Collect data to analyze and evaluate how cells making up muscle tissue perform specific functions, including energy metabolism, transportation of molecules, and disposal of wastes.

Gather, record, graph, and analyze data

Grades 7-10

Structured Inquiry

Laboratory activity with discussion: 1 hour

**NATIONAL SCIENCE EDUCATION CONTENT STANDARDS**

**Science Content Standard A** (subsection)
As a result of activities in grades 9-12, all students should develop

**Understanding about scientific inquiry**

- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

**Science Content Standard C** (subsection)
As a result of their activities in grades 9-12, all students should develop understanding of

**Matter, energy, and organization in living systems**

- The chemical bonds of food molecules contain energy. Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in phosphate bonds of a small high-energy compound called ATP.
- The complexity and organization of organisms accommodates the need for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.
GENERAL LESSON OVERVIEW

In this lesson, the effects of muscle fatigue on task performance are shown by comparing performance before and after repeatedly squeezing a hand grip. Students love to compete during this lab, often with surprising results. Sometimes a small girl will outperform the large male athletes on the muscle fatigue test. Whatever the outcome, this lab has consistently been one of our teachers’ favorites.

Lesson Opening:

Ask students how they might open a door without using their hands. You may wish to have a couple of students demonstrate techniques they think might work (don’t allow the use of mouths). After acknowledging that opening a door without hands is very difficult, ask students to imagine that they are in a bulky space suit performing an extravehicular activity using their hands inside thick gloves in microgravity conditions. Then ask them to imagine that the muscles in their hands are so fatigued that they can’t open the door to the spacecraft. In this case, the muscle fatigue of an astronaut’s hands could be life threatening. Fortunately, all the tired astronauts have made it safely back inside their spacecraft. In this lab, students have the opportunity to measure how well they perform before and after inducing muscle fatigue in one of their hands.

TEACHING HINTS

- It is important to discuss how to ensure that the “before” and “after” data recordings are fair comparisons. Lead the students to describe some of the variables that should be controlled in these kinds of comparisons.

- Students need to follow the reaction time procedure carefully. Some students are so eager to have fast reactions that they sacrifice test validity.

- Demonstrate the proper squeezing of the hand grip. Students tend to count incomplete squeezes. Try out the hand grips yourself before buying them to be sure they are not too hard to squeeze.

- A transparency of the data tables is helpful to display the data and assist the students in calculating reaction time mean values.
• Students may have to be guided through the calculation of percent change. The percent change equation has also been used in Puffy Head, Bird Legs and How Tall Are You? Rather than just plugging numbers into an equation, ask students if their reaction time is increasing (more time means a slower reaction) or decreasing (less time means a quicker reaction).

• Dominoes come in different widths. It is helpful to determine how many can be stacked on top of each other before beginning the lab. Students will know in advance the maximum number that can be stacked and will know when to begin a new stack of dominos. This will increase the efficiency and accuracy of the results.

**Guided Discussion:**

Discuss connections of the students’ lab experience to human muscle pathologies that result in muscle fatigue.

**BACKGROUND INFORMATION**

In space, astronaut muscles become deconditioned and exhibit reduced strength, endurance and atrophy. The muscles that have been found to be most affected are the anti-gravity or postural skeletal muscles. These muscles are located from the lower lumbar spine down to the feet. The extent of space-induced muscle atrophy is related to the length of time in space and also to the types, duration, and frequency of exercise performed during the mission as a countermeasure. Four to ten percent reductions in muscle volume were shown by magnetic resonance imaging (MRI) in Spacelab J (STS-47) crewmembers (LeBlanc et al., Aviation Space Environmental Medicine 66:1151-4, 1995). Reductions in muscle mass causes increased fatigue and affects movement control which can impact many mission tasks such as Intravehicular Activities, Extravehicular Activities, as well as landing and emergency egress operations. On Earth, muscle atrophy can occur when a limb is broken and is put in a hard plaster cast to heal. During this time, the muscles are not used and become weaker. When the cast is removed, therapeutic exercise must be performed to restore the full function of the broken limb.
BACKGROUND
In order for muscles to contract to perform work, they require energy. Just as an automobile cannot run without an energy source, neither can your body. While the automobile requires gasoline to move, your muscles require adenosine triphosphate (ATP) to contract and relax. Most ATP is produced in your body through aerobic (oxygen-requiring) respiration, though a smaller amount of ATP is produced from anaerobic respiration. When there isn’t enough oxygen available for aerobic respiration, muscle cells use the less efficient anaerobic metabolism for ATP production, which creates the by-product lactic acid. If muscles continue to contract without enough oxygen, lactic acid will collect in muscle tissue and reduce the ability of the muscle to contract. Eventually, the muscle becomes so fatigued that it can no longer contract and relax at all.

