Experiment HE-5: Resting Metabolic Rate (RMR)

Background
During the body’s oxidation of food into carbon dioxide and water, chemical and thermal energy are released. The chemical energy derived from glycolysis and oxidative phosphorylation is used by the body to perform work, like the contraction of muscles or the transport of molecules across membranes. The thermal energy generated from cellular processes helps to maintain the body’s optimal core temperature.

Energy Sources
The energy requirements of the body are met with a mixture of energy derived from carbohydrates, fats, and protein. The activity being performed and the stores of carbohydrates and fats available as energy sources determine the proportion of the three macromolecules that are utilized by the body. At rest, a body derives about 40% of its energy from carbohydrates and 60% from fats. As the intensity of activity and the demand for energy increase, a greater proportion of the energy is usually provided by the oxidation of carbohydrates. At the most intense exercise level, all the energy that is required is usually being supplied by carbohydrates.

Protein is usually not a significant source of energy in the body. Unlike fat and carbohydrates in the form of glycogen, the body has no storage deposits of protein. Proteins are important components of tissues, peptide hormones, and enzymes that are continually being broken down and replaced. However, during periods of exercise that are greater than 90 minutes, it is estimated that protein catabolism provides as much as 15% of the energy required. If the body’s supply of stored carbohydrates is low from a prior exercise period, protein catabolism could provide as high as 45% of the energy required. Because of its importance in tissues, the utilization of protein as an energy source could cause damage to these tissues. Severe damage to tissues does occur during long-term starvation, when protein is the principal source of energy.

Calorimetry
The amount of energy released during the oxidation of food can be measured by the amount of heat that is produced by the body. Heat production can be measured by either of two methods:

- Direct calorimetry, which uses a body calorimeter to measure the amount of heat given off by the body.
- Indirect calorimetry, which uses a spirometer to measure the amount of oxygen consumed by the body over a short period of time.

Indirect calorimetry is easy to perform because the amount of oxygen consumed during metabolism is directly proportional to the amount of heat released during the oxidation of food. The amount of oxygen consumed and the amount of heat released is also proportional to the type of energy source being utilized.

When examining the oxidation of the three macromolecules used as energy sources, it is shown that the stoichiometries of the reactions for each type of molecules are significantly different.
Using glucose as the example of a typical carbohydrate, the complete oxidation of glucose is expressed by the following equation:

$$6 \text{O}_2 + C_6\text{H}_{12}\text{O}_6 = 6 \text{CO}_2 + 6 \text{H}_2\text{O}$$

As shown in this equation, 6 moles of carbon dioxide are produced for every 6 moles of oxygen consumed during the oxidation of a mole of glucose, which is a respiratory quotient (RQ) of 1. See Table HE-5-B1.

When the moles of oxygen required for the complete oxidation of one mole of glucose is expressed as a volume, the oxidation of one mole of glucose consumes 134.4 liters of oxygen. The energy released during this oxidation is 673 kcal, or 5.007 kcal for each liter of oxygen utilized. The value, 5.007 kcal/liter $\text{O}_2$ is the caloric equivalent of glucose. Starch, a more complex carbohydrate, has a caloric equivalent of 5.061 kcal/liter $\text{O}_2$.

The complete oxidation of a mole of fatty acid, like palmitic acid, does not have the same stoichiometry or respiratory quotient as the oxidation of glucose. The oxidation of a fatty acid is expressed by following equation:

$$23 \text{O}_2 + C_{16}\text{H}_{32}\text{O}_2 = 16 \text{CO}_2 + 16 \text{H}_2\text{O}$$

As shown in this equation, 16 moles of carbon dioxide are produced for every 23 moles of oxygen consumed during the oxidation of one mole of palmitic acid, which is a respiratory quotient (RQ) of 0.696. The caloric equivalent of this fatty acid is 4.699 kcal/liter $\text{O}_2$.

The complete oxidation of a mole of protein, like albumin, is expressed by the following equation:

$$C_{72}\text{H}_{112}\text{N}_2\text{O}_{22}\text{S} + 77 \text{O}_2 = 63 \text{CO}_2 + 38 \text{H}_2\text{O} + \text{SO}_3 + 9 \text{CO(NH}_2)_2$$

As shown in this equation, 63 moles of carbon dioxide are produced for every 77 moles of oxygen consumed during the oxidation of a mole of albumin, which is a respiratory quotient (RQ) of 0.818. The caloric equivalent of this protein is 4.820 kcal/liter $\text{O}_2$.

