Lesson 10 Aerobic Exercise Physiology

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Lesson 10  AEROBIC EXERCISE PHYSIOLOGY

I. SCIENTIFIC PRINCIPLES

Exercise means increased activity of skeletal muscle. Most people think of it as performing rigorous activities, such as jogging, running, swimming, or weight lifting, but it also includes walking, climbing stairs, sitting down, getting up, and other routine tasks. Acute, short-term, often-intermittent exercise occurs as people perform daily routine activities. Chronic, long-term exercise tends to be more repetitive and regular, and is often associated with physical training. Both forms of exercise lead to beneficial physiological changes.

In acute exercise, the changes occur more quickly and are geared toward maintenance of homeostasis necessary for the active muscles to coordinate contractions and continue working. The changes include increasing the delivery of oxygen and nutrients to the muscles; increasing the removal of metabolic waste, including carbon dioxide; and preventing the muscles’ fluid environment from becoming too acidic.

The adaptations and physiological changes that develop during chronic exercise generally result in an increased ability of the muscle to perform work at greater levels of intensity and an increased capacity to work at any given level for a longer period of time before fatiguing. These abilities can be accounted for in part by the development of better neuromuscular coordination, increased muscle size and strength, and increased blood supply favoring more efficient oxygen/nutrient delivery and removal of metabolic waste. Several physiological adaptations to chronic exercise in other organ systems also help the muscular system perform at a higher level. In addition, the physiological adaptations to chronic exercise, initiated by even the most modest physical activity, play a major role in the prevention of obesity, hypertension and other cardiovascular diseases, respiratory disease, adult-onset (type II) diabetes, and other maladies associated with sedentary lifestyles.

The ability to exercise requires an adequate supply of energy to power skeletal muscle contraction and relaxation. The primary energy source, indeed the “universal currency” for energy used by all animal cells for processes of contraction, bioluminescence (flashing fireflies), conduction, secretion, and so forth is adenosine triphosphate (ATP).

ATP is a chemical compound containing large amounts of stored energy in some of its chemical bonds. An ATP molecule consists of a base, called adenine, combined with a sugar, called ribose, to form adenosine, to which are attached three inorganic phosphates (Fig. 10.1). The energy required for contraction of skeletal muscle is derived from the chemical energy released by breaking the terminal high-energy phosphate bond of ATP (Fig. 10.2), a process known as hydrolysis. Hydrolysis of ATP also produces adenosine diphosphate (ADP), an inorganic phosphate, both of which can be recycled when ATP is formed during the metabolism of foodstuff.

Although chemical energy is present in the proteins, carbohydrates, and fats people eat as food, this energy cannot be directly used for contraction and relaxation. As basic constituents of protein (amino acids), carbohydrates (monosaccharides) and fats (glycerol and fatty acids) are metabolized by the muscle fibers (Fig. 10.3), some of the released chemical energy is transformed into heat and some is transferred to ATP. The ATP molecules are then used as an energy source for contraction and relaxation.
Skeletal muscle fibers store very little ATP, so immediate and continued replenishment of ATP must occur if exercise is to continue. ATP can quickly be generated from muscle stores of creatine phosphate, another high-energy phosphate (Fig. 10.4). Although the energy in creatine phosphate cannot directly be used for contraction, it can be transferred with phosphate to ADP thereby replenishing ATP. Dietary creatine supplementation can slightly increase the ability to perform short-term high intensity exercise; however, creatine phosphate levels normally are sufficient by themselves only for very brief periods of acute exercise (e.g., the first five seconds of running a 100-meter sprint). After the first few seconds, the remaining energy requirement for contraction and relaxation is provided by ATP generated during glycolysis (some) and oxidative phosphorylation (most).