The National Space Biomedical Research Institute (NSBRI) and NASA are particularly concerned about muscle changes experienced by astronauts in microgravity conditions of space. Currently, a significant research effort is dedicated to understanding the causes of space-induced muscle atrophy and finding effective cures or countermeasures to prevent and/or alleviate this problem. In order to elucidate the mechanisms of muscle atrophy, research studies are performed with engineered muscle tissue models, rodents (hind end unloading model), human bedrest studies on Earth, and on astronauts on orbit. Such research on muscular atrophy and fatigue may also produce important new solutions for problems caused by muscle wasting pathologies associated with aging, injuries, cancer, long term illnesses and debilitating diseases.

INVESTIGATION QUESTIONS
1. How much work can a muscle do before fatigue occurs?
2. How does muscle fatigue affect reaction time?
3. How does muscle fatigue affect fine motor skills?

MATERIALS
- Stopwatch or clock with a second hand
- Spring hand grip
- Dominoes
- Metric ruler
- Calculator

INVESTIGATION GROUP
Form an investigation group with two other students. Switch roles and repeat the data collection until each of the group members have been tested.
- **Experimenter**: the person performing the experiment
- **Time keeper**: the person calling out the time every 10 seconds.
- **Recorder**: the person recording data on the experimenter’s data table
PROCEDURE

The group **recorder** will record the **experimenter’s** performance on two tasks before and after causing muscle fatigue.

**Before Muscle Fatigue**
1. Perform Test A: reaction time, and record the test results
2. Perform Test B: fine motor skills, and record the test results.

**Create and Measure Muscle Fatigue**
3. Perform the three muscle fatigue trials. Record # of squeezes per 10 second interval until you can no longer squeeze the hand grip for each of the three trials.

**After Muscle Fatigue**
4. Immediately repeat Test A: reaction time, and record the test results
5. Immediately repeat Test B: fine motor skills, and record the test results.

* Change roles and complete steps 1-5 until everyone in the group has been tested.

**TEST A**: Determination of Reaction Time
1. The **experimenter** should stand with his/her arm straight out in front, parallel to the floor.
2. The **time keeper** should hold a ruler vertically so that the bottom edge is even with and between the experimenter’s thumb and forefinger, which should be about 2 cm apart.
3. The **experimenter** should catch the ruler as quickly as possible after the **time keeper** drops it.
4. The group **recorder** should record the mean reaction time using the following chart.
5. Determine the **experimenter’s** reaction time by repeating the test at least three times, then calculating the mean of three consistent, reliable tests.

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Reaction Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.11</td>
</tr>
<tr>
<td>7</td>
<td>0.12</td>
</tr>
<tr>
<td>8</td>
<td>0.13</td>
</tr>
<tr>
<td>9</td>
<td>0.14</td>
</tr>
<tr>
<td>10</td>
<td>0.14</td>
</tr>
<tr>
<td>11</td>
<td>0.15</td>
</tr>
<tr>
<td>12</td>
<td>0.16</td>
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<tr>
<td>13</td>
<td>0.16</td>
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<td>14</td>
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<td>28</td>
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<tr>
<td>29</td>
<td>0.24</td>
</tr>
<tr>
<td>30</td>
<td>0.25</td>
</tr>
</tbody>
</table>

If you catch the ruler in less than 10 cm, you probably are holding your fingers too close to the ruler, or you are anticipating the drop by pinching at the ruler before you see it drop. Most normal people have a reaction time greater than 0.15 seconds.
**TEST B: Determination of Fine Motor Skills**

You will observe normal fine motor skills by stacking dominoes for a ten second time period. Be sure you have already stacked the dominoes to see how high they will stack. When you reach the maximum height during this test, begin another stack.

