**IMPORTANT TERMS**

1. Resting Metabolic Rate (RMR)
2. Basal Metabolic Rate (BMR)
3. Indirect calorimetry
4. Respiratory exchange ratio (RER)

**IMPORTANT CONCEPTS**

1. Use of RER to determine fuel consumption
2. Factors affecting RMR and BMR
   a. Body size
   b. Body composition
   c. Diet

**INTRODUCTION**

Resting metabolic rate (energy expenditure, RMR) will be evaluated using an indirect technique called open circuit spirometry. Measuring the volume and composition of expired air, and converting oxygen consumption to kilocalories will determine energy expenditure. The First Law of Thermodynamics states that energy can neither be destroyed nor created but only change in form. This idea is the theoretical basis behind open circuit spirometry.

Basal metabolic rate (BMR) is the minimal energy requirement to sustain vital functions during absolute rest. BMR includes the energy expended in ventilation, blood circulation, intestinal contraction, the activities of internal organs, and maintenance of thermal equilibrium. Stringent measurement of BMR requires that the subject be in a fasting (minimum of twelve hours), well-rested state having not exercised for the previous twelve hours and being in a supine position within a nonstressful, controlled environment for a minimum of thirty minutes prior to measurement.

Resting metabolic rate (RMR) is the energy expended while an individual is resting quietly in a supine position. RMR and BMR are sometimes used interchangeably but there are some small differences. RMR includes: the thermal effect of substrate metabolism (TEM), and heightened metabolic activity due to prior physical or mental activity and/or stress. These factors, collectively known as facultative thermogenesis, may be thought of as components of a person’s resting metabolic rate (RMR), and are not part of the BMR.

**FACTORS AFFECTING BASAL/RESTING METABOLIC RATE**

Body size and body composition are important determinants of basal/resting metabolic rate. A larger individual will generally have a higher basal metabolic rate than a smaller individual with a comparable body composition. A larger body will require a greater amount of energy at rest to support larger organ systems (ventilatory, circulatory, etc.) a greater muscle mass, and to maintain thermal equilibrium. Basal/resting metabolic rates are often expressed relative to an individual’s estimated body surface area in order to allow a comparison between individuals of different body sizes.

Body composition is also a major determinant of basal/resting metabolic rate. For two individuals of a given size, the individual with the greater lean body mass will generally have a higher BMR/RMR. This can be attributed to the greater metabolic activity of muscle as compared to fat. Differences in basal/resting metabolic rate between men and women (males and usually 5-10 percent higher) are a result of differences in body composition. If basal/resting metabolic rates are expressed per unit of fat-free mass, the difference between male
and female metabolic rates disappears. Most of the decrease in resting metabolic rate associated with aging is generally associated with body composition changes (i.e., a decrease in fat free mass).

The amount and type of food ingested by an individual affect RMR. It has been shown that severe caloric restriction decreases RMR. Resting metabolism represents the greatest percentage of daily caloric expenditure in sedentary individuals; therefore weight loss is slowed down. This situation slows the weight loss that would be expected due to the amount of dietary restriction and negative caloric balance. Also if severe caloric restriction continues, the weight loss will become progressively slower.

To obtain a true RMR value, the subject must be in a completely rested state and lying in the supine position. Use of leg and core postural muscles when the subject is sitting or standing will result in a greater oxygen consumption and cause the RMR to be higher. Additionally, a fasted condition is required to minimize the thermic effect of food. Thus, for this experiment, the pre-exercise energy expenditure is not a true RMR but rather a pseudo-resting measure, with the subject in a standing position.

**MEASUREMENT OF METABOLIC RATE OR ENERGY EXPENDITURE**

Energy expenditure can be measured in two different ways. The determination of energy expenditure by measuring the amount of heat produced over a period of time is called **direct calorimetry**. The determination of energy expenditure by measuring the amount of oxygen consumed over a period of time is called **indirect calorimetry**.

The experiments done by Laviosier and Laplace are important as they demonstrate that the rate of heat production by the human body is strongly correlated with the rate of substrate metabolism, which can be determined by measuring oxygen consumption and carbon dioxide production. During substrate metabolism, oxygen is consumed and utilized in the degradation of substrates (carbohydrate, fat, and protein) and carbon dioxide is produced.

