Experiment HE-8: Regulation of Body Temperature and the Respiratory Exchange Ratio (RER)

Background

Mammals and birds possess physiological mechanisms which enable them to maintain a relatively constant body temperature in spite of changing environmental temperature. These organisms are classified as homeotherms (in contrast to poikilotherms - organisms whose internal body temperature is dependent upon external environmental temperatures). See Table HE-8-B1.

Table HE-8-B1: Temperature Regulating Mechanisms

<table>
<thead>
<tr>
<th>Mechanisms Activated by Cold</th>
<th>To Increase Heat Production</th>
<th>To Decrease Heat Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shivering</td>
<td></td>
<td>Cutaneous vasoconstriction</td>
</tr>
<tr>
<td>Hunger</td>
<td></td>
<td>Curling up</td>
</tr>
<tr>
<td>Increased voluntary activity</td>
<td></td>
<td>Horripilation (goose bumps)</td>
</tr>
<tr>
<td>Increased secretion of norepinephrine and epinephrine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanisms Activated by Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>To Increase Heat Loss</td>
</tr>
<tr>
<td>Cutaneous vasodilation</td>
</tr>
<tr>
<td>Sweating</td>
</tr>
<tr>
<td>Increased respiration</td>
</tr>
</tbody>
</table>

Factors which influence homeothermic body temperature includes: diurnal variations (lowest in the morning; highest in the afternoon), physical work (the core body temperature can fluctuate by almost 3°C Celsius during heavy exercise), the menstrual cycle (lower before ovulation; higher after), and environmental temperature.

Sustained core body temperature above 41°C or below 36°C impairs the function of the central nervous system and further temperature extremes are not compatible with life. Normal human body temperature fluctuates within a range of 36.8°C +/- 0.07°C. Females tend to have slightly lower body temperatures than males.

Heat balance of the body is determined by the amount of heat present in the body and its specific heat. The average specific heat of the human body is 0.83 kcal, which means that a change in temperature every 1°C will occur if 0.83 kcal of body heat/kg of body weight is gained or lost. The changes in heat
content of the body is usually called “heat storage” (S). The amount of heat in the body and thus the body temperature is determined by two factors:

- the heat production in the body, and;
- the heat lost and gained between the body and the environment.

Heat is produced continuously in living organisms because all the processes taking place in the body are associated with transformation of energy, which in turn are associated with dissipation of some of the energy transferred in the form of heat. This is generally known as “metabolism” - M. Heat gain and loss by the body (heat exchange between the body and the environment) is carried out by four physical mechanisms:

- R - radiation - from the sun or to/from other sources of heat (such as blacktop)
- K - conduction - direct heat exchange by being on contact with a warm or cold object (electric blanket or ice pack)
- C - convection - heat transfer by movement or air currents over the body
- E - evaporation - heat transferred to the environment due to evaporative cooling by sweating

The heat balance in a body (assuming no external work) can be expressed by this simple equation:

\[ +/- S = M - E + (R+C+K) \]

There are two main sources of energy available for human metabolism (M): carbohydrates (CHO) and fats. These molecules are broken down, or catabolized, into carbon dioxide, water, and energy. The energy requirements for metabolism are met with a mixture of energy derived from carbohydrates and fats. The activity being performed determines the proportion of carbohydrates and fats being utilized. At rest, a body derives about 40% of its energy from carbohydrates and 60% from fats. As the intensity of activity increases, the demand for energy increases, and a greater proportion of this demand is met by the oxidation of carbohydrates. When maximal oxygen uptake is occurring at the most intense exercise level, 100% of the energy is being supplied by carbohydrates because the catabolism of fat is too slow to supply the amount of energy required.

Physical activity is not the only mechanism for expenditure of the body’s energy. Temperature regulation of the human body takes energy as well - both when trying to keep warm and trying to stay cool. Maintenance of human core body temperature is a direct result of cellular metabolism.

