Measurement of lung volumes provides a tool for understanding normal function of the lungs as well as disease states. The breathing cycle is initiated by expansion of the chest. Contraction of the diaphragm causes it to flatten downward. If chest muscles are used, the ribs expand outward. The resulting increase in chest volume creates a negative pressure that draws air in through the nose and mouth. Normal exhalation is passive, resulting from “recoil” of the chest wall, diaphragm, and lung tissue.

In normal breathing at rest, approximately one-tenth of the total lung capacity is used. Greater amounts are used as needed (i.e., with exercise). The following terms are used to describe lung volumes (see Figure 1):

- **Tidal Volume (TV):** The volume of air breathed in and out without conscious effort
- **Inspiratory Reserve Volume (IRV):** The additional volume of air that can be inhaled with maximum effort after a normal inspiration
- **Expiratory Reserve Volume (ERV):** The additional volume of air that can be forcibly exhaled after normal exhalation
- **Vital Capacity (VC):** The total volume of air that can be exhaled after a maximum inhalation: \( VC = TV + IRV + ERV \)
- **Residual Volume (RV):** The volume of air remaining in the lungs after maximum exhalation (the lungs can never be completely emptied)
  \[ VC + RV \]
- **Total Lung Capacity (TLC):** The volume of air breathed in 1 minute:
  \[ (TV)(breaths/minute) \]

In this experiment, you will measure lung volumes during normal breathing and with maximum effort. You will correlate lung volumes with a variety of clinical scenarios.
OBJECTIVES
In this experiment, you will
- Obtain graphical representation of lung capacities and volumes.
- Compare lung volumes between males and females.
- Correlate lung volumes with clinical conditions.

MATERIALS
- computer
- Vernier computer interface
- Logger Pro
- Vernier Spirometer
- disposable mouthpiece
- disposable bacterial filter
- nose clip

PROCEDURE
Important: Do not attempt this experiment if you are currently suffering from a respiratory ailment such as the cold or flu.

1. Connect the Spirometer to the Vernier computer interface. Open the file “19 Lung Volumes” from the Human Physiology with Vernier folder.

2. Attach the larger diameter side of a bacterial filter to the “Inlet” side of the Spirometer. Attach a gray disposable mouthpiece to the other end of the bacterial filter (see Figure 2).

3. Hold the Spirometer in one or both hands. Brace your arm(s) against a solid surface, such as a table, and click [8 Zer0] to zero the sensor. Note: The Spirometer must be held straight up and down, as in Figure 2, and not moved during data collection.

4. Collect inhalation and exhalation data.
   a. Put on the nose plug.
   b. Click [□ Colon] to begin data collection.
   c. Taking normal breaths, begin data collection with an inhalation and continue to breathe in and out. After 4 cycles of normal inspirations and expirations fill your lungs as deeply as possible (maximum inspiration) and exhale as fully as possible (maximum expiration). It is essential that maximum effort be expended when performing tests of lung volumes.
   d. Follow this with at least one additional recovery breath.

5. Click [ ■ Stop] to end data collection.
6. Click the Next Page button, [Page], to see the lung volume data. If the baseline on your graph has drifted, use the Baseline Adjustment feature to bring the baseline volumes closer to zero, as in Figure 3.

7. Select a representative peak and valley in the Tidal Volume portion of your graph. Place the cursor on the peak and click and drag down to the valley that follows it. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Tidal Volume in Table 1.

8. Move the cursor to the peak that represents your maximum inspiration. Click and drag down the side of the peak until you reach the level of the peaks graphed during normal breathing. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Inspiratory Reserve Volume in Table 1.

9. Move the cursor to the valley that represents your maximum expiration. Click and drag up the side of the peak until you reach the level of the valleys graphed during normal breathing. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Expiratory Reserve Volume in Table 1.

10. Calculate the Vital Capacity and enter the total to the nearest 0.1 L in Table 1.

   \[ VC = TV + IRV + ERV \]

11. Calculate the Total Lung Capacity and enter the total to the nearest 0.1 L in Table 1. (Use the value of 1.5 L for the RV.)

   \[ TLC = VC + RV \]

12. Share your data with your classmates and complete the Class Average columns in Table 1.

### DATA

<table>
<thead>
<tr>
<th>Volume measurement (L)</th>
<th>Individual (L)</th>
<th>Class average (Male) (L)</th>
<th>Class average (Female) (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume (TV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspiratory Reserve (IRV)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Expiratory Reserve (ERV)</td>
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<td></td>
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<tr>
<td>Vital Capacity (VC)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Residual Volume (RV)</td>
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<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Total Lung Capacity (TLC)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DATA ANALYSIS

1. What was your Tidal Volume (TV)? What would you expect your TV to be if you inhaled a foreign object which completely obstructed your right mainstem bronchus?

2. Describe the difference between lung volumes for males and females. What might account for this?

3. Calculate your Minute Volume at rest.
   \[(TV \times \text{breaths/minute}) = \text{Minute Volume at rest}\]
   If you are taking shallow breaths (TV = 0.20 L) to avoid severe pain from rib fractures, what respiratory rate will be required to achieve the same minute volume?

