

Day 3 Handout: Experimental Design **Answer Key**

DO NOW: Read the following passage from Physiopedia (https://www.physio-pedia.com/Muscle_Fatigue) and highlight important information pertaining to muscle fatigue.

Exercise and Muscle Fatigue



Physical exercise affects the biochemical equilibrium within the exercising muscle cells. E.g., inorganic phosphate (in ATP), protons, lactate (see anaerobic capacity) and free Mg^{2+} (an electrolyte) accumulate within these cells. These biochemical products directly affect the mechanical machinery of the muscle cell e.g. mitochondria. Furthermore, they negatively affect the different muscle cell organelles that are involved in the transmission of neuronal signals. The muscle metabolites produced, and the generated heat of muscle contraction, are released into the internal environment, putting stress on its steady state.

- The tremendous increase in muscle metabolism compared with rest conditions induces an immense increase in muscle blood supply, causing an increase in the blood circulatory system and gas exchange. Nutrients have to be supplied to the exercising muscle, emptying the energy stocks elsewhere in the body. Furthermore, the contracting muscle fibers release cytokines, which in their turn create many effects in other organs, including the brain.
- All these different mechanisms sooner or later create sensations of fatigue and exhaustion in the mind of the exercising subject. The final effect is a reduction or complete cessation of the exercise.
- Many diseases speed up the depletion of the energy stocks within the body. So diseases amplify the effect of energy stock depletion that accompanies exercise [4] (e.g., multiple sclerosis).

Do you think muscle fatigue is different between athletes and non-athletes when doing the same exercise? Please provide biological reasoning.

Possible answers:

- Yes, muscle fatigue tends to differ between athletes and non-athletes when performing the same exercise due to differences in muscle composition, energy utilization, and training adaptations. Muscle fatigue affects the neuronal signals in the muscle by reducing the efficiency of the neuronal signals by impairing neurotransmitter release, altering muscle fiber and changing the concentration, which leads to a decrease in muscle performance.
- Fatigue can make the neural signals overwork. This can lead to the body wasting all of its energy without being able to make it back. Thus, it will affect the performance of the muscles.

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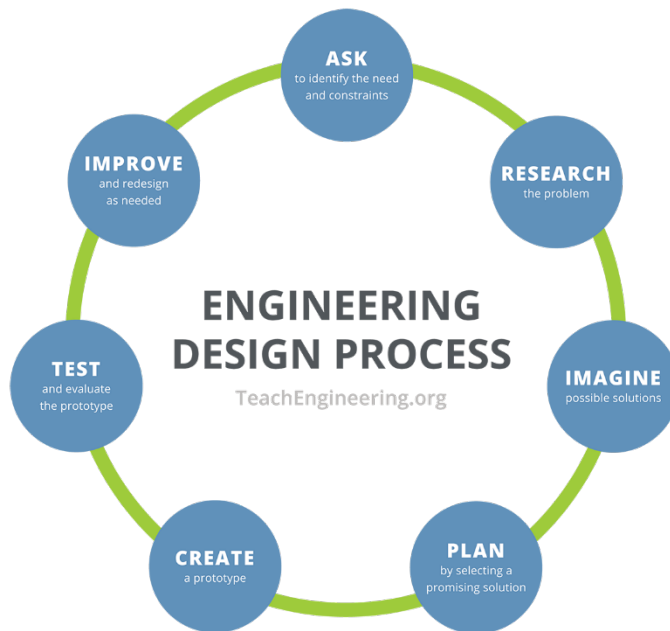
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Engineering Design Challenge

Introduction

You have already learned about motor units, muscle fibers, ATP, and both central and peripheral muscle fatigue through videos, readings, and diagrams. You also have experience using the micro:bit and completing simple coding tasks. Now, it's time to apply all of that knowledge in a real-world, hands-on design challenge. Working in small groups, you will use the engineering design process to answer the following question: **How can we measure changes in muscle activity (biopotential signals) to determine the effect of muscle fatigue?**



Start by working with your group to understand the challenge and define the problem you want to solve. Think about what you've already learned that can help you, and decide what you want your design to do. Talk through different ideas and explore a variety of possible solutions. Consider what materials, tools, or technology you might use, and sketch or describe your ideas to help guide your thinking. Once your group agrees on a direction, plan how you will build and test your prototype.