As the ratio of energy supplied by fats and carbohydrates shifts during changes in activity and regulation of core body temperature, the ratio of carbon dioxide produced to oxygen consumed also shifts. The ratio of carbon dioxide produced to oxygen consumed during cellular metabolism can be measured by determining the changes in the concentrations of oxygen and carbon dioxide in the air that passes into and out of the lungs. These measurements are possible because the amounts of oxygen and carbon dioxide exchanged between the alveoli and the capillaries in the lungs are directly dependent on the amounts of carbon dioxide produced and oxygen consumed during cellular respiration.
The amounts of oxygen consumed and carbon dioxide produced are measured using an oxygen/carbon dioxide gas analyzer connected to a spirometer. The gas analyzer measures the concentration of oxygen and carbon dioxide in inspired and expired air, and the spirometer determines the volumes of inspired and expired air. When the concentrations and volumes are brought together in a series of equations, the volume of oxygen consumed per minute, known as VO$_2$, and the volume of carbon dioxide produced per minute, known as VCO$_2$, are determined. The ratio of VCO$_2$/VO$_2$ is the Respiratory Exchange Ratio (RER), which can be used to determine the proportions of energy being produced by carbohydrates and fats, and the energy expended per liter of oxygen consumed (Table HE-8-B2).

**Table HE-8-B2: Respiratory Exchange Ratio (RER) as a Function of the Proportions of Energy Sources.**

<table>
<thead>
<tr>
<th>RER</th>
<th>Energy kcal/liter O$_2$</th>
<th>% Energy from CHO</th>
<th>% Energy from Fats</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>4.69</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0.75</td>
<td>4.74</td>
<td>15.6</td>
<td>84.4</td>
</tr>
<tr>
<td>0.80</td>
<td>4.80</td>
<td>33.4</td>
<td>66.6</td>
</tr>
<tr>
<td>0.85</td>
<td>4.86</td>
<td>50.7</td>
<td>49.3</td>
</tr>
<tr>
<td>0.90</td>
<td>4.92</td>
<td>67.5</td>
<td>32.5</td>
</tr>
<tr>
<td>0.95</td>
<td>4.99</td>
<td>84.0</td>
<td>16.0</td>
</tr>
<tr>
<td>1.00</td>
<td>5.05</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

The energy expended during temperature regulation can be calculated from the RER and the volume of oxygen consumed. For example, if the RER is 0.90, the energy expended is 4.92 kcal/liter O$_2$. If 2.5 liters of oxygen are consumed per minute for 20 minutes, a total of 246 kcal are expended during that time:

$$(2.5 \text{ L O}_2/\text{minute})(20 \text{ min})(4.92 \text{ kcal/liter O}_2) = 246 \text{ kcal expended}$$

If less energy is expended during the maintenance of body temperature then the RER values will be lower and vice-versa.

In this experiment, students will measure the VO$_2$ and VCO$_2$ of a subject while resting, while body temperature is raised (and the body is using energy to keep cool), and while cooling the body (using energy to keep warm). Students will use an iWire-GA CO$_2$/O$_2$ gas analyzer. The gas analyzer is connected to a spirometry system designed for quick and easy measurements of lung volumes and gas concentrations from samples of expired air. The RER for the variables will be calculated from the values for VCO$_2$ and VO$_2$. 

*Human Exercise – Regulation of Body Temperature-RER - Background*
Experiment HE-8: Regulation of Body Temperature and the Respiratory Exchange Ratio (RER)

Equipment Required
PC or Mac Computer
IXTA data acquisition unit, power supply and USB cable
TM-220 Temperature sensor with extension cable
Surgical tape
A-FH-300 Spirometer flow head and plastic tubes
iWire-GA CO₂/O₂ Gas Analyzer with filter, sample tubing
Breathing mask
Thermometer - either oral or rectal
Electric blanket
Cold packs
2 beakers
Cold water and warm water

Selecting Subjects and Bringing Clothing for Lab.
1. The number of subjects that can participate in this experiment will depend on the number of stations that are available, the length of the laboratory period, and the number of students in the lab section. It will take about one hour for each subject to complete the experiment.
2. Each subject should be paired up with another subject of the same gender and approximately the same body size.
3. Each subject should wear a t-shirt and a pair of gym shorts to lab.
4. In addition to the equipment listed in Step 3, each subject should bring a pair of warm socks, a heavy sweat shirt, a pair of heavy sweat pants, and a knit cap.