4. Exposure to occupational hazards such as coal dust, silica dust, and asbestos may lead to fibrosis, or scarring of lung tissue. With this condition, the lungs become stiff and have more "recoil." What would happen to TLC and VC under these conditions?

5. In severe emphysema there is destruction of lung tissue and reduced recoil. What would you expect to happen to TLC and VC?

6. What would you expect to happen to your Expiratory Reserve Volume when you are treading water in a lake?

EXTENSION
Repeat the experiment with the chest or abdomen constructed (use a giraffe or ace bandage).
Respiratory Response to Physiologic Challenges

The respiratory cycle of inspiration and expiration is controlled by complex mechanisms involving neurons in the cerebral cortex, brain stem, and peripheral nervous system, as well as central and peripheral receptors. These receptors respond to a variety of stimuli including chemicals and pressure. Central respiratory control (respiratory drive) occurs in the pons and medulla, which respond directly to chemical influences. Other input is received from stretch receptors in the lungs and chemoreceptors located in the carotid and aortic bodies (see Figure 1). The chemoreceptors respond most sensitively and rapidly to carbon dioxide but also to oxygen and pH (acidity). Constant adjustments in the respiratory cycle occur throughout the day to allow gas exchange in the lungs to maintain a steady level of CO₂ in the bloodstream. An increase in the CO₂ level stimulates breathing, while a decrease inhibits it. If the deviation from the “set point” is large enough you may experience shortness of breath. The oxygen level can also influence the respiratory cycle, but larger deviations are required before its influence is felt.

At rest, the average adult male produces approximately 200 mL of CO₂ each minute, but this may increase to over 2000 mL with exercise or heavy work. Hyperventilation lowers CO₂ levels due to an increased opportunity for gas exchange in the lungs. Holding one’s breath or re-breathing air (such as breathing into a paper bag) raises CO₂ levels because there is less opportunity for gas exchange.

In this experiment, you will alter CO₂ levels by holding your breath (hypoventilation), rapid breathing (hyperventilation), and exercise. You will compare the respiratory rate, tidal volume, and minute ventilation that result from each physiologic challenge to homeostasis.

**Important:** Do not attempt this experiment if you are currently suffering from a respiratory ailment such as the cold or flu.

OBJECTIVES

In this experiment, you will
- Obtain graphical representation of normal tidal volume.
- Compare tidal volumes generated by various physiologic challenges.
- Correlate your findings with real-life situations.
Experiment 2: Minute Ventilation after Hypoventilation and Hyperventilation.

PROCEDURE

Part 1 Tidal Volume Response to Breath Holding

1. Connect the Spirometer to the Vernier computer interface. Open the file “20 Respiratory Response” from the Human Physiology with Vernier folder.

2. Attach the larger diameter side of the disposable bacterial filter to the “Inlet” side of the Spirometer head. Attach a disposable Spirometer mouthpiece to the other end of the bacterial filter (Figure 2).

3. Hold the Spirometer in one or both hands. Brace your arm(s) against a solid surface, such as a table, and click [ ] to zero the sensor. Note: The Spirometer must be held straight up and down (as in Figure 2) during data collection.

4. Collect inhalation and exhalation data.
   a. Put on the nose clip.
   b. Click [ ] to begin data collection.
   c. Taking normal breaths, begin data collection with an inhalation and continue to breathe in and out. After 4 cycles of normal inspirations and expirations fill your lungs as deeply as possible (maximum inspiration) and hold your breath for 40 s.
   d. After 40 s of breath holding, resume normal breathing. Data will be collected for 120 s.

5. Click the Next Page button, [ ], to see the volume data. If the baseline on your volume graph has drifted, use the Baseline Adjustment feature to bring the baseline volumes closer to zero, as in Figure 3.
6. Select a representative peak and valley in the portion of your graph prior to the onset of breath holding. Place the cursor on the peak and click and drag down to the valley that follows it. Enter the \( \Delta y \) value displayed in the lower left corner of the graph to the nearest 0.1 L as the Before Challenge Tidal Volume in Table 1.

7. Select two adjacent peaks in the portion of your graph prior to the onset of breath holding. Click and drag the cursor from one peak to the next. Use the \( \Delta x \) value displayed in the lower left corner of the graph to calculate the respiratory rate in breaths/minute. Enter this value to the nearest 0.1 breaths/min as the Before Challenge Respiratory Rate in Table 1.

8. Repeat Steps 6 and 7, selecting regions in the portion of your graph after normal breathing had been resumed (between 60–80 s). Enter the values in the After Challenge section in Table 1.

9. Calculate the Minute Ventilation values for before and after the challenge and enter the results to the nearest 0.1 L in Table 1.

\[
\text{(Tidal Volume)} \times \text{(Respiration Rate)} = \text{Minute Ventilation}
\]

**Part II Tidal Volume Response to Rapid Breathing**

10. Clear the data from Part I by choosing Clear All Data from the Data menu.

11. Hold the Spirometer in one or both hands. Brace your arm(s) against a solid surface, such as a table, and click [B Zero]. Note: The Spirometer must be held straight up and down (see Figure 2) during data collection.