Next, create your design and set up a simple procedure to test it. Think about what information you'll need to collect, and how you'll know if your design is working well. As you test, observe carefully and record what happens. Use feedback from your group members, teacher, and results to make changes and improve your design. After refining and retesting, prepare a short presentation to share your process, what you learned, and how your work could relate to real-world problems or solutions.

1. **Ask** - Identify the need and constraints of the problem.

Work with your group to clearly define the challenge and understand the limits of your project. Consider the following questions to guide your thinking:

- a. What problem are you trying to solve?

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- b. What does muscle fatigue look like when measured with EMG signals?
- c. What kind of data do you need to collect to detect fatigue?
- d. Which muscle group and physical task will help you get clear, measurable results?
- e. What materials, tools, and technology are available for your design?

We are trying to figure out how to measure muscle fatigue using biopotential signals (EMG) during a physical task. Specifically, we want to see if there are measurable changes in EMG signals as a muscle gets tired.

Constraints include time and materials.

- Time: We only have class time.
- Materials: We have EMG sensors with electrodes, micro:bits, wires and clips, laptops or tablets for coding and data analysis, and physical items like small weights, clip grippers, or elastic bands. We also have access to coding platforms like MakeCode and data tools like spreadsheets.

2. Research – What do you know about measuring muscle fatigue using EMG sensors? (Hint: What did you learn from Handouts 1 and 2?)

Answers will vary. Some potential answers include:

- EMG signals show electrical activity in muscles and change when fatigue sets in.
- Increased signal amplitude and slower signal frequency are signs of fatigue.
- Sensors must be correctly placed to get accurate data.

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3. **Imagine** – Individually brainstorm FOUR different solutions/ways to set up your prototype and testing experiment. Think about:
- Which muscle group should you target? (e.g., biceps, forearm, calf)
 - What physical task will best induce fatigue? (e.g., repeated squeezing, holding a weight)
 - How and where will you position the EMG sensors for clean signals?
 - What features should your micro:bit code include?

Answers will vary.

a	b
c	d

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4. **Plan** – Have each team member share their ideas. As a team, select ONE prototype and testing procedure. This can be one specific solution or a mixture of ideas.

Prototype Sketch: Draw your team's agreed-upon prototype solution in the box below.

Answers will vary.

Materials: List all the materials needed to create your prototype and conduct your testing procedure.

Materials will vary depending on the students' experimental design. Materials may include:

- EMG sensor(s), to detect electrical activity in the muscles.
- electrode pads or adhesive patches, to attach the EMG sensor to the skin.
- micro:bit, for reading sensor data and basic processing.
- wires and alligator clips, to connect EMG sensor to the micro:bit.
- battery pack or USB cable, to power the micro:bit.
- laptop or tablet, to run code, view live readings, and collect data.
- coding interface, MakeCode, or Python environment for the micro:bit.
- textbook, small hand weight or water bottle (1–3 lbs).
- timer or stopwatch.

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Which muscles and movements will be tested? Where will the sensors be placed?

This will vary per group. Here are some examples of answers:

1. **Bicep** – Testing could involve lifting a weighted bag or small object repeatedly. The EMG sensor would be placed on the bicep muscle to measure changes during flexion and extension of the arm.
2. **Forearm (Flexor Carpi Ulnaris)** – Wrist curls or similar repetitive wrist movements could be used. The sensor would be placed on the inner forearm to detect muscle activity as the wrist moves up and down.
3. **Forearm (Pronator Teres)** – A task such as repeatedly opening and closing a wooden clip or twisting the wrist could activate this muscle. The sensor would be placed along the upper forearm, where the Pronator Teres is located.

How will you test your device? (Hint: What is the independent variable to be tested? What is the control variable?) You must provide a detailed step-by-step procedure for both experimental and control groups.

Experimental Group Procedure	Control Group Procedure
<p>This procedure will vary in each group. It is important that the group test the independent variable. This procedure will be done for the repetitions of given exercise to get those muscles to fatigue.</p> <p>Here is an example:</p> <ol style="list-style-type: none">1. The sensor will be connected to the micro:bit unit and then placed on the student's left wrist.2. The student will place three textbooks in a	<p>This procedure will vary in each group. Students will perform the same exercise but without causing fatigue to the muscles.</p> <p>Here is an example:</p> <ol style="list-style-type: none">1. The sensor will be connected to the micro:bit unit and then placed on the student's left wrist.2. The student will lift their wrist up and down for 1 minute (with no weight/books.)