Anaerobic glycolysis, a process that does not require oxygen, generates a small amount of ATP and hydrogen as glucose is metabolized to pyruvic acid (Fig. 10.5). In the presence of adequate oxygen, pyruvic acid is converted to acetyl CoA, which enters the citric acid cycle. Hydrogen produced before and during the conversion and during the citric acid cycle is oxidized to water, a process known as oxidative phosphorylation because in addition to requiring oxygen, ADP is phosphorylated resulting in the formation of a large amount of ATP.

If oxygen is not adequately supplied to the exercising muscle, pyruvic acid is converted to lactic acid, a metabolite that enters the extracellular fluid increasing its acidity (lactic acidosis). Immediately after exercise, lactic acid is taken up by the muscle, converted back to pyruvic acid, and metabolized to form ATP through oxidative pathways. The additional amount of oxygen, above the amount required by resting muscle, to process the lactic acid produced during exercise is called the oxygen debt.

The capacity of skeletal muscle to perform mild and moderate short-term exercise is primarily dependent on oxidative or aerobic mechanisms for ATP production. During dynamic exercise, oxygen consumption increases with increasing intensity of the exercise. In turn, increasing exercise intensity increases ATP breakdown, leading to increases in ADP and inorganic phosphate, and decreases in creatine phosphate (Fig. 10.6).

These changes in ADP, Pi, and creatine phosphate stimulate glycolysis and oxidative phosphorylation, thereby replenishing ATP. Therefore, the capacity of skeletal muscle to exercise, short-term or long-term, is limited by the ability of the cardiovascular and respiratory systems to deliver oxygen to skeletal muscle, and by the ability of the working muscle to use the provided oxygen.

The respiratory system provides for the input of oxygen during inhalation and the removal of carbon dioxide during exhalation. During exercise, cells may need to use over six times the oxygen used during rest. Because air is only 20% oxygen, the respiratory system makes many adjustments during exercise to provide the increased oxygen.
Some of the respiratory adjustments during moderate exercise are:

1. Breathing (ventilation) rates increase. The number of breaths/minute escalates at the onset of exercise and then increases slowly to a plateau.

2. The depth of ventilation increases.

One method of assessing the effects of long-term exercise or training on physical fitness is to measure maximal oxygen consumption during maximum-intensity dynamic exercise. Maximal oxygen consumption (L/min) is influenced by the age, gender, and training level of the person performing the exercise. Higher levels of maximal oxygen consumption developed during training, for example, are associated with increased maximum levels of exercise intensity and with a longer time to fatigue during submaximal exercise. In part, the greater capacity to perform is due to increased blood flow into skeletal muscles, which increases oxygen delivery and waste removal.

The increased blood flow into skeletal muscles that develops with long-term exercise is the result of a) new blood vessel growth to meet the increased demand for oxygen delivery and b) a beneficial increase in cardiac output (CO), the volume of blood pumped into systemic arteries by the heart each minute. CO is the product of stroke volume (SV), the volume of blood ejected per beat, and heart rate (HR), the number of beats per minute: CO = SV x HR. The increase in cardiac output associated with maximal and submaximal dynamic exercise intensity in the physically trained person is due to an increase in stroke volume. Heart rate for a given level of exercise intensity decreases with training, as does the person’s resting heart rate. It is not uncommon for a trained college athlete to have a resting heart rate of 60 beats per minute compared to the expected 72 beats per minute.

Thus, instead of measuring maximal oxygen consumption as a means of assessing physical fitness, measure changes in heart rate associated with varied levels of dynamic exercise intensity. Assess individual performance and compare it to a set of standards as well as compare performance levels between groups, such as young men vs. young women.

II. EXPERIMENTAL OBJECTIVES

1. Measure changes in heart rate associated with a specified set of dynamic exercises.
2. Assess individual physical fitness by measuring elevated heart rate at the immediate end of a specific exercise period.
3. Assess individual physical fitness by measuring the time from the end of exercise to the return of resting heart rate.
4. Compare performance levels between groups, such as young women vs. young men, or persons with body weight 75–150 lbs. vs. persons with body weight 151–250 lbs.
5. Observe and record respiratory changes to meet changing metabolic demands with changing activity levels.