In indirect calorimetry, the amount of heat produced during the oxidation of food is determined from the amount of oxygen consumed during metabolism. And, the amount of oxygen consumed is measured using a spirometer and a carbon dioxide/oxygen gas analyzer. The spirometer determines the volumes of air entering and exiting the lungs; and, the gas analyzer measures the concentration of oxygen and carbon dioxide in inspired and expired air. When the concentrations and the volumes are brought together in a series of equations, the volume of oxygen consumed per minute (VO$_2$) by the subject during various activities can be determined. The heat production and the metabolic rate of the subject are determined from the subject’s oxygen consumption and body surface area.
Table HE-5-B1: Respiratory Quotient (RQ) and Caloric Equivalent as a Function of the Proportions of Energy Sources.

<table>
<thead>
<tr>
<th>RQ</th>
<th>Caloric Equivalent (kcal/liter O₂)</th>
<th>Energy Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60</td>
<td>4.59</td>
<td></td>
</tr>
<tr>
<td>0.65</td>
<td>4.64</td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>4.69</td>
<td>Fat-Palmitic Acid (4.70)</td>
</tr>
<tr>
<td>0.75</td>
<td>4.74</td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td>4.80</td>
<td>Protein-Albumin (4.82)</td>
</tr>
<tr>
<td>0.85</td>
<td>4.86</td>
<td>Average Nutrition</td>
</tr>
<tr>
<td>0.90</td>
<td>4.92</td>
<td></td>
</tr>
<tr>
<td>0.96</td>
<td>4.99</td>
<td>Glucose (5.01)</td>
</tr>
<tr>
<td>1.00</td>
<td>5.05</td>
<td>Starch (5.06)</td>
</tr>
</tbody>
</table>

In this experiment, students will measure the resting metabolic rate (RMR) of a subject using a standardized set of conditions designed to minimize the effects of ingested food, temperature, and activity on the metabolic rate. Under the optimal conditions for measuring RMR:

- The subject should not ingest any food during the 12 hours prior to the test.
- The subject should be physically and mentally relaxed.
- The core temperature of the subject should be normal.
- The temperature of the room in which the test is conducted should be comfortable. A temperature that is a few degrees above or below 24°C (75°F) is suitable.

To measure basal metabolic rate (BMR), more stringent conditions must be met:

- Any drug or substance which could affect metabolism is avoided for 24 hours prior to the test; this includes caffeine, nicotine, and alcohol, and methylxanthine-type medications.
- The subject should avoid high sugar meals or snacks in the 24 hours before the test. These substances would falsely increase overall metabolic rate.
- Emotional disturbance must be minimized. Studies have shown that emotional upset, particularly apprehension, causes increases 15-40% increases in BMR.
- The test is scheduled in the morning, after the subject has a good night’s sleep at the facility where the test is conducted.
• The subject must be awake, but resting in bed. Sleep depresses BMR by about 10%, any muscle activity causes increases in BMR.

• The definitive BMR value should only be determined after at least ten minutes of steady state recording from the subject in the supine or sitting position. A steady-state condition exists when the VO2, VE, and heart rate do not vary by more than +5% over a five minute period.

The subject’s resting metabolic rate (RMR) will be measured using the iWorx spirometer, iWire-GA CO2/O2 gas analyzer, and iWorx data acquisition unit with LabScribe software. These devices and the software are configured to provide quick and easy measurements of the oxygen consumed by the subject. Then, the oxygen consumption and four formulas will be used to determine the subject’s heat production, and predicted and observed metabolic rates at the time of the experiment. The metabolic rate of the subject after recovering from moderate exercise will also be determined as a comparison.
Experiment HE-5: Resting Metabolic Rate (RMR)

