This chapter begins with a description of the measurement of aerobic metabolism by direct calorimetry and open-circuit indirect spirometry and proceeds with a discussion of oxygen drift as it occurs in submaximal exercise at approximately 70% VO₂max or above. The chapter also addresses oxygen consumption during incremental exercise to maximum, with emphasis placed on the criteria for the determination of maximal oxygen consumption. Respiratory quotient (RQ) and respiratory exchange ratio (RER) are compared and contrasted. The concepts and calculations for metabolic equivalents (METs), mechanical efficiency, and economy, as well as estimation techniques for oxygen consumption are discussed. The influence of sex and age on economy and possible mechanisms to explain the observed difference in children are described. The chapter ends with a discussion of the genetic influence on aerobic metabolic components.
AEROBIC METABOLISM DURING EXERCISE

MEDIA FOR INSTRUCTORS

To view the chapter resources and activities listed below, please visit The Physiology Place located at www.physiologyplace.com.

Chapter Features
- Objectives
- Passport to the Internet

Instructor Resources
- Chapter 5 Test

Student Resources
- Quiz 1 & 2
AEROBIC METABOLISM DURING EXERCISE

Outline

I. Introduction

II. Laboratory Measurement of Aerobic Metabolism
   A. Calorimetry
   B. Spirometry

III. Aerobic Exercise Responses
   A. Oxygen Consumption and Carbon Dioxide Production
      1. Short-Term, Light-to Moderate-Intensity Submaximal Exercise
      2. Prolonged, Moderate to Heavy Submaximal Exercise
      3. Incremental Exercise to Maximum
      4. Static and Dynamic-Resistance Exercise
   B. The Oxygen Cost of Breathing
   C. Respiratory Quotient/Respiratory Exchange Ratio
   D. Estimation of Caloric Expenditure
   E. The Metabolic Equivalent (MET)

IV. Field Estimates of Energy Expenditure During Exercise
   A. Metabolic Calculations Based on Mechanical Work or Standard Energy Use
   B. Motion Sensors and Accelerometers
   C. Activity Recalls and Questionnaires

V. Efficiency and Economy
   A. Efficiency
   B. Economy of Walking and Running
      1. The Influence of Sex on Economy
      2. The Influence of Age on Economy

VI. Why Do Economy and Efficiency Matter?

VII. Heritability of Aerobic Characteristics
AEROBIC METABOLISM DURING EXERCISE

Suggested Laboratory Activities

1. Measure oxygen consumption while performing the following exercises and during 5 minutes of recovery:
   - walk on the treadmill at 3.5 mi·hr⁻¹ at 0% grade for 10 minutes
   - run on the treadmill at 6 mi·hr⁻¹ at 3% grade for 45 minutes
   - an incremental test to maximum on the treadmill
   - static handgrip with maximal effort for 2 minutes
   - 1 set of 8 reps at 75% 1-RM of 2 arm biceps curls

   Graph, describe, and discuss the results.

2. Compute the RER for selected minutes of the above exercise sessions or any other exercise session of choice, and relate these values to fuel utilization.

3. Determine the caloric cost of at least 2 of the exercise sessions from number 1 or any other activity of choice.

4. Compare and contrast lactate accumulation using one recovery sample from each exercise session in number 1.

5. Verify, using physiological criteria, whether an incremental test was truly maximal or not.

6. Determine the MET level for the exercise session in number 1 or any activity of choice.

7. Determine the gross, net, and delta efficiency on the treadmill, cycle ergometer, Stair Master, Nordic Track or some other selected modality.

8. Determine and compare/contrast the velocity at VO₂max of two individuals in the class. Discuss the practical application of the results in terms of a 10 km run competition between the two.


1. Responses to Different Categories of Exercise: Integration and Analysis, page 29.
1. List the variables used to describe the aerobic metabolic response to exercise. Describe how each one is obtained from laboratory or field tests. Explain what each variable means.

