rate was 162 beats/min and your Max VO_2 was 35.9 (according to the table), therefore:

35.9 ml O_2/kg.min x 49.5 kg = 1777 ml O_2/min

4. Resting O_2 consumption is about 250 to 300 ml O_2/min. **How many fold did your O_2 uptake increase from rest to after exercise (your predicted VO_2)?** In the example above:

$$\frac{1777 \text{ ml } O_2/\text{min}}{300 \text{ ml } O_2/\text{min}} = 6 \text{ fold increase in } O_2 \text{ consumed per minute}$$

5. **If five shuttle crew members are at rest, and one is doing strenuous exercise, based on your calculation in #3 above, O_2 should be provided at at LEAST what rate to meet the needs of the crew?**

In the example above:

5 (250 ml O_2/min) + 1777 ml O_2/min = 3027 ml O_2/min...approximately 3 liters O_2/min)

Suggestions for Teachers

Module #4 *(Elaborate)*
The Elvis Experiment Papers

Purpose
To explore some of the factors which affect blood flow and blood pressure.

Objectives
1. To learn how the radius and length of a tube as well as the viscosity of the liquid flowing through it affects the flow rate of fluid through the tube (Poiseuille's Law).
2. To gain skills in experimental design.

Materials (1 per group unless otherwise noted)
- rubber or plastic tubing of various lengths and diameters (2 pieces per group)
- funnels that fit snugly into tubing (glass or plastic)
- straws
- water
- pancake syrup (full strength) or dark corn syrup diluted 1:1 (syrup:water)
- beakers of assorted sizes
- graduated cylinders
- spring clamps for tubing
- stopwatch or clock
- ring stand and clamps

Procedure
1. Prepare materials ahead of time and try a sample experiment for each of the three problems presented.
2. Divide the class into working groups of 2-4 students.
3. Assign each working group to one of the three problems.
4. Allow each group to design their experiment and get approval from you before proceeding.
5. For groups working on Problem 1, make sure they account for the effects of gravity on a column of fluid. Longer tubes can be looped around so that the vertical drop for both long and short tubes is the same. Alternately, the tubes can be supported horizontally rather than vertically.
6. Each group should present their results in the form of a table or graph. If desired, have each group prepare a poster to explain their hypothesis, methods, results, and conclusions and present it to the whole class.
7. Results should be shared with the class. **From the findings of your class**, go on to explain Poiseuille's Law. We encourage you to NOT USE the experiments to confirm or demonstrate Poiseuille's Law; rather let students' experimental findings lead to a discussion of Poiseuille's Law.
8. If time allows, have students thoroughly rinse tubes with warm water, especially those with syrup residue. If time does not allow, soak tubes and beakers in warm water. Clean promptly.
9. **Hints for Problem 1:** First, remember, Poiseuille's Law can be stated as:

$$\textbf{Flow} = \frac{\pi\ \textbf{(pressure difference)(tube radius)}^4}{\textbf{8 (tube length)(fluid viscosity)}}$$

Poiseuille's Law predicts that flow through a tube will decrease with increasing resistance for a constant pressure difference. We found it easiest to measure flow as the volume of liquid collected at the end of the tube during a measured time (liters/min) while liquid is continually poured into a funnel at the top of the tube. It is best to have the tube "primed" with fluid, and to clamp the tubing. Then start timing the flow when the clamp is released. It is also best to stop the flow at a measured time by reclamping (or bending) the tube, rather than waiting until all of the fluid has emptied from the tube. **Please note: This is ONE way to approach this problem...allow students to design their own experiments...do not prescribe one particular approach.** In Problem 1, the students should examine the effect of substituting tubes of different lengths with the same radius on the calculated resistance:

$$\textbf{Resistance} = \frac{\textbf{Pressure}}{\textbf{Flow}}$$

Keep track of units. You should be consistent, that is, will you measure in minutes or seconds, liters or ounces? The pressure difference driving flow is the difference in height between the top of the funnel and the end of the tube (in cm H_2O). Maintaining a constant pressure difference may require putting a loop or curve in longer tubes. The effect of the pressure difference on flow with a constant resistance can be studied by changing the distance between the ends of the tube. For example, a graph plotting flow versus pressure difference has a slope of 1/Resistance, in liters/(min.cm H_2O).

Although resistance is predicted to increase in direct proportion with tube length by Poiseuille's Law, it usually decreases less with this set up. This is because there are actually two resistances in series: the resistance to flow inside the tube, and the resistance to flow at the opening of the tube. This latter resistance involves turbulence, while Poiseuille's Law describes laminar (streamlined) flow. Even with this additional resistance, you will be able to demonstrate the dramatic difference between the effects of tube length and radius on resistance.

10. **Hints for Problem 2:** It is easy to demonstrate that changing the radius by a factor of two has a much greater effect on resistance than changing the length by a factor of two. It is much more difficult to "discover" the fourth power relationship of Poiseuille's Law, however. The important point is that the body regulates resistance, and the distribution of blood flow and arterial pressure, by this more efficient method. Vasoconstriction and vasodilation, not lengthening and shortening of the blood vessels, provide the rapid, reflex control of the circulation necessary for adjustments to activities like exercise and suddenly standing up.