Equipment Required
PC or Mac Computer
IXTA data acquisition unit, power supply, and USB cable
Flow head tubing and A-FH-1000 flow head
A-GAK-201 Reusable mask and non-rebreathing valve
6ft Smooth-bore tubing (35mm I.D.)
5 Liter Mixing Chamber
Nafion gas sample tubing
iWire-GA CO₂/O₂ Gas Analyzer with filter
A-CAL-150 Calibration kit
3 Liter Calibration syringe

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.
3. Turn on the IXTA and the iWire-GA.
4. Open LabScribe.
5. Click Settings → Human Exercise-iWireGA → RMR.
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)

Setup the Metabolic Cart
1. Locate the A-FH-1000 flow head and tubing in the iWorx kit (Figure HE-5-S1).
Figure HE-5-S1: The A-FH-1000 flow head, and airflow tubing.

2. Carefully attach the two airflow tubes onto the two sampling outlets of the A-FH-1000 flow head and the other ends of the two airflow tubes onto Channel A1 on the front of the IXTA (Figure HE-5-S4).

Note: Make sure to connect the airflow tubing so that the ribbed tube is attached to the red outlet port of the flow head and also to the red inlet port of the spirometer. The smooth side of the tubing attaches to the white ports.

3. Locate the mixing chamber in the iWorx kit (Figure HE-5-S2).

4. Connect the inlet of the A-FH-1000 flow head to the outlet of the mixing chamber (Figure HE-5-S3).

Note: Be sure to connect the flow head to the mixing chamber so that the red outlet port is facing towards the mixing chamber.

Figure HE-5-S2 and HE-5-S3: The mixing chamber showing the 1000L/min flow head connected to the outlet.
5. Locate the non-rebreathing valve, mask, and smooth interior tubing in the iWorx kit (Figure HE-5-S5).

6. Attach one end of the smooth interior tubing to the inlet of the mixing chamber (Figure HE-5-S6), and the other end to the outlet of the non-rebreathing valve. There are arrows on the valve that indicate the direction of air flow.

7. Attach the mask to the side port of the non-rebreathing valve.

Figure HE-5-S4: The iWire-GA gas analyzer connected to an IXTA. All tubings are connect properly in this image.
8. On the iWire-GA, place one filter on the “Room Air” port, place a second filter on the “Sample In” port. Attach the braided end of the Nafion sampling tube to the filter on the “Sample In” port.

9. Place the other end of the Nafion sampling tube on the gas sampling port near the outlet of the mixing chamber (Figure HE-5-S6).

10. Plug the outlet tubing from the iWire-GA to the port on the mixing chamber, opposite the flow head.
The non-rebreathing valve can be used with the attached mask or with an optional mouthpiece.

If the subject is using a mask (preferred method):
- Attach the head gear to the mask.
- Attach the non-rebreathing valve to the mask. Depending on the model of the mask, an adapter may be required.
- Instruct the subject to try on the assembly. Adjust the straps so that the mask fits the subject comfortably. Make sure there are no leaks around the mask.

If the subject is using a mouthpiece:
- Attach the headgear to the brackets on the non-rebreathing valve. The pair of straps with the narrowest spacing go over the top of the subject’s head.
- Connect the mouthpiece to the side port of the valve so that the valve is oriented horizontally, and the saliva trap of the mouthpiece is pointed downward.
- Instruct the subject to try on the assembly. Adjust the straps so that the mouthpiece fits the subject comfortably. Make sure there are no leaks between the mouthpiece and the valve or around the mouthpiece.

The gas analyzer must warm up for at least 15 minutes.

Note: For increased accuracy, users must complete the flow Head Calibration procedure. Please see Appendix I for directions on how to perform this calibration. The calibration of the 1000L flow head requires a 3L Calibration Syringe.

Load a PreSaved flow Head Calibration (*.iwxfcd) File

Note: This procedure is used once a calibration curve has been generated using the Spirometer Calibration directions in Appendix I.

All of the following directions will be prompted by the software. Follow the directions as they pop up on the LabScribe software.

1. Load the lab settings file you wish to perform as stated in the “Start the Software” section (Figure HE-5-S7).
2. Assemble the spirometer, flow head, tubing, mixing chamber and calibration syringe as shown in Appendix I or in the Spirometer Calibration directions.
3. Click the Setup button shown in the left side window. Follow the directions as prompted by the (Figure HE-5-S8). The Online Setup Dialog window will open
   - Enter your subject's information or Load a subject from a previously saved file.
   - Click “Settings” to change any parameters you wish to view (Figure HE-5-S9).
Figure HE-5-S7: Initial screen for starting a Fitness Assessment test. Follow the directions as prompted by the buttons on the left side of the window.