Assistants and Their Duties.
1. At least one other student, who is not a subject, should join each pair of subjects to form a lab group. While one of the subjects is performing the lab exercises, the other subject and the other student in the group will perform the various duties needed to run the experiment successfully.
2. One member of the group should:
   • Time the rest, heating, and cooling periods;
   • Measure the core temperature of the subject with the thermometer.
3. The other member of the group should:
   • Operate the computer system that records VCO2, VO2, and skin temperature;
   • Record the values for VCO2, VO2 and skin temperature of the subject in the Journal or on a separate data table.

**Setup the IXTA and iWire-GA**

1. Connect the iWire-GA to the iWire1 port on the front of the IXTA, and plug it into the wall using the power supply.
2. Plug the IXTA into the wall and, using the USB cable, to the computer.

**NOTE: The iWire-GA must be plugged into the IXTA prior to turning both machines on.**

3. Turn on the IXTA and the iWire-GA.
4. Open LabScribe.
5. Click Settings → Human Exercise-iWireGA → RegulationBT-RER.
6. Once the settings file has been loaded, click the Experiment button on the toolbar to open any of the following documents:
   • Appendix
   • Background
   • Labs
   • Setup (opens automatically)

**Temperature Sensor, Spirometry Equipment and Gas Analyzer Setup**

1. Locate the TM-220 temperature sensor in the iWorx kit (Figure HE-8-S1).

![Figure HE-8-S1: The TM-220 temperature sensor.](image)

2. Plug the connector of the TM-220 temperature sensor into the “Temp” Channel input of the IXTA.
3. Locate the A-FH-300, and the airflow tubing in the iWorx kit (Figure HE-8-S2).
4. Carefully connect the two air flow tubes onto the two outlets on the A-FH-300 flow head.
5. Connect the other ends of the two air flow tubes onto the two inlets of the Channel A1 input of the IXTA (Figure HE-8-S3).

Figure HE-8-S2: The FH-300 flow head, and the airflow tubing.

7. Position the gas analyzer on the desktop, so that the analyzer can be connected to the IXTA and the sample port of the breathing mask at the same time.

Figure HE-8-S3: The iWire-GA gas analyzer connected to an IXTA unit. The tubings are shown all connected properly for testing. You will not use the outlet tubing.
8. Have the subject try on the mask. Adjust the length of the straps so that the mask fits the subject comfortably. Check around the edge of the mask to make sure there are no leaks between the subject’s skin and the rim of the mask. Remove the mask from the subject.

9. Connect the mask to the inlet of the A-FH-300 flow head. Place the braided end of a Nafion sampling tube on the gas sampling port of the mask (Figure HE-8-S3).

10. Place a filter on the “Sample In” port of the iWire-GA. Attach the other end of the Nafion sampling tube to this filter.

11. Turn on the analyzer and let it warm-up for at least 5 minutes before using it.

**Calibrating the iWire-GA Gas Analyzer**

*Note: Warm up the gas analyzer for at least 15 minutes prior to use. Make sure the calibration gas tank is located close to the gas analyzer.*

This procedure will calibrate both the $O_2$ and $CO_2$ channels.

Connect the gas sample tubing of the A-CAL-150 Calibration Kit (Figure HE-8-S4) to the Luer-Lock connector on the output of the regulator.

*Figure HE-8-S4 Calibration Kit (A-CAL-150).*

1. Click the Calibrate Gas Analyzer button. Click Perform Quick Software Gas Calibration.

2. Follow the directions as prompted. Room air will be sampled for 10 seconds. Calibration gas will be sampled for 15 seconds.

3. If necessary, move the cursors into correct position (Figure HE-8-S5).
Calibration of the Temperature Sensor

Note: The TM-220 temperature probe is pre-calibrated and additional calibration is not necessary. The directions below are for your information if you would like to perform another calibration.