12. Collect inhalation and exhalation data.
   a. Put on the nose plug.
   b. Click [Collect] to begin data collection.
   c. Taking normal breaths, begin data collection with an inhalation and continue to breathe in and out. After 4 cycles of normal inspirations and expirations, begin breathing deeply and rapidly for 40 s. Note: If you begin to feel faint, slow your breathing rate.
   d. After 40 s of rapid breathing, resume normal breathing. Data will be collected for 120 s.

13. Click the Next Page button, \( \equiv \), to see the volume data. If the baseline on your graph has drifted, use the Baseline Adjustment feature to bring the baseline volumes closer to zero.

14. Select a representative peak and valley in the portion of your graph prior to the onset of rapid breathing. Place the cursor on the peak and click and drag down to the valley that follows it. Enter the \( \Delta y \) value displayed in the lower left corner of the graph to the nearest 0.1 L as Before Challenge Tidal Volume in Table 1.

15. Select two adjacent peaks in the portion of your graph prior to the onset of rapid breathing. Click and drag the cursor from one peak to the next. Use the \( \Delta x \) value displayed in the lower left corner of the graph to calculate the respiratory rate in breaths/minute. Enter this value to the nearest 0.1 breaths/min as Before Challenge Respiratory Rate in Table 1.

16. Repeat Steps 14 and 15, selecting regions in the portion of your graph after normal breathing had been resumed (between 60–80 s). Enter the values in the After Challenge section in Table 1.

17. Calculate the Minute Ventilation values for before and after the challenge and enter the results to the nearest 0.1 L in Table 1. Return to Page 1 to prepare for Part III.
18. Clear the data from Part II by choosing Clear All Data from the Data menu.

19. Hold the Spirometer in one or both hands and click [Zero]. Note: The Spirometer must be held straight up and down (see Figure 2) during data collection.

20. Collect inhalation and exhalation data.
   a. Put on the nose plug.
   b. Click [Collect] to begin data collection.
   c. Taking normal breaths, begin data collection with an inhalation and continue to breathe in and out. After 4 cycles of normal inspirations and expirations begin running in place for 40 s.
   d. After 40 s of running in place, stand quietly. Continue to breathe into the Spirometer. Data will be collected for 120 s.

21. Click the Next Page button, [n], to see the volume data. If the baseline on your graph has drifted, use the Baseline Adjustment feature to bring the baseline volumes closer to zero.
## Respiratory Response to Physiologic Challenges

### DATA

<table>
<thead>
<tr>
<th>Table 1</th>
<th>A: Holding Breath</th>
<th>B: Rapid Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Challenge</strong></td>
<td></td>
<td></td>
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<tr>
<td>Tidal volume (L)</td>
<td>Δy</td>
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<tr>
<td>Respiratory rate (breaths/min)</td>
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<tr>
<td>Initial minute ventilation (L/min)</td>
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<tr>
<td><strong>After Challenge</strong></td>
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<td></td>
</tr>
<tr>
<td>Tidal volume (L)</td>
<td>Δy</td>
<td></td>
</tr>
<tr>
<td>Respiratory rate (breaths/min)</td>
<td>Δt</td>
<td></td>
</tr>
<tr>
<td>Minute ventilation (L/min)</td>
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<td></td>
</tr>
</tbody>
</table>

### Table 2—Exercise

| Before Challenge | | |
| Tidal volume (L) | | |
| Respiratory rate (breaths/min) | | |
| Minute ventilation (L/min) | | |
| During Challenge | | |
| Tidal volume (L) | | |
| Respiratory rate (breaths/min) | | |
| Minute ventilation (L/min) | | |
| After Challenge | | |
| Tidal volume (L) | | |
| Respiratory rate (breaths/min) | | |
| Minute ventilation (L/min) | | |
DATA ANALYSIS

1. Describe the changes in respiratory rates, tidal volumes, and minute ventilations that occurred after each of the following physiologic challenges in terms of CO₂ levels and their effect on respiratory drive:

   (a) breath holding

   (b) rapid breathing

   (c) exercise

2. Which challenge caused the greatest change in respiratory rate (pre-challenge vs. post challenge)? Tidal volume? Minute ventilation? Did respiratory rate or tidal volume change the most relative to its resting value?

3. How might breathing into a paper bag help someone who is extremely anxious and hyperventilating?

4. Some patients with severe emphysema have constant high levels of CO₂ because of inadequate ventilation. The central nervous system breathing center in these patients becomes insensitive to CO₂ and more dependent on the level of O₂, which is low. These patients are said to have “oxygen-dependent respiratory drive.” What might happen if you give such a person high levels of supplemental O₂?

5. Would breathing pure O₂ help the air hunger experienced by athletes who have just completed a race? Why or why not?