Figure HE-5-S8: Online Metabolic Setup Dialog window.
Figure HE-5-S9: Settings dialog of the Online Metabolic Setup window.

4. Perform the Quick Flow Calibration by clicking the button and following the prompted directions (Figure HE-5-S10).
   - When you click “Load”, you will be prompted to load the .iwxfcd file created when you performed the full flow head calibration.

Figure HE-5-S10: Spirometer Calibration dialog window.
5. Select Save As in the File menu, type a name for the file. Click on the Save to save the data file.

**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 $\text{O}_2$ and $\text{CO}_2$ channels.

Connect the gas sample tubing of the A-CAL-150 Calibration Kit (Figure HE-5-S11) to the Luer-Lock connector on the output of the regulator.

![Calibration Kit (A-CAL-150)](image)

*Figure HE-5-S11 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-5-S12).
Figure HE-10 -S12: Advanced units conversion dialog for room air and calibration gas.
Appendix I: Initial Spirometer flow head Calibration

For accuracy of measurements, users must include this calibration procedure as part of the Exercise Physiology Lab protocol.

*It is suggested that this procedure be followed at the beginning of every term and when using a new flow head-spirometer combination.*

Note: This calibration protocol precedes the actual calibration of the GA-200 or GA-300 gas analyzer. You will not need the gas analyzer at this time.

Note: Whenever you will be using a different flow head, you will need to repeat this calibration procedure from the beginning by loading a new Spirometer Calibration settings file.

1. Open the LabScribe software.
2. Click Settings - Human Exercise-iWireGA. Choose SpirometerCalibration to launch the calibration settings file.
3. Assemble the flow head, tubing, mixing chamber and calibration syringe.
4. Plug the tubing into the internal spirometer channel A1.
   
   • Connect the flow head to the IXTA using the flow head tubing, making sure that the ribbed side of the tubing connects the red marked port on the flow head to the red marked port on the spirometer (Figure HE-5-S13).
   
   • Connect the smooth side of the tubing to the other ports.
5. Connect end of the 1000L flow head with the red marked onto white flange of the mixing chamber. Make sure the tubing is in an upright direction (Figure HE-5-S14).

![Figure HE-5-S13: The 1000L flow head and Figure HE-5-S14: The 1000L flow head attached to the mixing chamber showing the tubing in an upright position and the red port facing the mixing chamber.](image-url)
Note: Make sure the red port on the flow head faces into the mixing chamber.

6. Connect one end of the smooth bore tubing to the 3L calibration syringe as shown in Figure HE-5-S16).

7. Connect the other end of the smooth bore tubing to the mixing chamber, opposite the flow head (Figure HE-5-S17).

8. If also setting up the gas analyzer at this time:
   - Connect the braided Nafion tubing to the filter on the gas analyzer and to the flow head side of the mixing chamber. Make sure the braided end is connected to the filter (Figure HE-5-S15).
   - Connect the thin flexible tubing from the outlet of the gas analyzer to the port next to the smooth bore tubing on the opposite side of the mixing chamber.
9. If not using the gas analyzer at this time, connect the flexible tubing from the port on one side of the mixing chamber to the port on the other. This ensures there is no air leaking from the chamber.

10. Pull the plunger on the 3L Calibration Syringe all the way out until it stops.

11. Click the Record button.

12. Wait for at least 10 seconds of recording so that there is no flow of air moving through the syringe.

13. Push the plunger in all the way until it stops. Pull the plunger out all the way until it stops.

14. Repeat the procedure in Step 13, for at least 50 repetitions, varying the speed and force on the plunger. Make sure to pause between strokes.

15. The faster the speed of the stroke, the higher the flow through the calibration syringe.

Note: Ideally the flow head calibration recording should span air flow values to include the minimum to maximum flow levels for the particular experiment being conducted.

16. After at least 50 repetitions have been performed, wait at least 5 seconds after the final repetition and then click Stop.