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<p>bookbag.</p> <p>3. The student will lift the three textbooks up and down with his wrist for 1 minute.</p> <p>4. The results will be recorded using the EMG tracker during the last few seconds of each trial.</p> <p>5. Steps 1-4 will be repeated three times (i.e., three trials).</p>	<p>3. The results will be recorded using the EMG tracker during the last few seconds of each trial.</p> <p>4. Steps 1-3 will be repeated three times (i.e., three trials).</p>
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5. **Create** – Build your prototype as shown in your group’s drawings.

6. **Test** – Test your design using your testing procedures above on your group’s chosen muscle group.

- Collect data for three trials of the experimental procedure.
- Collect data for three trials of the control procedure.
- Graph each set of data, making sure to label your data correctly.
- Put a screenshot of your experimental procedure data here: (Note: Organize by trials 1, 2, & 3.):

Students need to take screenshots of the data (graph). It must be labeled as trial 1, trial 2, and trial 3. Emphasize that when they take a screenshot, it should be during the last few seconds of the 1 minute of exercise.

- Put a screenshot of your control procedure data here: (Note: Organize by trials 1, 2, & 3.):

Students will add a screenshot of the data (graph) when students are performing the chosen physical activity without muscle fatigue.

What worked in your design, and why?

Answers will vary.

What did not work in your design, and why?

Answers will vary.

7. **Improve** – Based on your testing and results, how would you improve your design? Why?

Answers will vary.

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Conclusion:

After collecting your data, you will write a conclusion using the claim, evidence, and reasoning (CER) format. Your claim should summarize what your data shows about muscle fatigue. Support this with specific evidence from your experiment, such as patterns or trends in the EMG signals. In the reasoning section, explain how your evidence connects to neuroscience concepts—such as motor and sensory units, how fatigue affects muscle function, and the role of the technology used to measure these changes. Be sure to identify at least one potential source of error in your experiment. Finally, reflect on what you learned and connect your findings to a real-world application, such as sports performance, rehabilitation, or wearable technology.

Conclusion paragraphs will vary.

Here are a few examples:

Example 1:

Our data shows that muscle fatigue causes a decrease in EMG signal amplitude over time during repeated wrist curls. In our data, the EMG signal amplitude was highest at the beginning of the exercise (around 3.2V) and gradually decreased to about 1.1V by the end of the task, indicating reduced electrical activity in the muscle. As muscles fatigue, motor units are less able to generate forceful contractions. This decline in amplitude reflects reduced recruitment of motor units and slower firing rates. Our EMG sensor and micro:bit setup helped us capture these biopotential signals during the task. One possible source of error was sensor placement—if not placed directly over the muscle belly, the signals may be weaker. This type of testing can be applied in physical therapy to monitor recovery progress in patients after injury.

Example 2:

Our results suggest that EMG amplitude increases before muscle fatigue, but then plateaus or decreases as the muscle becomes exhausted. During the first two minutes of squeezing a stress ball, the amplitude increased from 1.8V to 3.0V. However, during the final minute, the signal plateaued and then began to drop slightly, even though the effort remained the same. This pattern shows how motor units are recruited more intensively at first to meet the increased demand, but as the energy stores in the muscle fibers are depleted and lactic acid builds up, performance drops. Our setup used a micro:bit connected to surface EMG sensors. A potential error in our test was the timing of data collection—it's possible we didn't capture the precise moment of peak fatigue. This experiment could help in designing smarter athletic training programs that adjust workload based on live fatigue data.

Example 3:

Our data did not show a clear change in EMG signal amplitude, suggesting that our setup did not effectively measure muscle fatigue. The EMG signals stayed between 2.5V and 2.7V throughout the three-minute lifting task, with no consistent trend up or down. This might be because the task was not strenuous enough to produce measurable fatigue, or the EMG sensors weren't positioned correctly on the biceps. Additionally, movement artifacts or loose sensor connections may have interfered with accurate readings. The micro:bit recorded data, but inconsistent placement could lead to weak or noisy signals. Even though our prototype had limitations, the process helped us understand how biosensors can be applied in wearable tech such as fitness trackers or posture monitors.