**Tables 5.1, 5.2, 5.4, 5.5, 5.6; Pgs. 123, 131-138**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxygen consumed (VO₂ cons)</td>
<td>amount of oxygen taken up, transported and used in cellular respiration</td>
<td>open-circuit indirect spirometry, standardized formula based on mechanical work</td>
</tr>
<tr>
<td>carbon dioxide produced (VCO₂ prod)</td>
<td>amount of carbon dioxide produced as by product of cellular respiration</td>
<td>open-circuit indirect spirometry</td>
</tr>
<tr>
<td>respiratory exchange (RER)</td>
<td>ratio of VCO₂/VO₂, which indicates relative carbohydrate and fat substrate utilization</td>
<td>open-circuit indirect spirometry</td>
</tr>
<tr>
<td>caloric cost (kcal or kcal ·min⁻¹)</td>
<td>amount of energy expended that is dependent on aerobic metabolism</td>
<td>open-circuit indirect spirometry, charts</td>
</tr>
<tr>
<td>MET level</td>
<td>multiples of resting seated energy expenditure</td>
<td>open-circuit indirect spirometry, charts</td>
</tr>
</tbody>
</table>
2. Diagram the oxygen consumption response during (a) short term, light-to-moderate intensity, dynamic exercise; (b) prolonged, moderate to heavy submaximal exercise; (c) incremental exercise to maximum; (d) static exercise; and (e) dynamic resistance exercise.

Figures 5.4, 5.5, 5.6; Pgs. 127-131

3. Describe the relationship between the oxygen cost of breathing and exercise intensity.

**Page 131**

The oxygen cost of breathing and the intensity of exercise go hand in hand. Some oxygen that is used is for the respiratory muscles. At rest, the respiratory system uses about 1-2% of oxygen consumption (2.5 mL·min⁻¹). During light exercise where the $V_E$ is less than 60 L·min⁻¹, the oxygen cost changes minimally (25 - 100 mL·min⁻¹). During heavy exercise where $V_E$ is between 60 - 120 L·min⁻¹ then the oxygen response may rise from 50 to 400 mL·min⁻¹. During incremental exercise to maximum the initial oxygen cost of breathing shows a very gradual curvilinear rise, reflecting the submaximal changes noted previously. At workloads above those requiring a $V_E$ greater than 120 L·min⁻¹ a dramatic exponential curve occurs in the oxygen cost of breathing rising from 3 to 13% of the VO₂ used in exercise.
4. Explain the respiratory quotient and the respiratory exchange ratio. Relate them to the determination of energy substrate utilization, theoretically and numerically according to exercise intensity, duration and type.

**Tables 5.3, 5.4, 5.5; Pgs. 131-135**
Both the respiratory quotient (RQ) and the respiratory exchange ratio (RER) are computed from the formula \( \frac{VCO_2}{VO_2} \). The RQ reflects what is occurring on the cellular utilization level and can be obtained for carbohydrate, fat and protein using mole or molecules. The RER is obtained from total body open circuit indirect spirometry measures. The RER indicates the relative percentage of calories expended from carbohydrate and fat but not protein. The RQ represents just fuel utilization; the RER represents fuel utilization confounded by anaerobic metabolism, non-working muscle metabolism and non-metabolic CO\(_2\). The metabolic range of both is from 0.7 to 1.0.

<table>
<thead>
<tr>
<th></th>
<th>RQ</th>
<th>RER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>1.0</td>
<td>0.85= 49%; Short-term, light to heavy submaximal exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0= 100%; high-intensity exercise to maximum</td>
</tr>
<tr>
<td>Fat</td>
<td>0.7</td>
<td>0.7= 100%;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.85= 51%</td>
</tr>
<tr>
<td>Protein</td>
<td>0.74 (BCAA) - 0.81 (PRO)</td>
<td>cannot determine</td>
</tr>
</tbody>
</table>

5. Explain the similarities and differences in describing activity by kilocalories and MET levels. How can both be practically applied?