11. **Hints for Problem 3:** The effect of viscosity on resistance is almost impossible to quantify in the teaching laboratory, but it is easy to show that resistance increases with viscosity. Note that viscosity is not linearly related to the concentration of syrup either. One clever group of students decided to make serial dilutions of syrup with water, and plot the resistance versus syrup concentration. The curve was very non-linear, in contrast to Poiseuille's Law which predicts a linear effect of viscosity on resistance. Bioengineering laboratories would use a viscometer to quantify fluid viscosity and Poiseuille's Law. The students are also assuming that the relationship between viscosity and syrup concentration is linear...which may not be true.

Safety

Students should wear safety goggles; take normal laboratory precautions.

Suggestions for Assessment

The initial experimental design submitted by each group for approval can serve as an assessment tool. Group posters and/or presentations also can be used for assessment. Go back to Module #3 — ask students to use their results from these experiments to recreate the flow model with the egg carton, but alter it to demonstrate how changes in vascular resistance can increase or decrease flow and therefore change the amount of oxygen available to the tissues.

References and Resources

Vander, A.J., Sherman, J.H., & Luciano, D.S. (1994). *Human Physiology: The Mechanisms of Body Function (6th edition)*. New York: McGraw-Hill, Inc.

Information for Students

Module #4
The Elvis Experiment Papers

Dear Friends:

Just before Elvis faked his death and went into hiding, his blood pressure was a mess. His arteries were full of cholesterol from too many fried peanut butter and banana sandwiches. Also, his heart muscle was thin and weak from lack of exercise and the extra salt also caused his body to retain water and increased the total volume of blood. Doctors told him that these factors would lead to a dangerous increase in blood pressure and heart failure, but Elvis did not trust them.

Elvis, worried that he would die if things did not change, secretly hired a group of teenage physiology students to perform experiments on factors that influence blood pressure. He trusted teens more than doctors. Elvis burned the reports after reading them and the rest is history.

What does all of this have to do with you? Elvis is writing a book to be released on the day he returns and wants to reconstruct the student reports for the chapter on why he faked his death. He has contacted your school and given your teacher the limited information he recalls about the experiments. For the honor of your school and to bring Elvis back, you develop and conduct the experiments on blood pressure described below.

Sincerely,
"Jon Burrows"

Materials

- rubber or plastic tubing of various lengths and diameters
- funnels
- straws
- water
- syrup
- beakers
- graduated cylinders
- spring clamps for tubing
- stopwatch or clock
- ring stand and clamps

Note: You may or may not need ALL of these materials!

Problem 1

Design and conduct an experiment to determine the relationship between the length of a blood vessel and the resistance to blood flow through it.

1. Describe the method you will use, through words and/or diagrams.
2. What were your results? Be sure to include numbers or a graph to describe your results.
3. What were your conclusions? How could your findings help Elvis understand his blood pressure?

Problem 2

Design and conduct an experiment to determine the relationship between the radius of a blood vessel and the resistance to blood flow through it.

1. Describe the method you will use, through words and/or diagrams.
2. What were your results? Be sure to include numbers or a graph to describe your results.
3. What were your conclusions? How could your findings help Elvis understand his blood pressure?

Problem 3

Design and conduct an experiment to determine the relationship between the viscosity ("thickness") of blood on the resistance to blood flow through it.

1. Describe the method you will use, through words and/or diagrams.
2. What were your results? Be sure to include numbers or a graph to describe your results.
3. What were your conclusions? How could your findings help Elvis understand his blood pressure?

Suggestions for Teachers

Module #5 *(Evaluate)*
Cardiovascular System and Exercise — What Do You Know?

Purpose
To evaluate student's acquisition of the concepts and skills developed through Modules #1-4.

Objectives
1. To identify and clarify students' misconceptions and areas of understanding.
2. To allow students to apply their knowledge to a real-life problem (My Health Lifestyle Inventory).

Materials
- KWL charts or concept maps completed by groups during Module #1 (have additional stick-on notes available)
- My Health Lifestyle Inventory (previously completed by student)

Procedure
1. Each group should re-assess their KWL chart. Are the concepts listed in column 1 correct? What have they learned in Modules 1-4?
2. Each group should finalize their chart for presentation to the whole class and/or submission to the teacher.
3. Each student should review his/her My Health Lifestyle Inventory and write down at least two things they are doing which contribute to his/her good health. Next, they should write down at least two things they could do to improve their good health (that is, to increase their overall score on the Inventory). These can be submitted to the teacher, if preferred.

Safety
None.

Suggestions for Assessment
The KWL chart can be used for assessment. Complete a My Health Lifestyle Inventory for a fictitious student. Ask students to note at least two things this student could do to improve his/her health (that is, to increase their overall score on the Inventory) and two things the student is currently doing which contributes to his/her good health. Students should be able to relate at least one of these items to something they know/learned about the cardiovascular system and/or exercise.

References and Resources
U.S. Department of Health and Human Services. (1981). *Healthstyle: A Self-test*. DHHS Publication No. (PHS) 81-50155. Washington, DC: U.S. Department of Health and Human Services, Public Health Service.

Note: There is NO student handout for Module #5.

PHYSIOLOGY OF FITNESS

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