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.

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.)

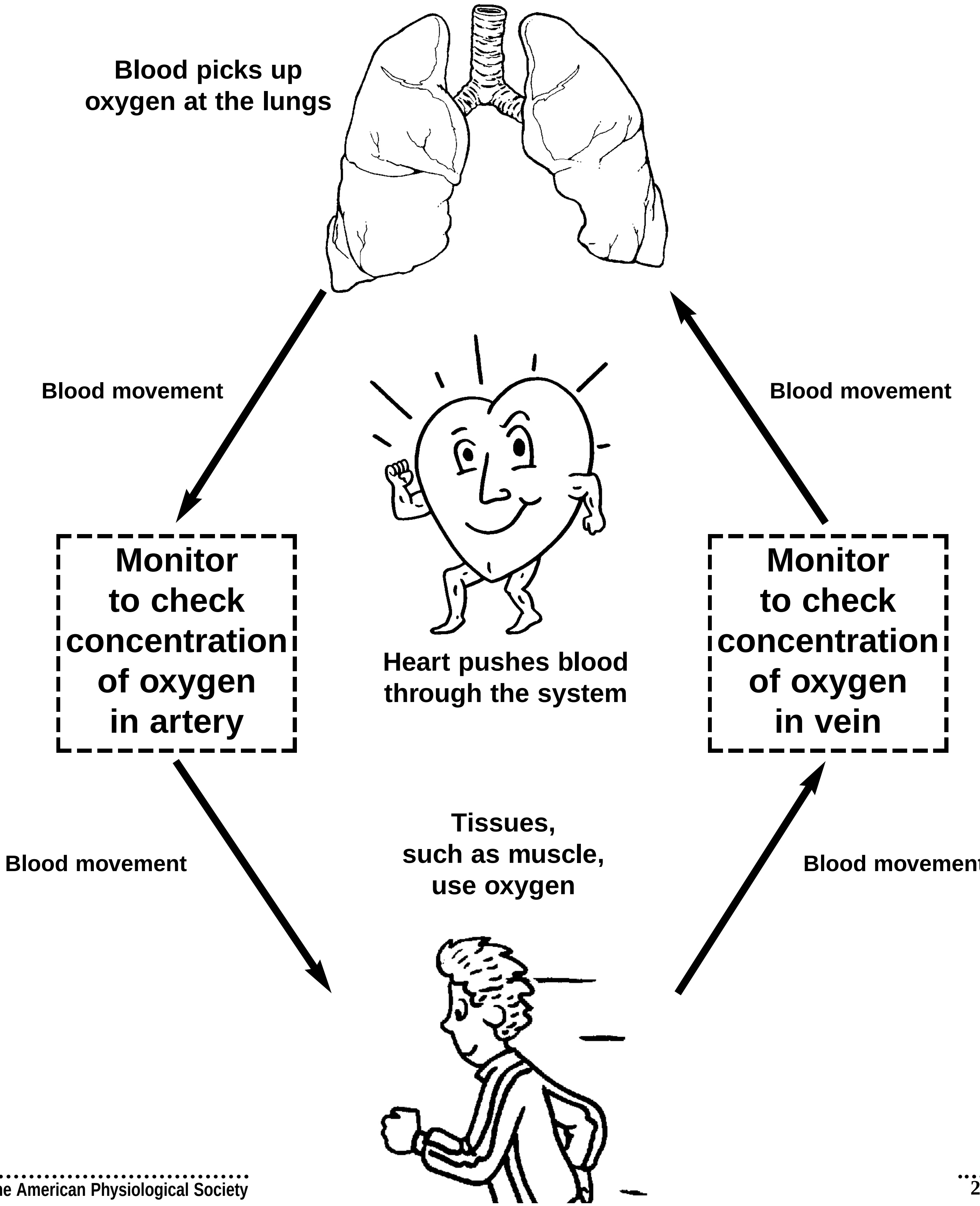
Now demonstrate this process:

- 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 after 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

Transparency Master 3.1



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 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