**Table 5.6, 5.7; Pgs. 134-138**
Describing physical activity by kcal and MET levels is similar because both are based on oxygen consumption and both express energy expenditure. METs are based on approximate resting values of 3.5ml kg min and all activity is then expressed as a multiple of a resting MET value of 1. Caloric cost requires some knowledge of an RER values. Exercise prescription can be based on either using available charts. Estimate of energy expenditure are important for weight control, etc.
6. Differentiate, in terms of definition, calculation, and application, between gross efficiency, net efficiency and delta efficiency. How can a cyclist maximize his or her efficiency?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Calculation % (x 100)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Efficiency</td>
<td>The percentage of energy input that appears as useful external work</td>
<td>work output / energy expend</td>
<td>Used when calculating values for specific workloads, in nutritional studies</td>
</tr>
<tr>
<td>Net Efficiency</td>
<td>The energy expended is corrected for resting metabolic rate</td>
<td>work output / (energy expend - RMR)</td>
<td>When only the efficiency of the work bout itself is wanted</td>
</tr>
<tr>
<td>Delta Efficiency</td>
<td>Is the efficiency based on the difference between two workloads</td>
<td>difference in work output / difference in energy expenditure between the same 2 loads</td>
<td>When a relative indication of energy cost from an additional work load is wanted</td>
</tr>
</tbody>
</table>

A cyclist can maximize their efficiency by adjusting seat height to 109% if leg length, pedal frequency to between 40 and 60 rev·min⁻¹, and drafting off of other cyclists.

7. Compare running economy by sex and age. Discuss possible reasons for any observed differences. Give three situations where any observed differences could have significant practical meaning.

Figures 5.9, 5.10, 5.11; Pgs. 143-146

The influence of sex on the interindividual variation in economy is unclear. However, even if the oxygen cost is equal at any given speed, the female typically has a lower VO₂max and hence will be working at a higher % VO₂max at any given speed. Practical significance- the female is likely to be unable to run at as fast a pace in a long distance event as a male.

Children and adolescents are less economical than adults; the elderly may be less economical than young and middle-aged adults.

Possible reasons for the lower economy in children include:
- children have a higher basal/resting metabolic rate than adults, hence gross exercise oxygen consumption may be higher because RMR is higher.
- children have a greater surface area per unit of mass than adults which necessitates a higher RMR to maintain body temperature.
- children exhibit immature running mechanics, however, the only one likely to impact oxygen cost is the higher stride frequency. When one stride is considered the oxygen cost does not differ between children and adults, however, at any given pace the child has a higher number of strides thus using more energy both to accelerate and brake the body’s mass.
• children have a higher ventilatory equivalent than adults. The processing of this additional air requires additional energy
• children are less able to generate ATP anaerobically than adults. Adults may be providing more energy even at submaximal levels anaerobically than children while children rely more on aerobic metabolism.

Practical significance:
• children are at a disadvantage (e.g. must work at a higher % VO₂ max) when running with or competing against more mature children, adolescents or adults.
• performance on tests of cardiovascular fitness will improve as children mature despite no change in VO₂ max.
• adult prediction equations based on VO₂/speed relationships to predict VO₂ max cannot be used for children.

8. Show how efficiency or economy can have an impact on exercise performance.

**Pgs. 146-148**
Higher efficiency, such as in cycling, should increase performance; higher economy is running should do the same, if the event is endurance in nature. If two runners have the same VO₂ max and can run at the same percentage of the VO₂ max, the more economical runner will have a definite advantage. The velocity at VO₂ max or the speed at which an individual can run when working at his or her VO₂ max that is based on both economy and VO₂ max may be the most important predictor of endurance performance.

9. Describe the impact of genetics on aerobic metabolism.

**Pgs. 148-149**
There appears to be a significant genetic effect at low work intensities, not at high intensities.

<table>
<thead>
<tr>
<th>Workload (watts, W)</th>
<th>Genetic Influence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>75</td>
<td>78</td>
</tr>
<tr>
<td>100</td>
<td>46</td>
</tr>
<tr>
<td>125</td>
<td>not significant</td>
</tr>
<tr>
<td>150</td>
<td>not significant</td>
</tr>
</tbody>
</table>