Effect of Exercise on Oxygen Usage

Oxygen plays a key role in aerobic cellular metabolism, facilitating the conversion of glucose, protein, and lipids into usable energy. For every 6 molecules of oxygen used in the breakdown of glucose, 6 molecules of carbon dioxide are produced, along with water and adenosine triphosphate (ATP), according to the following equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6\ H_2O + \text{energy (heat or ATP)}$$

The average person uses 200–250 mL of O_2 per minute at rest. This may increase to 2–3 L per minute during heavy exercise and to twice that amount in highly trained athletes. The increase of oxygen consumption is proportional to the amount of work performed up to a maximum level which is dependent on conditioning. At the start of exercise, anaerobic metabolism is used briefly, but this quickly changes to aerobic metabolism as blood flow to muscles increases.

As O_2 is consumed and CO_2 is produced by muscle cells (and other cells), a pressure gradient is created between the cells, the interstitial fluid, and the bloodstream. A marked lowering of O_2 in interstitial fluid as it is used up by cells leads to O_2 diffusion from the bloodstream. While dissolved O_2 provides an immediate supply to replenish the interstitial fluid and cells, the majority of O_2 is carried on hemoglobin molecules. Oxyhemoglobin dissociates more readily as the oxygen concentration is lowered (and CO_2 concentration increased), rapidly replenishing the supply of dissolved O_2. Carbon dioxide gas diffuses from active cells (where it is produced in high concentration) to the interstitial fluid and bloodstream, where it is transported to the lungs mainly as bicarbonate. In the lungs, the opposite is true. Oxygen gas follows a pressure gradient from the alveoli into the bloodstream and CO_2 follows a pressure gradient from the bloodstream into the alveoli.

In this experiment, you will measure oxygen concentrations of deeply inhaled and exhaled air at rest and after exercise. You will use these measurements and an estimate of exhaled volume to calculate the resulting differences in oxygen consumption.

OBJECTIVES

- Obtain graphical representation of changes in O_2 concentration with breathing at rest and after exercise.
- Calculate oxygen consumption at rest and after exercise.
- Correlate your findings with clinical situations.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct O_2 Gas
BioChamber 250 with cap
disposable mouthpiece for spirometer

PROCEDURE

Important: Do not attempt this experiment if you have pulmonary or musculoskeletal problems that might be aggravated by exercise.

Part I Oxygen utilization at rest

1. Launch Graphical Analysis. Connect the Go Direct O_2 Gas Sensor to your Chromebook, computer, or mobile device.

2. Set up the data-collection mode.
   a. Click or tap Mode to mode to open Data Collection Settings.
   b. Change Rate to 100 samples/s and End Collection to 120 s.
   c. Click or tap Done.

3. Prepare the BioChamber (see Figure 1).
   a. In one hand, hold the BioChamber and the disposable spirometer mouthpiece so that the mouthpiece is in contact with the mouth of the bottle (see Figure 1).
   b. Hold the O_2 Gas Sensor in the other hand.
   c. Make sure that the BioChamber cap is nearby.

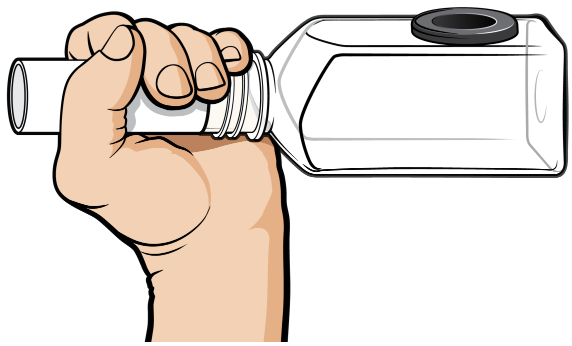

Figure 1

4. Collect baseline and exhalation data.
   a. Click or tap Collect to start data collection.
   b. Wait for 10 seconds to establish a baseline.
   c. Take a deep breath, hold it for a full 5 seconds, then exhale fully through the disposable mouthpiece and into the BioChamber. Upon completion of your exhalation, quickly replace the mouthpiece with the cap and insert the O_2 Gas Sensor into the grommet (see Figure 2).
   d. Data collection will continue for 120 seconds.

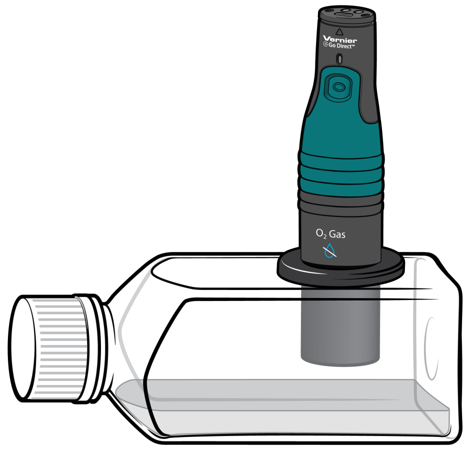

Figure 2

5. Determine the change in oxygen concentration.
   a. Click or tap Graph Tools, , and choose View Statistics.
   b. Using the maximum and minimum values for oxygen concentration, calculate the total change in concentration to the nearest 0.01%.
   c. Record your data as the total pre-exercise ΔO_2 concentration in Table 1.

6. Repeat Steps 3–5 for a total of three breaths, entering the Δy values for each breath in Table 1.

Part II Oxygen utilization during exercise

7. Begin running in place for 2 minutes, moving arms as well as legs.

8. At the end of 2 minutes, prepare the BioChamber as in Step 3.

9. Collect baseline and exhalation data.
   a. Click or tap Collect to start data collection.
   b. Wait for 10 seconds to establish a baseline.
   c. Take a deep breath, hold it for a full 5 seconds, then exhale fully through the disposable mouthpiece and into the BioChamber. Upon completion of your exhalation, quickly replace the mouthpiece with the cap and insert the O_2 Gas Sensor into the grommet (see Figure 2).
   d. Data collection will continue for 120 s.

10. Determine the change in oxygen concentration.
   a. Click or tap Graph Tools, , and choose View Statistics.
   b. Using the maximum and minimum values for oxygen concentration, calculate the total change in concentration to the nearest 0.01%.
   c. Record your data as the total post-exercise ΔO_2 concentration in Table 1.

11. Repeat Steps 7–10 for a total of three breaths, entering the Δy values for each breath in Table 1.

DATA

Table 1		
Breath	ΔO_2 concentration (%)	
	Pre-exercise	Post-exercise
1		
2		
3		
Average		

DATA ANALYSIS

1. Use the value of 4 L for exhaled volume and ΔO_2 concentration (%) from Table 1 to calculate the average O_2 consumed pre- and post-exercise per breath and over the combined four breaths:

$$\Delta O_2 \text{ concentration (\%)} \times \text{exhaled volume (4 L)} = O_2 \text{ consumed per breath}$$

$$O_2 \text{ consumed per breath} \times 3 \text{ breaths} = O_2 \text{ consumed over that time interval}$$

2. Carbon dioxide gas was not measured. What would you expect the volume of exhaled CO_2 to be in this experiment at rest and after exercise?

EXTENSIONS

1. Oxygen consumption with exercise is directly proportional to the muscle mass being used. Demonstrate this principle by performing this experiment exercising with your legs only and/or with your arms only.

2. Perform this experiment after exercising for varying lengths of time (1 minute or 5 minutes).