III. MATERIALS

- Computer system (running Windows XP or Mac OS X)
- Biopac Science Lab system (MP40 and software)
- Electrode lead set (40EL lead set)
  - Disposable vinyl electrodes (EL503), three electrodes per subject
- Optional: Tape or clip to stabilize lead cables during exercise
Lesson 10: Aerobic Exercise Physiology

IV. EXPERIMENTAL METHODS

A. Set Up

**EQUIPMENT**

**SUBJECT**

**Fig. 10.7**

**Fig. 10.8 Lead II configuration**

**FAST TRACK**

1. **Turn the computer ON.**
2. **Set the MP40 dial to OFF.**
3. **Attach three electrodes** as shown above.
4. **Connect the electrode leads (40EL) to the electrodes, matching lead color to electrode position as shown above.**

**IMPORTANT**

Clip each electrode lead color to its specified electrode position.

5. **Optional:** Tape or clip the lead cables to the Subject to minimize movement and/or cable strain during exercise.
6. **Have the Subject sit in a chair and relax.**
7. **Start** the Biopac Science Lab software.
8. **Choose lesson L10-AEROBICEX-1** and click **OK.**
9. **Type in a unique file name.** No two people can have the same file name, so use a unique identifier, such as the subject’s nickname or student ID#.
10. **Click OK.**

**Details**

Attach three electrodes to the Subject in a Lead II chest configuration, as shown in Fig. 10.8.
- Place one electrode just below the clavicle (collarbone) on each side of the body. Place the third electrode on the left side beneath the rib (cage).
- This configuration is convenient for recording during exercise and much less prone to EMG artifact.

Excessive motion artifact (from cable movement or strain) will corrupt the ECG signal (with EMG and/or noise data).
B. Check

**FAST TRACK**

**MP40 Check**
1. Set the dial to ECG/EOG.
2. Press and hold the Check pad.
3. When the light is flashing, click.
4. Wait for the MP40 Check to stop.
5. Let go of the Check pad.
6. Click Continue.

**Signal Check**
7. Click Check Signal.
8. Click OK and then wait for the Signal Check to stop.
9. Review the data.
   - If correct, go to the Record section.
   - If incorrect, click Redo Signal Check.

10. Calculate the Subject's target heart rate for exercise.

    *To be safe, target 80% of the maximum heart rate:*

    \[
    \text{Max HR} = 220 - \text{age}\\
    \text{Target} = \text{Max HR} \times .8
    \]

    For example, if the Subject is 16 years old:
    \[
    \text{Max HR} = 220 - 16 = 204\\
    \text{Target HR} = 204 \times .8 = 163.2
    \]
    The Target HR for a 16-year-old subject is 163 bpm.
C. Record

**FAST TRACK**

1. Prepare for the recording and have the Subject sit down and relax.

**Details**

You will record the Subject in three conditions:
- Segment 1: Baseline Resting Heart Rate (sitting, at rest)
- Segment 2: During Exercise (push-ups, jumping jacks, sit-ups)
- Segment 3: Post-exercise (sitting, at rest)

In order to work efficiently, read this entire section so you will know what to do for each recording segment.

Stop each recording segment as soon as possible so you don’t use an excessive amount of time (time is memory).

**Tips for obtaining optimal data:**

a) The Subject should not talk or laugh during any of the recording segments.

b) When asked to sit, the Subject should do so in a chair, with arms relaxed on the armrest (if available).

c) The Subject should be as still as possible during the After Exercise recording segment.

**SEGMENT 1 — Baseline Resting Heart Rate**

2. Click **Record**.

3. Recorder instructs Subject to breathe normally and inserts markers for five inhales.

   - **Inhale** (five times)

4. Click **Suspend** after at least 20 seconds.

5. Review the data.
   - If correct, go to **Step 6**.

   **Recording continues…**

When you click **Record**, the recording will begin and an append marker labeled **Baseline** will automatically be inserted.