1. Place the tip of the temperature probe in cold water of a known temperature (~10 °C). Type the Calibration <Cold> in the Mark box to the right of the Mark button on the LabScribe Main window.
2. Click on the Record button and press the Mark button. Record data until the voltage on the temperature channel reaches a plateau; this usually takes about 20 seconds.
3. While recording at this temperature, type the Calibration <Warm> in the Mark box.
4. Without stopping the recording, move the tip of the probe from cold to warm water of a known temperature (~40 °C).
5. Press the Mark button. Record the change in voltage on the Temperature channel until a plateau is reached (Figure HE-8-S6). Click on the Stop button to halt the recording.
6. Use the Display Time icons to adjust the Display Time of the Main window to show the recording at both temperatures in the same window.
7. Click the 2-Cursor icon so that two cursors appear on the Main window. Place a cursor on the plateau of the temperature recording taken from cold water and the other cursor on the plateau of the temperature recording from the warm water.

8. To convert the voltages at the positions of the cursors to temperatures, use the Simple Units Conversion dialogue window (Figure HE-8-S7). To access this dialogue window, click on the arrow to the left of the channel title, Skin Temp, to open the channel menu. Select Units from the channel menu, and select Simple from the Units submenu.

Figure HE-8-S6: The output of the TM-220 temperature probe recorded at two different temperatures. Data is used to calibrate the TM-220.

Figure HE-8-S7: The Simple Units Conversion Dialogue Window with the voltages at the cursors set to equal the temperatures of the water used to calibrate the temperature sensor.
9. On the Simple Units Conversion window, make sure 2 point calibration is selected in the pull-down menu in the upper-left corner of the window. Put a check mark in the box next to Apply units to all blocks. Notice that the voltages from the positions of the cursors are automatically entered into the value equations. Enter the two temperatures used in the calibration recording in the corresponding boxes on the right side of the conversion equations. Enter the name of the units, °C, in box below the pressures. Click the OK button to activate the units conversion.

10. Click on the Save button to save the data file.

Calibration of the Spirometer

*Note: Read the procedures for each exercise completely before beginning the experiment. Have a good understanding of how to perform these exercises before making recordings.*

*Warning: It is important that the subject is healthy and has no history of respiratory or cardiovascular problems.*

1. The settings file, RegulationBT-RER-iWireGA, used in this experiment programs the computed function used on the Lung Volume STPD channel to convert the data recorded on the Air Flow channel to breath volumes at standard temperature and pressure, dry (STPD).

2. Enter the room temperature, and water vapor pressure into the Spirometer Calibration Dialog window used on the Lung Volume STPD channel:
   - Click on the words STPD Vol. Human (Air Flow), which are next to the title of the Lung Volume STPD channel, to open the computed function pull-down menu.
   - Select Setup Function from this pull-down menu to open the Spirometer Calibration Dialog window.
   - Make sure IXTA is set for the “Type of Spirometer”. Select 300L flow head.
   - Make sure the “No Reset” time is selected, and the first 10 seconds of the recording are used to zero the baseline of the Lung Volume STPD channel.
   - Use the built-in barometer or enter the values for the Atmospheric Pressure in mmHg; Enter the Room Temperature in °C.
   - Click OK.

3. Allow the unit to warm up for 15 minutes before recording for the first time.

4. Determine if the airflow tubes between the flow head to the spirometer amplifier are attached to the proper inlets on each device.
   - Since this test does not need to be recorded, click on the Save to Disk button in the lower left corner of the Main window. If LabScribe is in Preview mode, there will be a red X across the Save to Disk button.
   - Click on the Preview button.
**Note:** If the user clicks the Preview button and an error window appears on the Main window indicating the iWorx hardware cannot be found, make sure the iWorx unit is turned on and connected to the USB port of the computer. Then, click on the OK button in the error window. Pull down the LabScribe Tools menu, select the Find Hardware function, and follow the directions on the Find Hardware dialogue window.

- Have the subject inhale through the mask while the flow head is connected to the mask. Click on the AutoScale button at the upper margin of the Air Flow and Lung Volume STPD channels.
- If the proper end of the flow head is attached to the mask, the traces on the Air Flow and Lung Volume STPD channels will go up during inhalation.
- If the traces on these channels go down during inhalation, reverse the positions of the airflow tubing at the inlets of the spirometer amplifier.
- Click on the Stop button.

5. Also, the settings file programs LabScribe to record the concentrations of oxygen and carbon dioxide in the inhaled and exhaled air. The computed functions used on the Relative VCO2 and Relative VO2 channels convert the data recorded on the O2 and CO2 Concentration channels, and the Lung Volumes STPD channel, to the VCO2 and VO2 in each breath.