1. The **experimenter** should begin stacking dominoes on their long, narrow sides when the **time keeper** says to begin.

![Image of dominoes]

2. The **time keeper** says “stop” after ten seconds.

3. The **recorder** writes the number of dominoes successfully stacked in ten seconds in the **experimenter’s** data table.

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**CREATE AND MEASURE MUSCLE FATIGUE**

1. **Experimenter**:
   - Place the spring hand grip in your writing hand.
   - When the **time keeper** says “Go!” begin to squeeze the grip rapidly **at a constant** rate, making sure grip handles touch completely (no space between the ends of the grip).
   - Count the number of squeezes made every 10 seconds.
   - The **time keeper** will say “Go” or some other signal every 10 seconds so that the **experimenter** can begin the squeeze count over.
   - Continue until there is complete fatigue in your hand and forearm.

2. Rest for one minute and repeat the procedure for two more trials. Immediately at the end of the third trial, the **experimenter** will perform three reaction time determinations and repeat the fine motor skill determination.

3. The **recorder** records data in the chart provided.

4. Switch roles with your partners and repeat the procedure until all students in the group have data.

5. Plot the results of the three trials on a graph according to teacher directions. The **x** coordinate should be used for time in seconds, and the **y** coordinate for the number of muscle contractions.
Make some educated guesses:

How many times do you think you will be able to squeeze the spring hand grip in 30 seconds?

______________

How many times will you be able to squeeze the hands grip in 30 seconds the second time you do it?

______________

What do you predict is the effect of muscle fatigue on reaction time?

_________________________________________________________________________

What do you predict is the effect of muscle fatigue on fine motor skills?

_________________________________________________________________________

INDIVIDUAL PERFORMANCE DATA

<table>
<thead>
<tr>
<th>Test</th>
<th>Before Muscle Fatigue</th>
<th>After Muscle Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Reaction Time (seconds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. ______</td>
<td>1. ______</td>
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<td>2. ______</td>
<td>2. ______</td>
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<td>3. ______</td>
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<tr>
<td>mean = ______</td>
<td>mean = ______</td>
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<tr>
<td>B. Skill Task (# of stacked dominoes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

INDIVIDUAL MUSCLE FATIGUE DATA

<table>
<thead>
<tr>
<th>Time</th>
<th>10 sec Interval</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
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<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
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<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
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</tbody>
</table>
GRAPH OF INDIVIDUAL MUSCLE FATIGUE DATA

Present your muscle fatigue data on this graph. Remember to title your graph and label your axes, including measurement units.

GROUP DATA TABLE

Record the reaction times of all group members before and after muscle fatigue in the table below. Calculate the % change in reaction time using this formula:

\[
\% \text{ change} = \left( \frac{\text{mean time after fatigue} - \text{mean time before fatigue}}{\text{mean time before fatigue}} \right) \times 100
\]

Show your work:

<table>
<thead>
<tr>
<th>Student Initials</th>
<th>Mean Reaction Time Before Muscle Fatigue</th>
<th>Mean Reaction Time After Muscle Fatigue</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
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<tr>
<td>3.</td>
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</tbody>
</table>
ANALYSES AND CONCLUSIONS

1. Compare and contrast the results from your own three muscle fatigue trials.

________________________________________________________________________________

2. Using your knowledge of cellular respiration, account for any differences in the amount of work done by the muscles during the three trials.

________________________________________________________________________________

3. Examine your reaction times before and after muscle fatigue. Describe any differences in your reaction times.

________________________________________________________________________________

4. Describe any difference in the reaction rates of different group members. Why do you think there are differences in individual reaction rates?

________________________________________________________________________________

5. Describe any differences in your fine motor (domino-stacking) skills before muscle fatigue versus after muscle fatigue.

________________________________________________________________________________

6. Why would muscle fatigue be a greater concern to astronauts in space compared to humans on Earth?

________________________________________________________________________________

7. Describe a way that research on muscle fatigue might help people on Earth.

________________________________________________________________________________
INVESTIGATION QUESTIONS

Use the data you collected as evidence to support your answers to the investigation questions:

- How much work can a muscle do before fatigue occurs?

- How does muscle fatigue affect reaction time?

- How does muscle fatigue affect fine motor skills?