17. Select Save As in the File menu, type a name for the file.

18. Click on the Save button to save the raw data for generation of a flow head calibration *.iwxfcd file.

19. Click AutoScale on the Air flow channel.

20. Use the Display Time icons to adjust the Display Time of the Main window to show the complete calibration data (Figure HE-5-S18).

21. Click the Double Cursor icon so that two cursors appear on the Main window.

Figure HE-5-S18: The LabScribe toolbar.

22. Click Advanced on the main toolbar. Then click Metabolic, and Calibrate flow head (Figure HE-5-S19).

23. Place the two blue vertical cursors so that:
• The left-hand most cursor is on the flat line prior to the start of the calibration data. Make sure the cursor is at the beginning of the 10 second baseline.

• The right-hand most cursor is on the flat line after the final calibration stroke (Figure HE-5-S20).

Figure HE-5-S20: Calibrate flow head dialog window.

24. In the new window that opens (Figure HE-5-S22), enter these values:
   • flow channel = Expired Air flow
   • Baseline = Use the first 10 seconds as zero
   • Calibrate difference between cursors to 3 L.

25. Click the Calibrate the difference between cursors to button. This will generate the curve as shown above.

26. A new window will open prompting you to Save your file as an *.iwxfcd flow head calibration file. Name your file and click Save.

27. Click OK.

Note: At this point, a raw calibration data file (*.iwxdata) and a flow head calibration file (*.iwxfcd) have been generated.

28. Exit LabScribe or open a Human Exercise lab settings file.

Note: Once a saved *.iwxfcd file is loaded, a simple 5-10 stroke calibration procedure can be used to update the file for immediate use.
Figure HE-5-S21 The calibration recording showing the vertical cursors in the correct position for generating a calibration curve. Note – the recording you generate should look similar to this.

Figure HE-5-S22: Calibration syringe data.
Experiment HE-5: Resting Metabolic Rate (RMR)

Before Starting

1. Read the procedures for the experiment completely before beginning the experiment. Have a good understanding of how to perform the experiment before making recordings.
2. It is important that the subject is healthy and has no history of respiratory or cardiovascular problems.
3. Allow the spirometer 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 and exhale through the mask 2 or 3 times while the complete spirometry circuit is assembled.
   • Click on the AutoScale button at the upper margin of the Expired Air Flow and Lung Volume channels.
   • If the proper end of the flow head is attached to the outlet of the mixing chamber, the traces on the Air Flow and Lung Volume channels will go up when the subject exhales.
   • If the traces on these channels go down during exhalation, remove the flow head from the outlet of the mixing chamber and place the other end of the flow head on the outlet of the mixing chamber.
   • Click on the Stop button.
5. 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.
Set Up the Online Metabolic Calculations Module

*Note: This should be completed during the setup portion of lab and should open automatically. If not:*

1. Pull down the Advanced menu and select Metabolic.
2. Select Mixing Chamber: Online Calculations from the submenu to open the Online Metabolic Calculations Dialog window (*Figure HE-5-L1*).
3. Click the down arrow to the left of the dialog window (Metabolic).
   - Click Setup.
   - Make sure the correct channels are selected for CO2, O2, and Volume.
   - Select the time for averaging - generally between 10 and 30 seconds.
   - Enter the weight of the subject.
   - Set the O2 and CO2 concentrations for inhaled air.
   - Click OK.
4. The Online Metabolic Calculations are now set to record real time parameters during the lab experiments.

*Figure HE-5-L1: Online Metabolic Calculations dialog window.*
Exercise 1: Resting Metabolic Rate

Aim: To determine the resting metabolic rate of a subject using the conditions described earlier.

Procedure

1. Instruct the subject to sit quietly, become accustomed to breathing through the spirometry equipment, and breathe normally before any recordings are made.

2. Once the subject and recording equipment are all prepared, disconnect the smooth-bore tubing from the mixing chamber to ensure that no air is entering the system at this time.

Note: So that the LabScribe software can zero the Lung Volume channel, no air can be moving through the system during the first ten seconds of the recording.