As all aerobic energy-producing reactions in the body depend on oxygen, measuring a person’s oxygen consumption provides an indirect estimate of energy expenditure. During metabolic energy transformations, oxygen is consumed and heat is produced. Either of these variables can therefore be used to estimate energy expenditure. Using the fact that one liter of oxygen liberates 4.82 kcal of heat energy when a mixture of carbohydrate, fat and protein is burned in a bomb calorimeter, a highly accurate indirect measure of energy production is possible. Two procedures of indirect calorimetry are closed circuit and open-circuit spirometry. You will use open-circuit spirometry for this laboratory experiment.

In the open circuit method, the subject breathes in ambient room air. Expired air is either collected in some form of closed container (i.e., Douglas bag, gasometer, meteorological balloon), from which the volume is later obtained, or is passed directly through a gas meter. Both the volume of air breathed per unit time and the percentage of oxygen and carbon dioxide exhaled are needed for determination of oxygen consumption and energy expenditure.

**RESPIRATORY EXCHANGE RATIO (RER)**

The **respiratory exchange ratio (RER)** is the ratio of the volume of CO₂ produced to the volume of O₂ consumed at the whole body level. Because of inherent chemical differences in the composition of carbohydrates, fats, and proteins, different amounts of oxygen are required to completely oxidize the carbon and hydrogen atoms in carbohydrates, fats, and protein into carbon dioxide and water. Thus the quantity of carbon dioxide produced relative to the oxygen consumed will vary depending on the proportional mix of energy nutrients (carbohydrate, fat, protein) metabolized.

\[
\text{RER} = \frac{\text{VCO}_2}{\text{VO}_2}
\]

This ratio is termed the respiratory exchange ratio (RER). The ‘RER’ value is important not only in determining the body’s rate of energy expenditure, but it also enables the investigator to determine the nutrient mixture being metabolized during rest or exercise.
RER for Carbohydrate

The ratio of hydrogen to carbon and oxygen atoms in carbohydrates is 2:1. Therefore all of the oxygen consumed is used to oxidize the carbon to carbon dioxide. Consequently, during the complete oxidation of a glucose molecule, six molecules of carbon dioxide are produced and six molecules of oxygen are consumed. Thus, the RER for carbohydrate will be: \( \frac{V_{CO_2}}{V_{O_2}} = \frac{6}{6} = 1 \). The overall reaction is:

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O
\]

RER for Fat

The chemical composition of fats differs from carbohydrates in that fats contain considerably less oxygen atoms in proportion to atoms of carbon and hydrogen. Consequently, when fat is oxidized, more oxygen is required to convert fat into \( CO_2 \) and \( H_2O \). For example, when palmitic acid is oxidized, 16 carbon dioxide molecules are produces for every 23 oxygen molecules consumed:

\[
C_{16}H_{32}O_2 + 23O_2 \rightarrow 16CO_2 + 16H_2O
\]

Therefore, the RER for this fatty acid is: \( \frac{16CO_2}{23O_2} = 0.696 \). The RER value for fat is considered to be 0.70.

RER for Protein

Protein is first determined (the amino or nitrogen groups are removed) in the liver and the nitrogen and sulfur fragments are released and excreted. The remaining fragments (‘keto acids’) are then oxidized to carbon dioxide and water. As with fats, more oxygen is needed for complete combustion. For example, the protein albumin is oxidized as follows:

\[
C_{72}H_{112}N_2O_{22}S + 77O_2 \rightarrow 63CO_2 + 38H_2O + SO_3 + 9CO(NH_2)_2
\]

The RER for this protein would be \( \frac{63CO_2}{77O_2} = 0.818 \). The RER for protein is 0.82.

Non-Protein RER

Once the nitrogen atoms and atoms other than carbon and oxygen are removed from protein, the protein ‘looks like’ a fat or carbohydrate. Therefore, it is not possible to separate out the contribution of protein in substrate utilization using expired air. Therefore, the RER is called a non-protein RER. It really is not a non-protein RER but rather one cannot determine the contribution of proteins to energy metabolism.

One way to estimate the contribution of protein to energy metabolism, is to measure urinary nitrogen. It has been determined that approximately 1 gram of urinary nitrogen is excreted for every 6.25 grams of protein metabolized, and every gram of nitrogen results in approximately 4.8 liters of \( CO_2 \) produced with 6.0 liters of \( O_2 \) consumed. With this information, it would be possible to estimate the contribution of protein to energy metabolism.