Subject is seated (seconds 0-20) to establish a baseline. Subject should sit with arms relaxed, preferably in a chair with armrests.

To insert a marker: Windows=F9, Mac=Esc.

When you click **Suspend**, the recording will halt, giving you time to review the data and prepare for the next recording segment.

Data should resemble Fig. 10.10.

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6. **Note the Subject’s** baseline heart rate.

   **SEGMENT 2 — During Exercise**

7. Recall the **Subject’s** target heart rate.
8. Click **Resume**.
9. Have the **Subject** start an exercise that will elevate the heart rate, such as running in place or jumping jacks.
   - Try to minimize strain on the MP40 cables; **Subject** can hold the MP40, clip it to clothing, or tuck it in a pocket.
10. **Recorder** inserts an event marker for five inhaled
    - **Inhale** (five times)
11. Click **Suspend** after at least three minutes or when the **Subject** reaches the target heart rate.
12. **Subject** sits in a chair after exercise.
    - **Note**  Try to move to the next segment as quickly as possible.
13. Review the data.
   - If correct, go to Step 14.

   - If incorrect, click **Redo**.

The data would be incorrect if:
   a) The **Suspend** button was pressed prematurely.
   b) An electrode peeled up causing a large baseline drift, spike, or loss of signal.
   c) The **Subject** has too much muscle (EMG) artifact.

If the data is incorrect, click **Redo** and repeat Steps 2-5; the data you just recorded will be erased.

**SEGMENT 2 — During Exercise**

The baseline heart rate is required for Segment 3:
___________ BPM

Target heart rate was calculated in Set Up as 80% of max heart rate.

When you click **Resume**, the recording will continue and an append marker labeled **During exercise** will be automatically inserted.

**Subject** should perform an exercise to elevate his/her heart rate fairly rapidly, such as push-ups or jumping-jacks.

**Subject** is exercising (seconds 21-180).
During this time, the **Recorder** should insert five event markers when the **Subject** inhales and should label these markers **Inhale**.

Monitor heart rate in the bar display and click **Suspend** when the **Subject** reaches the target heart rate. When you click **Suspend**, the recording will halt, giving you time to review the data and prepare for the next recording segment.

Data should resemble Fig. 10.11.

![Fig. 10.11 After Sitting Up](image)

**Recording continues…**

The data would be incorrect for the reasons in Step 5.
If the data is incorrect, click **Redo** and repeat Steps 8-13; the data you just recorded will be erased.
SEGMENT 3 — Recovery

14. Recall the Subject’s baseline heart rate.

15. Click Resume.
   □ Inhale (five times)

16. Record until the Subject’s heart rate returns to the established baseline and insert markers at the following intervals until baseline is reached:
   □ Inhale (+30 seconds)
   □ Inhale (+60 seconds)
   □ Inhale (+90 seconds)
   □ Inhale (until baseline reached)

17. Click Suspend.

18. Review the data.
   • If correct, go to Step 19.
   • If incorrect; click Redo.

19. Optional: Click Resume to record additional segments.

20. Click Done.

21. Click Yes.

22. Choose an option and click OK.

23. Remove the electrodes.

The Subject’s baseline heart rate was determined in Segment 1: ______________.

In order to capture the heart rate variation, it is important that you resume recording as quickly as possible after the Subject has performed the exercise and is seated. When you click Resume, the recording will continue and an append marker labeled Recovery will be automatically inserted. Insert markers at each inhale for five breath cycles immediately after Subject sits.

Subject is seated in a relaxed state, recovering from exercise. Monitor heart rate in the bar display. Insert markers at 60-second intervals until Subject’s heart rate returns to baseline.

To insert a marker: Windows=F9, Mac=Esc.

Click Suspend when the Subject returns to the baseline heart rate.

When you click Suspend, the recording will halt. Your data should resemble Fig. 10.12.