3. Type <Subject’s Name> baseline in the Mark box that is to the right of the Mark button.

4. Click on the Record button. After waiting ten seconds for the Lung Volume channel to zero, the smooth bore tubing should be reconnected to the mixing chamber. Make sure that the tubing is firmly attached to the chamber.

5. Click the AutoScale buttons on all channels.

6. On the Expired CO2 Concentration (%) channel, notice that the CO\textsubscript{2} concentration increases in the first few minutes of the recording and then reaches a near-steady level.
   - The time that it takes the chamber to be filled with expired air and reach a near-steady level of carbon dioxide is dependent on the tidal volume and respiration rate of the subject and the volume of the mixing chamber. It will take longer to fill the chamber if the subject’s respiration rate and tidal volume are low, or the chamber is large.
   - Every breath exhaled into the mixing chamber pushes a matching volume of expired air out of the mixing chamber.
   - Record baseline data, while the mixing chamber air is replaced with the subject’s expired air, for approximately 5-10 minutes prior to beginning any experiments.

7. On the Expired O2 Concentration (%) channel, notice that the O\textsubscript{2} concentration decreases in the first few minutes of the recording and then stays a near-steady level. As pointed out in the previous step, the size of the mixing chamber, the tidal volume, and respiration rate of the subject, determine the time it takes for the concentration of oxygen to reach that near-steady level.

8. On the Expired Air Volume channel, the STPD Volume-MC spirometry function converts the data from the Air Flow channel to the volumes of expired air at STPD. Notice that the recorded volume increases in a ramp-like manner with each breath.

9. Continue to record until approximately five minutes of data are recorded while the concentrations of oxygen and carbon dioxide in expired air are at a steady level.

10. Once the appropriate duration of data is recorded, click Stop to halt the recording. Your recording should be similar to the data displayed in Figure HE-5-L2.
11. Select Save As in the File menu, type a name for the file. Choose a destination on the computer in which to save the file, like your lab group folder. Designate the file type as *.iwxdata. Click on the Save button to save the data file.

**Data Analysis**

1. Display the complete data recording in the Main window. Use the Display Time icons to adjust the Display Time of the Main window to show the complete recording on the Main window.

2. Select and display a 60-second section of the recording while the oxygen and carbon dioxide concentrations were at a steady level on the Main window.

3. Select the 60-second section of the recording by:
   - Placing the cursors on either side of the 60-second section of data; and
   - Clicking the Zoom between Cursors button on the LabScribe toolbar (Figure HE-5-L3) to expand the selected section of data to the width of the Main window.

![Figure HE-5-L2: Gas concentrations and volumes of a resting subject displayed on the Main window. Concentrations of gases reach a steady state after the mixing chamber is filled.](image-url)
Calculate and Plot Metabolic Parameters

Values for VO\textsubscript{2}, VCO\textsubscript{2}, RER, TV, and other parameters (Table HE-5-L1) from the segments of the test can be calculated automatically by using the Metabolic Calculations window.

1. To use the Metabolic Calculations window, pull down the Advanced menu and select Metabolic. Select Mixing Chamber: Offline Calculations from the submenu to open the Metabolic Calculations Dialog window.

2. On the left side of the Metabolic Calculations window:
   - Pull down the CO\textsubscript{2}, O\textsubscript{2}, Volume, Heart Rate, and Energy Channel menus to select the channels on which the CO\textsubscript{2} and O\textsubscript{2} concentrations, lung volumes, heart rates, and workload were recorded.
   - When analyzed, the data file will be divided into time segments. The average of each parameter in each segment will be reported in the data table on the Metabolic Calculations window. Enter the time (in secs) in the Average box to select the time length of each segment.

   **Note:** For this experiment - the time for averaging should be 60 seconds.

   - In the O\textsubscript{2} and CO\textsubscript{2} Concentrations in Inhaled Air boxes, enter the concentrations of oxygen and carbon dioxide in the inhaled air, which is room air in most tests.

3. Click on the Calculate button on the left side of the Metabolic Calculations Dialog window to calculate the average value of each parameter listed in the table for each time segment of the recorded data, and to plot the selected parameters against each other in the plot panel (Figure HE-5-L4).