6. Enter the channels used to calculate VCO2 and VO2, the weight of the subject, and the concentrations of oxygen and carbon dioxide in room air into the Metabolic Output Calculation Dialog window used on the Relative VCO2 and Relative VO2 channels.

   - Click on the words VCO2 (Lung Volumes STPD) that are next to the title of the Relative VCO2 channel, to open the computed function pull-down menu.
   - Select Setup Function from this pull-down menu to open the Metabolic Output Calculation Dialog window.
   - Select the CO2 Concentration (%) as the carbon dioxide channel and Lung Volumes STPD as the volume channel. Enter the weight (in kg) of the subject and the concentration of carbon dioxide (%) in inhaled air on the window.
   - Click on the words VO2 (Lung Volumes STPD) that are next to the title of the Relative VO2 channel, to open the computed function pull-down menu.
   - Select Setup Function from this pull-down menu to open the Metabolic Output Calculation Dialog window.
   - Select the O2 Concentration (%) as the carbon dioxide channel and Lung Volumes STPD as the volume channel. Enter the weight (in kg) of the subject and the concentration of oxygen (%) in inhaled air on the window.
   - Click OK.

7. Click on the Save to Disk button, in the lower left corner of the Main window, to change LabScribe from Preview mode to Record mode. If LabScribe is in Record mode, there will be a green arrow on the Save to Disk button.

8. Select Save in the File menu to save your file to disk.
Experiment HE-8: Regulation of Body Temperature and the Respiratory Exchange Ratio (RER)

Note: Read the procedures for each exercise completely before beginning the experiment. Have a good understanding of how to perform these exercises before making recordings.

Warning: It is important that the subject is healthy and has no history of respiratory or cardiovascular problems.

Exercise 1: VCO₂, VO₂, and RER at Rest

Aim: To determine the effect of breathing at rest on VCO₂, VO₂, and RER.

Procedure

1. The subject should be comfortably dressed in t-shirt, shorts and socks.
2. Use surgical tape to tape the TM-100 or TM-220 temperature sensor to the inside of the subject’s thigh where it will not come in contact with the electric blanket or ice packs.
3. Take the subject’s core body temperature using his/her axillary temperature.
   • Place the thermometer underneath the subject’s armpit.
   • Leave the thermometer in place for at least two minutes until you get an accurate temperature reading.
   • Record the subject’s core temperature on Table HE-8-L1.
4. Instruct the subject to sit quietly, become accustomed to breathing through the mask and the flowhead, and breathe normally before any recordings are made.
5. Have the subject remove the mask from his or her face before the volume channels are zeroed.
6. Type <Subject’s Name> Rest in the Mark box that is to the right of the Mark button.

Note: The LabScribe software will zero the Lung Volume STPD channel during the first ten seconds of recording. No air should be moving through the flowhead during this time.

7. Click on the Record button. After waiting ten seconds for the Lung Volume STPD channel to zero, the subject should put on the mask and check for leaks. Press the Enter key on the keyboard to mark the recording as the subject begins breathing through the mask and the flowhead.
8. Click the AutoScale buttons on all channels.
9. Notice that the CO₂ concentration increases with each exhalation and decreases with each inhalation as the O₂ concentration does the opposite.
10. On the Lung Volume STPD channel, the STPD Vol. Human function converts the data from the Air Flow channel to the tidal volumes at the standard temperature and pressure, dry.
11. On the Relative VCO2 channel, the VCO2-Breath function is programmed to determine the volume of carbon dioxide produced during the exercise. The volume of carbon dioxide produced in a minute is the parameter known as VCO$_2$.

12. On the Relative VO2 channel, the VO2-Breath function is programmed to determine the volume of oxygen consumed during the exercise. The volume of oxygen consumed in a minute is the parameter known as VO$_2$.

13. Record at least five minutes of data while the subject’s respiration rate and volume are steady. Once the data is recorded, click Stop to halt the recording. Your data should be similar to Figure HE-8-L1.