Rate of Energy Expenditure

The rate of energy expenditure of a subject during rest or activity is the amount of energy/heat liberated over a period of time. It is calculated by taking the oxygen consumed (\( VO_2 \)) times the caloric equivalent per liter of oxygen consumed (taken from Table 1) for the RER value obtained.

\[
\text{Rate of Energy Expenditure} = VO_2 \times \text{caloric equivalent (kcal/min)} = (l/min) \times (kcal/l)
\]

For example, using the mixed-diet RER of 0.82, the amount of energy liberated per liter of oxygen consumed is 4.825 kcal (see Table 1). If the rate of oxygen consumption (\( VO_2 \)) is 0.25 liters per minute, the rate of energy expenditure is:

\[
4.825\text{ kcal/l} \times 0.25\text{ l/min} = 1.2\text{ kcal/min}
\]
If the above data were obtained from a subject at rest, we refer to the rate of energy expenditure as the resting metabolic rate (RMR). Thus, for the above data, the RMR would be 1.2 kcal/min, or 72 kcal/hr.

**EXPERIMENTAL PROBLEM**

For this lab, each group will calculate and compare RER and energy expenditure values for two subjects (one trained, one untrained) at rest and during exercise. Through this experiment, you will 1) use RER data to determine the probable fuel source used at rest and during exercise, 2) observe how energy expenditure changes from rest to exercise and throughout exercise, and 3) compare resting and exercise energy expenditures in trained and untrained subjects. You should make hypotheses reflecting each of these goals.

**PROCEDURE**

**Equipment Required:**

1. Open circuit spirometry apparatus—computer analysis (metabolic cart)
2. Stop watch
3. Treadmill
4. Heart rate monitor

**Experimental Procedure:**

In this lab, each group will test two subjects.

Pre-test instructions for subjects:

1. Subjects must refrain from exercise 24 hours prior to test.
2. Subjects should minimize activity the day of the test, and if possible, drive to lab.
3. Subjects must fast (including all food and beverages, except water) for 12 hours prior to the test.

Test procedures:

1. Obtain subject data and environmental conditions (temperature, barometric pressure, and humidity). Record it on lab sheet.
2. Secure the heart rate monitor and prepare receiver to record heart rate.
3. Instruct subject to lay quietly on patient bed or a mat on the floor. Dim the lights and try to maintain a low-stimulus environment.
4. Calibrate the metabolic cart.
5. Input subject data into computer.
6. Secure the mouthpiece and head gear.
7. Begin collecting metabolic data.
8. Allow subject to rest quietly for 20 minutes. Record resting metabolic data.
9. Instruct the subject to stand quietly on the treadmill for 3 minutes. Record pre-exercise metabolic data.
10. At the end of the three minutes, record resting heart rate, VO₂ and VCO₂.
11. Begin exercise. The subject will walk on the treadmill for 8 minutes at a speed of 3.5 mph and a grade of 7%.
12. Record heart rate, VO₂ and VCO₂ at the end of each minute

**Data Analysis:**

1. Calculate the RER at rest and for each minute of exercise. Use the final minute of rest for resting calculations. (See sample calculations below.)
2. Use the caloric equivalents from Table 1 and the RER values you calculated to calculate energy expenditure at rest and during each minute of exercise. (See sample calculations below.)
3. Enter the descriptive data, RER values, and energy expenditure values for your two subjects on the google docs spreadsheet.
4. Based on what you’ve learned from writing previous lab reports, create a table that shows the subject descriptive data. Be sure that your table reflects a comparison between the trained and untrained groups.

5. Create the following two graphs, using the averages from the trained and untrained subjects:
   a. graph that compares resting and exercise RER in trained and untrained subjects. (Use the RER during the last minute of exercise for the exercise value.)
   b. graph that shows energy expenditure at rest and during 8 minutes of exercise in trained and untrained subjects.
   c. Be sure graphs include a title and descriptive caption.

6. Attach data collection tables and sample calculations to the end of your lab report.

Sample Calculations:

1. **Determine the Respiratory Exchange Ratio (RER)**

   \[
   \text{VO}_2 = 0.17 \text{ l/min} \\
   \text{VCO}_2 = 0.15 \text{ l/min} \\
   \]

   \[
   \text{RER} = \frac{\text{VCO}_2}{\text{VO}_2} = \frac{0.15}{0.17} = 0.8947
   \]

2. **Use Table 1 to convert R to its caloric equivalent and determine the rate of energy expenditure at rest (RMR) and during exercise.**

   From Table 1, an RER value of 0.89 is the equivalent of 4.911 kcal/l (4.911 kcal are liberated per liter of oxygen consumed).