4. In the lower left corner of the plot panel, click on the arrow to open the pull-down menu listing the types of plots (Table HE-5-L2) that can be made with the metabolic parameters calculated by this analytical tool. Select the plot to be displayed in the plot panel when the calculations are performed.

   **Note:** The first time using the Advanced Metabolic Calculations will require the entry of a User Name and Serial Number. These were supplied when you received your equipment.
Table HE-5-L1: List of Parameters Calculated on the Mixing Chamber Offline Metabolic Window

<table>
<thead>
<tr>
<th>Term</th>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abs.VO₂</td>
<td>Absolute VO₂</td>
<td>Volume of oxygen (O₂) consumed per minute</td>
<td>Liters/minute</td>
</tr>
<tr>
<td>Abs.VCO₂</td>
<td>Absolute VCO₂</td>
<td>Volume of carbon dioxide (CO₂) produced per minute</td>
<td>Liters/minute</td>
</tr>
<tr>
<td>Rel.VO₂</td>
<td>Relative VO₂</td>
<td>Volume of O₂ consumed per kg body weight per minute</td>
<td>milliliters/kg/minute</td>
</tr>
<tr>
<td>Rel.VCO₂</td>
<td>Relative VCO₂</td>
<td>Volume of CO₂ produced per kg body weight per minute</td>
<td>milliliters/kg/minute</td>
</tr>
<tr>
<td>RER</td>
<td>Respiratory Exchange Ratio</td>
<td>Ratio of VCO₂/VO₂</td>
<td>None</td>
</tr>
<tr>
<td>REE</td>
<td>Resting Energy Expenditure</td>
<td>5.46 (Absolute VO₂) + 1.75 (Absolute VCO₂)</td>
<td>kcal/day</td>
</tr>
<tr>
<td>METS</td>
<td>Metabolic Equivalent of Task</td>
<td>1 MET = 3.5ml O₂/kg/min or 1kcal/kg/hr</td>
<td>MET</td>
</tr>
<tr>
<td>O₂ Min.</td>
<td>O₂ Minimum - exhalation</td>
<td>Minimum concentration of O₂ recorded during test period</td>
<td>Percentage</td>
</tr>
<tr>
<td>CO₂ Max.</td>
<td>CO₂ Maximum - exhalation</td>
<td>Maximum concentration of CO₂ recorded during test period</td>
<td>Percentage</td>
</tr>
<tr>
<td>VE</td>
<td>Expired Tidal Volume</td>
<td>Volume of air displaced during normal exhalation</td>
<td>Liters/breath</td>
</tr>
<tr>
<td>P</td>
<td>Power</td>
<td>Workload during the stages of the test</td>
<td>Watts</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
<td>Number of beats in a minute - divide (60 sec/min) by the beat period (sec/breath)</td>
<td>Beats/Minute</td>
</tr>
</tbody>
</table>
Table HE-5-L2: Plots Available on the Offline Metabolic Window.

<table>
<thead>
<tr>
<th>Available Plots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Y-Axis Parameter 1</strong></td>
</tr>
<tr>
<td><strong>Y-Axis Parameter 2</strong></td>
</tr>
<tr>
<td><strong>Y-Axis Parameter 3</strong></td>
</tr>
<tr>
<td><strong>X-Axis Parameter</strong></td>
</tr>
</tbody>
</table>
Figure HE-5-L3: The metabolic parameters, and plots of VO$_2$, VCO$_2$, and RER vs. Time, displayed in the Metabolic Calculations window used offline to analyze data collected during an aerobic fitness test. Notice that the VO$_2$ and VCO$_2$ values increase quickly as the subject performs more strenuous segments of the test.
Calculations

1. Determine the body surface area (BSA) of the subject using the Monsteller Formula. In many clinical tests, this formula has been established as a very accurate method for determining body surface area. The formula can be used easily on a calculator with a square root function:

\[ \text{BSA (m}^2\text{)} = \left( \frac{\text{Height (cm) x Weight (kg)}}{3600} \right)^{\frac{1}{2}} \]

2. Determine the observed resting heat production of the subject for each one-minute resting measurement period using the following formula:

\[ \text{Observed Resting Heat Production (kcal/m}^2\text{/hr)} = \frac{\text{O}_2 \text{ Consumed (LO}_2\text{/min)} \times 60(\text{min/hr)} \times 4.859 \text{(kcal/LO}_2\text{)}}}{\text{Body Surface Area (m}^2\text{)}} \]

The amount of heat produced for the amount of oxygen consumed is dependent upon the diet of the subject. In this formula, it is assumed that the subject’s diet is composed of the average proportions of protein, carbohydrates, and fats which has a caloric equivalent equal to 4.859 kcal/liter O\textsubscript{2} and a corresponding respiratory quotient (RQ) equal to 0.85.