14. Select Save in the File menu.

Note: In this experiment, the weight of the subject is incorporated into the determination of VCO$_2$ and VO$_2$. These parameters are expressed as ml/min/kg body weight, and are commonly called Relative VCO$_2$ and Relative VO$_2$.

![Figure HE-8-L1: Gas concentrations, lung volume (STPD), relative VCO2, relative VO2, and RER of a resting subject displayed on the Main window.](image-url)
Data Analysis

1. Scroll to a section of the data where the subject’s respiration rate and depth were consistent.

2. Use the Display Time icons to adjust the Display Time of the Main window to show at least a one-minute of the recording on the Main window. The required data can also be selected by:
   - Click the 2-Cursor icon *(Figure HE-8-L2)* on the LabScribe toolbar so that two blue cursors appear on the Main window.
   - Placing the cursors on either side of data required
   - Clicking the Zoom between Cursors button on the LabScribe toolbar to expand the calibration data to the width of the Main window.

3. Click on the Analysis window icon in the toolbar or select Analysis from the Windows menu to transfer the data displayed in the Main window to the Analysis window *(Figure HE-8-L3)*.

4. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical function, Mean and T2-T1, should appear in this table. Values for each parameter on each channel are seen in the table across the top margin of each channel.

5. Once the cursors are placed in the correct positions for determining the mean VCO2 and VO2 values for a one-minute section of data as indicated by the value for T2-T1, the mean VCO2 and VO2 values can be recorded in the on-line notebook of LabScribe by typing the name and values directly into the Journal. The functions in the channel pull-down menus of the Analysis window can also be used to enter the name and values of the parameter from the recording to the Journal. To use these functions:
   - Place the cursors at the locations used to measure the means of the VCO2, VO2, and skin temperature over one minute.
   - Transfer the name of the mathematical function used to determine these mean values to the Journal using the Add Title to Journal function in the Relative VCO2 Channel pull-down menu.
   - Transfer the values for the means of the VCO2, VO2, RER, and skin temperature to the Journal using the Add All Data to Journal function in the Relative VCO2 Channel pull-down menu.
6. Use the mouse to click on and drag the cursors to positions on the Relative VCO2 channel that are one minute apart (Figure HE-8-L3). The values for the following parameters are determined when the cursors are positioned as directed:

   • The value for Mean on the Relative VCO2 channel is the average volume of carbon dioxide produced in one minute per kg body weight.
   • The value for Mean on the Relative VO2 channel is the average volume of oxygen consumed in one minute per kg body weight.
   • The value for Mean on the RER channel is the average respiratory exchange ratio (RER) over the time between the cursors on the Analysis window.
   • The value for Mean on the Skin Temp channel is the average skin temperature over the time between the cursors on the Analysis window.

7. Record the values for the Means in the Journal using one of the techniques described in Steps 5 or 6, and on Table HE-8-L1.
Exercise 2: Effect of High Body Temperature on VCO₂, VO₂, and RER

Aim: To measure the effect of higher than normal body temperature on VCO₂, VO₂, and RER.

Procedure

1. Ask the subject to put on sweat pants, a sweatshirt and socks over his/her shorts and t-shirt.
2. Wrap the subject in the electric blanket and turn the setting up so the subject can feel the warmth from the blanket. Do not make the temperature too high.
3. Let the subject sit wrapped in the electric blanket for at least 15 minutes, but no longer than 25 minutes.
4. Turn off and remove the electric blanket.
5. Immediately take the subject’s body temperature using the method described in Exercise 1. Record the temperature on Table HE-8-L1.
6. Use the same procedures used in Exercise 1 to record the lung volumes and skin temperature from the subject while the gas concentrations are reaching a steady state immediately after the 15 minute warming period and removal of the blanket, 5 minutes after removal of the blanket, and 15 minutes after removal of the blanket.

Note: The subject will have his/her breathing recorded for a minimum of 20 minutes without stopping the recording. Stop the recording only after you have recorded data for five minutes after the 15 minutes after removal of the blanket.

7. Mark the recording with a comments that indicate the name of the subject and the beginning of the three periods being recorded.