   Energy expenditure (kcal/min) = \( \text{VO}_2 \text{ (l/min)} \times \text{caloric equivalent} \)

   \[
   = 0.17 \text{ l/min} \times 4.911 \text{ kcal/l} \\
   = 0.8349 \text{ kcal/min}
   \]

Lab Report Instructions

You should write up a lab report with introduction, methods, results, discussion that includes the information requested in the “Data Analysis” section above.

In the discussion section, summarize the data and address the following questions in paragraph format:

1. What was the probable fuel source during rest? Is this what you expected? Explain.
2. What was the probable fuel source at the end of the steady-state exercise? Is this what you expected? Explain.
3. How did energy expenditure change from rest to exercise? What happened to energy expenditure during the 8 minutes of exercise? Why does this happen?
4. How did the RMR and exercise energy expenditure values compare in the trained and untrained subjects? Discuss the physiological factors that might explain inter-subject differences in energy expenditure.
5. For this experiment, you compared energy expenditure in trained and untrained subjects. What would you expect to happen if, instead, you compared males and females? How would you expect energy expenditure to compare in males and females and why?

Be sure to reference material properly if you used it to obtain answers to lab report questions.
Data Collection Sheet  
(to be turned in with lab. You do not need to retype this for your results section.)

Note: *You must calculate the RER, not read it from the chart.*

Subject:

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<th>VC\textsubscript{O}_2 L/min</th>
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<th>HR</th>
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Subject:

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Table 1: Thermal Equivalent of O₂ for Non-Protein RER

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<th>% Kcal derived from Grams per liter O₂</th>
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<tr>
<td>All calculations are successful and sufficiently comprehensive to solve the problem and shown work is presented clearly and accurately.</td>
<td>Calculations are mostly successful and sufficiently comprehensive to solve the problem. Work is not necessarily presented.</td>
<td>Calculations are either unsuccessful or represent only a portion of the calculations required to comprehensively solve the problem.</td>
<td>Calculations are both unsuccessful and are not comprehensive.</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Representation</th>
<th></th>
<th>Milestones</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Skillfully converts relevant information into insightful mathematical portrayal in a way that contributes to a further or deeper understanding</td>
<td>Competently converts relevant information into an appropriate and accurate mathematical portrayal.</td>
<td>Completes conversion of information but resulting mathematical portrayal is only partially appropriate or accurate.</td>
<td>Completes conversion of information but resulting mathematical portrayal is inappropriate or inaccurate.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interpretation/Description</th>
<th></th>
<th>Milestones</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides thorough, accurate descriptions of information presented in mathematical forms and uses numerical information skillfully in the descriptions.</td>
<td>Provides accurate descriptions of information presented in mathematical forms. If numerical information is used in the description, it is accurate but not skillfully integrated.</td>
<td>Provides some accurate descriptions of information presented in mathematical forms, but occasionally makes minor errors (e.g., computations, units) or is vague.</td>
<td>Attempts to describe information presented in mathematical forms, but draws incorrect statements about what the information means.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Judgments/Conclusions</th>
<th></th>
<th>Milestones</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Uses the quantitative analysis of data as the basis for deep and thoughtful judgments, drawing insightful, carefully qualified conclusions from this work.</td>
<td>Uses the quantitative analysis of data as the basis for competent judgments, drawing reasonable and somewhat qualified conclusions from this work.</td>
<td>Uses the quantitative analysis of data as the basis for workmanlike (without inspiration or nuance, ordinary) judgments, drawing plausible conclusions from this work. No attempt to qualify the conclusions or minor errors exist in the conclusions.</td>
<td>Uses the quantitative analysis of data as the basis for tentative, basic judgments, although is hesitant or uncertain about drawing conclusions from this work. Or conclusions are not appropriate or are incorrect to the given data.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applies content knowledge, methods and/or results to new situations</th>
<th></th>
<th>Milestones</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Makes accurate and comprehensive conclusions about a new situation using information previously learned in another context.</td>
<td>Makes accurate conclusions about a new situation using information previously learned in another context.</td>
<td>Applies previously learned information to a new situation but makes some inaccurate conclusions.</td>
<td>Attempts to apply previously learned information to a new situation but makes inaccurate conclusions.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumptions</th>
<th></th>
<th>Milestones</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicitly describes assumptions and provides compelling rationale for why each assumption is appropriate. Shows awareness that confidence in final conclusions is limited by the accuracy of the assumptions.</td>
<td>Explicitly describes assumptions and provides compelling rationale for why assumptions are appropriate.</td>
<td>Explicitly describes assumptions.</td>
<td>Attempts to describe assumptions.</td>
<td></td>
</tr>
</tbody>
</table>