3. Determine the predicted basal heat production of the subject using one of the following Harris and Benedict Equations:

- For men: Predicted Basal Heat Production\textsubscript{Men} (kcal/m\textsuperscript{2}/hr) =

\[ (66.4730+(13.7516 \times W)+(5.0033 \times H)-(6.7550 \times A))/24 \]

- For women: Predicted Basal Heat Production\textsubscript{Women} (kcal/m\textsuperscript{2}/hr) =

\[ (655.0955+(9.5634 \times W)+(1.8496 \times H)-(4.6756 \times A))/24 \]

Where \( W \) is the subject’s weight in kilograms, \( H \) is the subject’s height in centimeters; and \( A \) is the subject’s age in years.

4. Determine the percentage deviation between the predicted basal and observed resting metabolic rates of the subject for each one-minute resting measurement period using the following formula:

\[ \text{Percent Deviation of Observed Resting Metabolic Rate} = \frac{\text{Observed RMR} - \text{Predicted Basal Heat Production}}{\text{Predicted Basal Heat Production}} \]
Exercise 2: Effect of Moderate Exercise on RMR

Aim: To measure the effects of moderate exercise on the oxygen consumed and heat production of a subject after a period of recovery from exercise.

Procedure

1. Instruct the subject to perform five minutes of moderate exercise (brisk walking).
2. After completing the exercise period, instruct the subject to rest in a reclining position for eight minutes.
3. Use the same procedures used in Exercise 1 to record the oxygen consumed by the subject during the first, second, third, and fourth minutes after the end of the eight-minute rest period.
4. Mark the recording with comments that indicate the name of the subject and the beginning of each minute being recorded.

Data Analysis

1. Use the same procedures used in Exercise 1 to determine the oxygen consumed in each minute ($\text{VO}_2$) of the post-recovery period.
2. Record the values for the oxygen consumed in each minute ($\text{VO}_2$) of the post-recovery period on Table HE-5-L3.
3. Use the same procedures used in Exercise 1 to determine the observed heat production and resting metabolic rate of the subject in each minute of post-recovery. Record these measurements in the data table.

Questions

1. Was the subject’s observed resting metabolic rate recorded during the initial resting period higher or lower than his or her predicted basal metabolic rate?
2. Are there any factors in the calculation of the subject’s predicted basal metabolic rate that could lead to an inaccurate determination?
3. Are there any factors in the experimental conditions that could lead to an inaccurate determination of the subject’s observed resting metabolic rate?
4. Was the subject’s observed resting metabolic rate recorded during the post-recovery period higher or lower than his or her predicted basal metabolic rate?
5. Was the subject’s observed resting metabolic rate recorded during the post-recovery period higher or lower than his or her observed resting metabolic rate that was recorded during the initial resting period?
Table HE-5-L3: Oxygen Consumed (VO2), Heat Production, and Metabolic Rate of Subject at Rest and after Exercise.

<table>
<thead>
<tr>
<th>Environmental &amp; Personal Factors</th>
<th>Values of Factors</th>
<th>Experimental Periods</th>
<th>Oxygen Consumed (ml/min)</th>
<th>Observed Heat Production (kcal/m²/hr)</th>
<th>Resting Metabolic Rate (% Above or Below Normal for Age/Gender)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Temperature (°C)</td>
<td></td>
<td>Resting-Min 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barometric Pressure (mmHg)</td>
<td></td>
<td>Resting-Min 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td></td>
<td>Resting-Min 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td>Resting-Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>Post-Rest-Min 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td></td>
<td>Post-Rest-Min 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td>Post-Rest-Min 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Basal Heat Production</td>
<td></td>
<td>Post-Rest-Min 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kcal/m²/hr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>