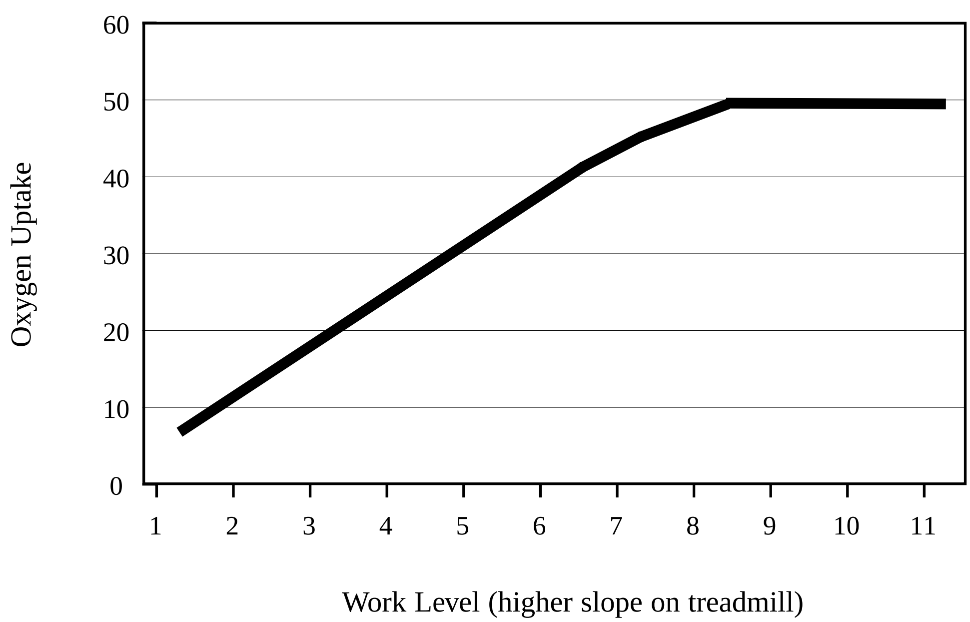
Ask students to calculate the oxygen uptake, given a set of arterial and venous measurements and a cardiac output rate provided by you. Ask students to design an experiment to determine the effects of three different types of exercise on oxygen uptake of tissues. See the extension activity on the following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

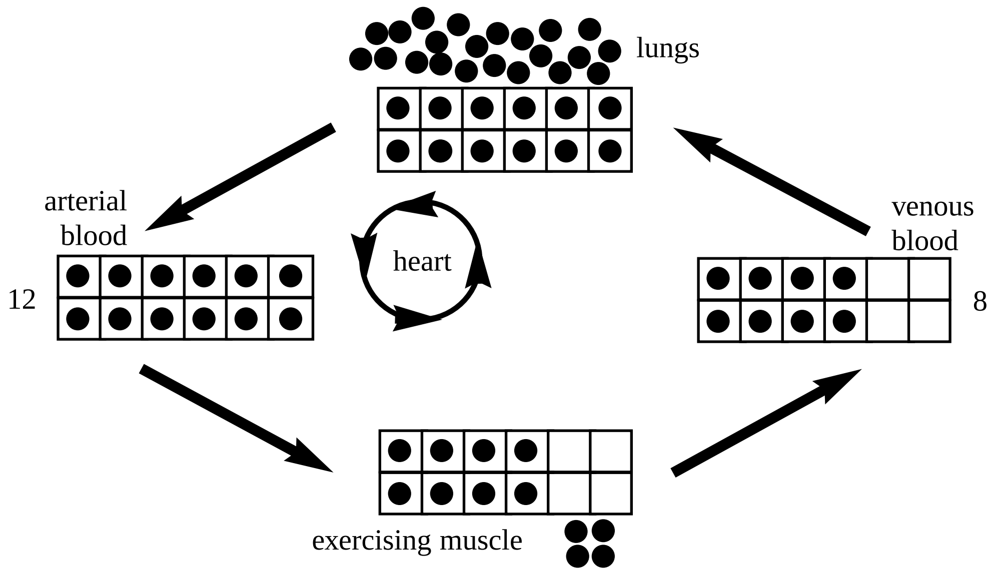
Note: There is NO student handout for Module #3.

