ELECTROMYOGRAPHY (EMG) Laboratory

Motor unit recruitment & Fatigue
Comparison of dominant versus non-dominant arm using a within subject repeated measures statistical analysis

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I. INTRODUCTION

Mechanical work, in the physical sense, refers to the application of a force that results in the movement of an object. Skeletal muscle performs mechanical work when the muscle contracts and an object is moved, as in lifting a weight. To lift a weight, your muscles must exert a force great enough to overcome the weight. If you exert less force, then the weight does not move (Fig. 2.1).

Physiologically, skeletal muscle is stimulated to contract when the brain or spinal cord activates motor units of the muscle. Motor units are defined as a motoneuron and all of the muscle fibers that the motoneuron innervates. An action potential (AP) in a human motoneuron always causes an action potential in all of the muscle fibers of the motor unit. As a matter of fact, humans generally do not send just one AP at a time down a motoneuron. Instead, a train of APs is sent — enough to induce tetany (the sustained fusion of individual muscle twitches) in the muscle fibers of the motor unit. [A discussion of motor units and their control was presented in Lesson 1.]

Most human skeletal muscles are composed of hundreds of motor units (Fig. 2.2). When a skeletal muscle is called on to perform mechanical work, the number of motor units in the muscle activated by the brain is proportional to the amount of work to be done by the muscle; the greater the amount of work to be done, the greater the number of motor units activated. Thus, more motor units are simultaneously active when a skeletal muscle lifts 20 kilograms than when the same muscle lifts 5 kilograms.

The brain determines the number of active motor units required for a muscle to perform a given task by utilizing sensory information from stretch receptors in the muscle and associated tendons and joint capsules. For example, when lifting a bucket of water from the ground, the brain first activates several motor units in the requisite skeletal muscles. If sensory information returning from the muscles indicates the muscles are contracting but not developing adequate power to lift the bucket, the brain activates additional motor units until the sensory information indicates the bucket is being lifted. The sequential activation of motor units to perform a designated task is called motor unit recruitment.

Once you have lifted a light object, the brain recruits approximately the same number of motor units to keep the object up, but cycles between different motor units. The muscle fibers consume stored energy available in the muscle, and generate a force by contracting. As the muscle fibers deplete this fuel source, more energy must be created in order to continue contracting. By recruiting different motor units, motor units can relax and replenish their fuel sources.
Skeletal muscles performing acute maximum work or chronic submaximum work of a repetitive nature will eventually **fatigue**. Fatigue is defined as a decrease in the muscle’s ability to generate force. Fatigue is caused by a reversible depletion of the muscle’s fuel supply. If the muscle uses its energy sources faster than they can be generated by cellular metabolism, fatigue occurs. During contraction, skeletal muscle cells convert chemical energy into thermal and mechanical energy, and, in the process, produce chemical waste products.

Normally the waste products are removed from the muscle by the circulatory system as the blood brings nutrients to the muscle for energy transformation. If certain waste products (metabolites) are not removed at an adequate rate, they will accumulate and chemically interfere with the contractile process, thereby hastening the onset of fatigue. Some accumulated waste products also stimulate pain receptors in surrounding connective tissue and induce cramping of skeletal muscle, a general sign of inadequate blood flow to the muscle.

In this lesson, you will examine motor unit recruitment and skeletal muscle fatigue by combining **electromyography** with **dynamometry**.

When a motor unit is activated, the component muscle fibers generate and conduct their own electrical impulses, which cause the fibers to contract. Although the electrical impulse generated and conducted by each fiber is very weak (less than 100 μvolts), many fibers conducting simultaneously induce voltage differences in the overlying skin which are large enough to be detected by a pair of surface electrodes.

The detection, amplification, and recording of changes in skin voltage produced by underlying skeletal muscle contraction is called electromyography, and the recording thus obtained is called an **electromyogram (EMG)**.

**Power** is defined as the amount of work done per unit of time. **Dynamometry** means the measurement of power (dyno = power, meter = measure), and the graphic record derived from the use of a dynamometer is called a **dynagram**.

In this lesson, the power of contraction of clench muscles will be determined by a **hand dynamometer** equipped with an electronic transducer for recording.

The BIOPAC system will simultaneously record three bands of information:

1) The force you exert on the transducer,
2) The electrical signal produced by the muscle during contraction, and
3) The integrated waveform, which is an indication of the activity levels of the muscle.

**II. EXPERIMENTAL OBJECTIVES**

1) To determine the maximum clench strength for right and left hands and compare differences between male and female.
2) To observe, record, and correlate motor unit recruitment with increased power of skeletal muscle contraction.
3) To record the force produced by clench muscles, EMG, and integrated EMG when inducing fatigue.