Data Analysis

1. Use the same procedures used in Exercise 1 to determine the oxygen consumed (VO₂), carbon dioxide produced (VCO₂), and respiratory exchange ratio (RER), and skin temperature during high body temperature, and at both 5 minutes and 15 minutes after removal of the electric blanket.
2. If the concentrations of oxygen and carbon dioxide were at a steady level for less than a minute, prorate volumes to minute volumes. For example, if the oxygen and carbon dioxide concentrations reached a steady level for 30 seconds during the different time periods, the measured volumes are converted to minute volumes by multiplying the 30-second values by 2.
3. Record the values for the means of the VCO₂, VO₂, RER, and skin temperature, and the core temperature, in the Journal and on the data table.
Table HE-8-5: VCO₂, VO₂, the Respiratory Exchange Ratio (RER), and Temperatures of a Subject at Rest, During High Body Temperature, and During Low Body Temperature.

<table>
<thead>
<tr>
<th>Environmental Conditions</th>
<th>Experimental Periods</th>
<th>Core Body Temp. (°C)</th>
<th>Skin Temp. (°C)</th>
<th>Mean VCO₂ (ml/min/kg)</th>
<th>Mean VO₂ (ml/min/kg)</th>
<th>RER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Temperature (°C)</td>
<td>Resting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High Body Temperature (Immediate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barometric Pressure (mmHg)</td>
<td>5 Minutes After High Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 Minutes After High Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cold Body Temperature (Immediate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>5 Minutes After Cold Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 Minutes After Cold Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exercise 3: Effect of Cold Temperature on VCO₂, VO₂, and RER

Aim: To measure the effects of colder than normal body on VCO₂, VO₂, and RER.

Warning: If using a different subject for the Cold Temperature exercise, you MUST repeat Exercise 1 for the subject at Rest. If using the same subject, let the subject remain at room temperature for 15 minutes while he/she cools back down to normal body temperature prior to starting Exercise 3.

Procedure
1. Ask the subject to sit comfortably in only his/her t-shirt and shorts. Bare feet are suggested.
2. Place cold packs on the subject’s core body area, and on the hands and feet if possible.
3. Let the subject sit with the cold packs on for at least 15 minutes, but no longer than 25 minutes.
4. Remove the cold packs.
5. Immediately take the subject’s body temperature using the method described in Exercise 1. Record the temperature on the data table.
6. Use the same procedures used in Exercise 1 to record the lung volumes and skin temperature from the subject while the gas concentrations are reaching a steady state immediately after the 15 minute cooling period and removal of the cold packs, 5 minutes after removal of the cold packs, and 15 minutes after removal of the cold packs.
7. Mark the recording with a comments that indicate the name of the subject and the beginning of the three periods being recorded.

Data Analysis
1. Use the same procedures used in Exercise 1 to determine the oxygen consumed (VO$_2$), carbon dioxide produced (VCO$_2$), and respiratory exchange ratio (RER), and skin temperature during low body temperature, and at both 5 minutes and 15 minutes after removal of the cold packs.
2. If the concentrations of oxygen and carbon dioxide were at a steady level for less than a minute, prorate volumes to minute volumes. For example, if the oxygen and carbon dioxide concentrations reached a steady level for 30 seconds during the different time periods, the measured volumes are converted to minute volumes by multiplying the 30-second values by 2.
3. Record the values for the means of the VCO$_2$, VO$_2$, RER, and skin temperature, and the core temperature, in the Journal and on the data table.

Note: The subject will have his/her breathing recorded for a minimum of 20 minutes without stopping the recording. Stop the recording only after you have recorded data for five minutes after the 15 minutes after removal of the cold packs.

Questions
1. During which experimental period was the subject’s VCO$_2$ the highest? In which period was it the lowest?
2. During which period was the subject’s VO$_2$ the highest? In which period was it the lowest?
3. During which period did the subject have the highest RER? In which period was the RER the lowest?
4. What is the direct correlation between maintaining body temperature, RER, and metabolism?
5. Is it easier to maintain body temperature when an individual is hot or cold? Explain your answer. You may need to use additional sources other than your textbook.
Appendix: Optional Spirometer FlowHead Calibration

For increased accuracy of measurements, Users may want to perform an optional calibration procedure on their flowhead. This procedure uses an optional 3 liter calibration syringe. Directions are included with the syringe.