Figure 2



Transparency Master 3.2

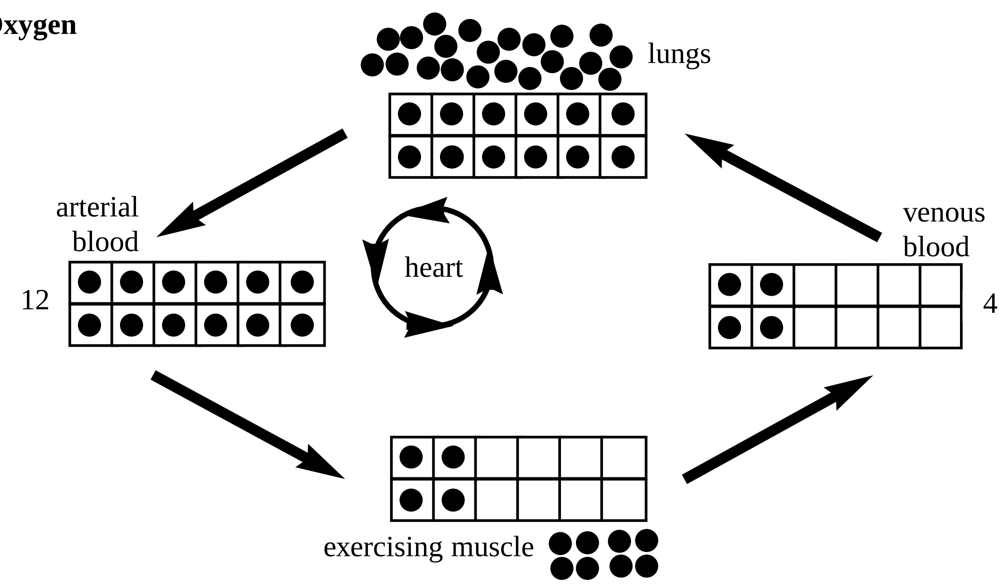
1. At Rest



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

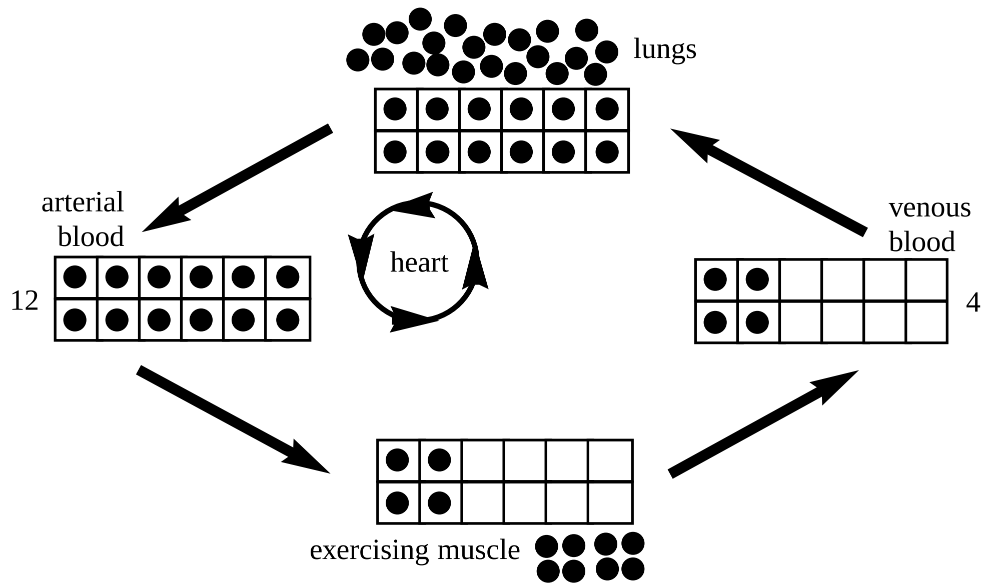


Flow = 1 box per 20 seconds = 3 boxes per minute
Arterial-Venous Difference = 12-4 = 8 O_2
Oxygen consumption = 8 O_2 per 20 seconds = 24 O_2 per minute

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

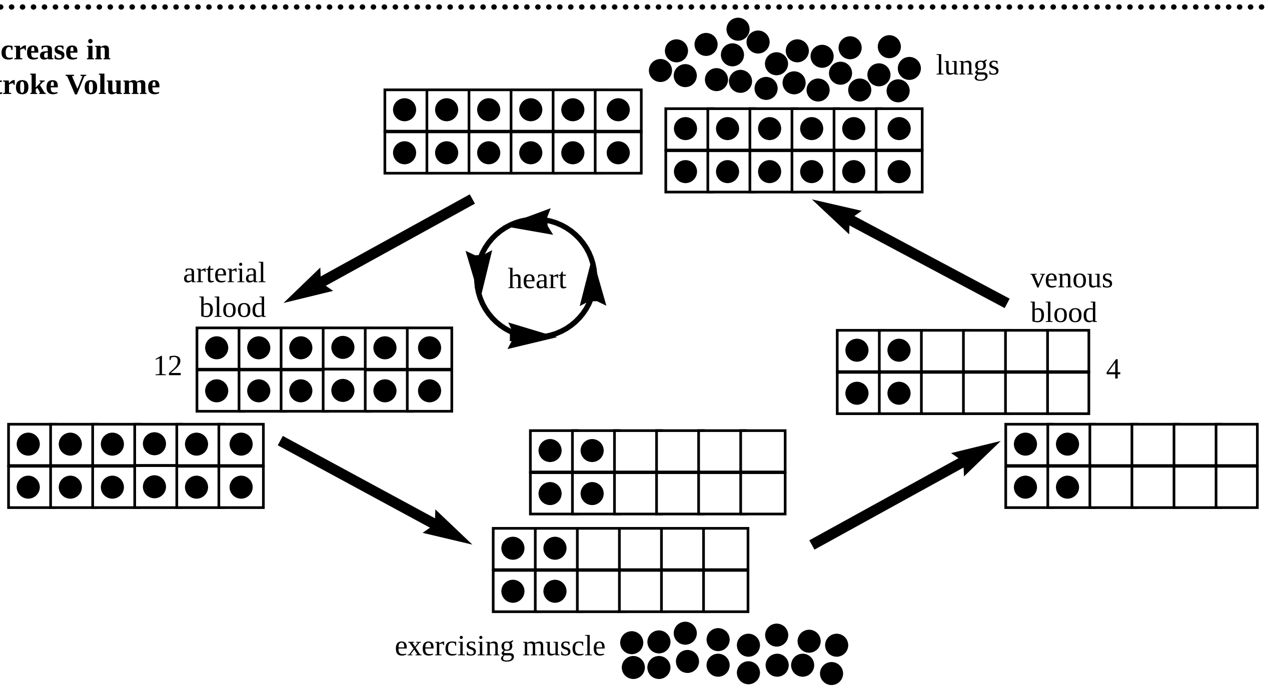
Transparency Master 3.3

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.

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)