Fig. 10.12 Recovery

The data would be incorrect for the reasons in Step 5.

Note The Recovery recording may have some baseline drift (as shown in Fig. 10.12). Baseline drift is fairly normal and, unless excessive, does not necessitate redoing the recording.

If incorrect, redo the recording by having the subject exercise to the target heart rate and then sit before clicking Redo and repeating Steps 15-18; the data you just recorded will be erased.

Optional: You can record additional segments by clicking Resume instead of Done. A time marker will be inserted at the start of each added segment.

When you click Yes, a dialog with options will be generated. Make your choice, and click OK.

• If you choose Analyze current data file, go to the Analyze section for directions.

Disconnect the lead clips and peel off the electrodes.
V. **ANALYZE**

**FAST TRACK**

1. Enter the **Review Saved Data** mode and choose the correct file.

   **Details**

   To review saved data, choose **Analyze current data file** from the Done dialog after recording data, or choose **Review Saved Data** from the **Lessons** menu and browse to the required file.

   The data window should come up the same as Fig. 10.14.

   Note Channel Number (CH) designation:
   
   - CH45  ECG
   - CH46  Heart Rate

2. Set up the measurement boxes as follows:

   **Details**

   The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click on them.

   **Brief definition of measurements:**
   
   - **Value** returns the value of the selected single point.
   - **BPM** (beats per minute) calculates the difference in time between the end and beginning of the selected area (same as Delta T), and then divides this value into 60 seconds/minute.
   - **Mean** computes the mean amplitude value or average of the data samples between the endpoints of the selected area and displays the average value.
   - **Delta T** returns the time from the start to the end of the selected area.

   **Note** The “selected area” is the area selected by the I-beam tool (including the endpoints).

3. Set up your display window for optimal viewing of three breaths from Segment 1.

   **Analysis continues...**
4. Using the I-Beam cursor, select the area between two marked inhales.

5. Repeat Step 4 for two additional cycles in the same segment.

6. Set up your display window for optimal viewing of three breaths from Segment 2.

7. Repeat Steps 4-5 in Segment 2 data.

8. Set up your display window for optimal viewing of three breaths from Segment 3.

9. Repeat Steps 4-5 in Segment 3 data.

Note Measure more segments if necessary until baseline heart rate is reached.

10. Scroll to Segment 2 – During Exercise and take measurements at every 30-second interval (0 sec., 30 sec., 60 sec., etc.) to complete Table 10.2 of the Data Report.

11. Scroll to Segment 3 – Recovery and take measurements at every 30-second interval (0 sec., 30 sec., 60 sec., etc.) to complete Table 10.2 of the Data Report.

12. Select the area from the start of Segment 2 – During Exercise to the target heart rate and record the Delta T.

13. Select the area from the start of Segment 3 – Recovery to the baseline heart rate and record the Delta T.

14. Save or print the data file.

15. Exit the program.

16. Set the MP40 dial to Off.

Try to go from R wave peak to R wave peak as precisely as possible. Fig. 10.16 shows an example of the selected area.

Choose a point value for the heart rate (CH46 value) and select an area from the start of one inhale to the start of the next inhale for the breathing rate (CH45 BPM).

You may save the data to a drive, save notes that are in the journal, or print the data file.

END OF LESSON 10
Complete the Lesson 10 Data Report that follows.

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The Data Report starts on the next page.
Lesson 10: AEROBIC EXERCISE
Cardiovascular Adjustments During & After Exercise

DATA REPORT

Student’s Name: ____________________________________________________________
Lab Section: ______________________________________________________________
Date: ____________________________________________________________________

I. Data and Calculations

Subject Profile

Name ___________________________________________ Age __________________
Gender: Male / Female
Height _________________ Weight ________________

Calculated target heart rate: ____________________________

A. Heart Rate vs. Respiration

Complete Table 10.1 with the requested measurements from each recorded segment.

<table>
<thead>
<tr>
<th>Table 10.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
</tr>
<tr>
<td>Baseline</td>
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<td>During</td>
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<tr>
<td>Exercise</td>
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</tbody>
</table>
B. Heart Rate During Exercise

Complete Table 10.2 with the requested measurements for Segment 2 and Segment 3 data.

*Note* Time references are the starting points of the exercise segment and do not correspond to the data window’s horizontal time scale. You may not have collected 5 minutes of data.

Table 10.2 Heart Rate Response to Exercise

<table>
<thead>
<tr>
<th>Time*</th>
<th>Segment 2 During Exercise</th>
<th>Segment 3 Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>Sec.</td>
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<td>0</td>
<td>0</td>
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<td></td>
<td>30</td>
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<td>1</td>
<td>60</td>
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<td></td>
<td>90</td>
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<td>2</td>
<td>120</td>
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<td>150</td>
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<td>3</td>
<td>180</td>
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<td></td>
<td>210</td>
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<td>4</td>
<td>240</td>
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<td>270</td>
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<td>5</td>
<td>300</td>
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<td></td>
<td>330</td>
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<tr>
<td>6</td>
<td>360</td>
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</tr>
</tbody>
</table>

C. Heart Rate Response

How long did it take Subject’s heart rate to rise from baseline to target? _______________ seconds

How long did it take Subject’s heart rate to return to baseline from target? _______________ seconds

Compare the Subject’s time to target heart rate and time to return to baseline heart rate with several other groups of students in the class. Use the groups suggested below and/or make up your own comparison groups.

Table 10.3 Heart Rate Response to Exercise Comparison Among Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Subject</th>
<th>Time to Raise Heart Rate From Baseline to Target [CH46] Delta T</th>
<th>Time for Heart Rate to Return to Baseline From Target [CH46] Delta T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young Women</td>
<td>1.</td>
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<td>2.</td>
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<td></td>
<td>Average Time</td>
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<td>1.</td>
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<td>Average Time</td>
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<tr>
<td>Young Men</td>
<td>1.</td>
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<td>Average Time</td>
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<tr>
<td>Group</td>
<td>Subject</td>
<td>Time to Raise Heart Rate From Baseline to Target [CH46] Delta T</td>
<td>Time for Heart Rate to Return to Baseline From Target [CH46] Delta T</td>
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<td>Weight of 75-150 lb</td>
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<td>Average Time</td>
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<td>Weight of 151-250 lb</td>
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II. Questions:

D. What physiological mechanisms are operating during the post-exercise period?

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________________________________________________________________________
________________________________________________________________________

E. Name two physiological changes that occur as a consequence of a chronic exercise program.

________________________________________________________________________
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F. Define adenosine triphosphate and explain its origin and how it is used in skeletal muscle.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
G. Explain the benefit of creatine phosphate in skeletal muscle.


H. Which sequence of cellular chemical reactions produces the largest amount of ATP? How much ATP is generated?


I. What does the term “oxygen debt” refer to?


J. Cardiac output increases as a higher level of maximum intensity dynamic exercise is achieved with training but heart rate decreases. Explain how this is possible.


End of Biopac Science Lab Lesson 10 Data Report
VI. ACTIVE LEARNING LAB

Design a new experiment to test or verify the scientific principle(s) you learned in the Biopac Science Lab recording and analysis segments.

For this lesson, you might examine how gender, duration of exercise, and changing body position influence the ECG and/or time to return to baseline.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. Hypothesis
Describe the scientific principle to be tested or verified.

B. Materials
List the materials you will use to complete your investigation.

C. Method
Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

- See the Set Up section or Help > About Electrodes for electrode placement guidelines.

Run Your Experiment

D. Setup
Set up the equipment and prepare the subject for your experiment.

E. Recording
Use the Record, Resume, and Suspend buttons in the Biopac Science Lab program to record as many segments as necessary for your experiment.

Click on Done when you have completed all of the segments required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.