**III. MATERIALS**

- BIOPAC Hand Dynamometer (SS25LA or SS25L)
- BIOPAC Headphones (OUT1)
- BIOPAC electrode lead set (SS2L)
- BIOPAC disposable vinyl electrodes (EL503), 6 electrodes per subject
- BIOPAC electrode gel (GEL1) and abrasive pad (ELPAD) or Skin cleanser or Alcohol prep
- Computer system
- Biopac Student Lab software
- BIOPAC acquisition unit (MP30) with associated cables
IV. EXPERIMENTAL METHODS

A. SET UP

FAST TRACK SET UP

1. Turn computer ON. Login: PSYNEURO / Password: Psychology1

2. Make sure that the BIOPAC MP30 unit is OFF.

3. Plug the equipment in as follows:
   Hand Dynamometer (SS25LA or SS25L) — CH 2
   Electrode lead Set (SS2L) — CH 1
   Headphones (OUT1) — back of unit

4. Turn ON the BIOPAC MP30 unit.

5. Remove any jewelry or watches from your wrists.
   Attach three electrodes to each forearm as shown in Fig. 2.4.

6. Attach the electrode lead set (SS2L) to the Subject’s dominant forearm, following the color code (Fig. 2.4). You can also verify your electrode placement with the picture on the title page.

   IMPORTANT
   Make sure the electrode lead colors match Fig. 2.4.

Set Up continues…

Detailed Explanation

Attach three electrodes to each forearm as shown in Fig. 2.4.

- For optimal electrode adhesion, place electrodes on the skin at least 5 minutes before the start of Calibration.

   Attach the lead set (SS2L) to the Subject’s dominant forearm (Fig. 2.4) for recording Segments 1 and 2 (forearm 1).

   - If the subject is right-handed, the right forearm is generally dominant; if the subject is left-handed, the left forearm is generally dominant.

   - You will switch the lead set to the Subject’s non-dominant arm for recording Segments 3 and 4 (Forearm 2).

   - The electrode lead cables are each a different color and each must be attached to a specific electrode position,
as shown in Fig. 2.4.

- The pinch connectors work like a small clothespin and will only latch onto the nipple of the electrode from one side of the connector.

There is a shortcut for the Student Lab program on the desktop.

This filename will be used to create a folder to store your data. I suggest that you use your username: Last Name, First & Middle Initial (for example: PittmanDW)

This ends the set-up procedure.
B. CALIBRATION

The Calibration procedure establishes the hardware’s internal parameters (such as gain, offset, and scaling) and is critical for optimum performance. Pay close attention to the Calibration procedure.

### FAST TRACK CALIBRATION

1. Click Calibrate.

2. Set the hand dynamometer down and click OK.

3. Grasp the BIOPAC hand dynamometer with your hand.

**SS25LA:** Place the short grip bar against the palm, toward the thumb, and wrap your fingers to center the force.

### IMPORTANT

Hold the dynamometer in the same position for all measurements from each arm. Note your hand position for the first segment and try to repeat it for the other segments.

4. Follow the instructions in the successive pop-up windows and click OK when ready for each.

5. When Calibration recording begins, wait about two seconds, then clench the hand dynamometer lightly enough to make a response on the screen, and then release.

6. Wait for Calibration to stop.

7. Check the Calibration data.
   - If correct, proceed to the data Recording Section.
   - If incorrect, Redo Calibration.

### END OF CALIBRATION

### Detailed Explanation of Steps for Calibration

A pop-up window will tell you to remove any grip force from the hand dynamometer. To do so, set the hand dynamometer down.

Remove your hands from the transducer to ensure there is no force on the transducer. This establishes a zero-force calibration before you continue the calibration sequence.

Clench with the hand of your dominant forearm.

![SS25LA grip position](Fig. 2.5)

Pop-up windows will guide you through the initial calibration sequence. After you click OK on the third pop-up window, the Calibration recording will begin.

The program needs a reading of your maximum clench to perform an auto-calibration.

**It is important not to exceed 25 kg force in the calibration so that everyone is on the same scale.**

The Calibration procedure will last eight seconds and stop automatically, so let it run its course.

After the Calibration recording, the screen should resemble Fig.2.6.

![Fig. 2.6](Fig. 2.6)

If your recording does not begin with a zero baseline (Subject clenched before two seconds), repeat calibration to match Fig. 2.6.
C. RECORDING LESSON DATA

FAST TRACK RECORDING

1. Prepare for the recording.

2. Note your Assigned Increment level from the journal.

SEGMENT 1 – Dominant Arm Muscle Fatigue Test - Max

3. Click Record.

4. Clench the hand dynamometer with your maximum force. Note this force and try to maintain it.

5. When the maximum clench force displayed on the screen has decreased by more than 75%, click Suspend.

6. Review the data on the screen. If correct, proceed to recording Segment 3 – Non-dominant Arm Motor Unit Recruitment.

Detailed Explanation of Steps for Recording Lesson Data

In order to work efficiently, read this entire section so you will know what to do before recording. You will record two segments on each forearm:

a. Segments 1 and 4 record maximum fatigue.

b. Segments 2 and 5 record motor unit recruitment.

c. Segments 3 and 6 record half-maximum fatigue.

Based on your calibrated grip force, the software determines the optimal grid display and force increments. **Check to make sure that you didn’t exceed 25kg of force and that your assigned increment in the journal window is 5kg:**

<table>
<thead>
<tr>
<th>Force Calibration</th>
<th>Assigned Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25 kg</td>
<td>5 kg</td>
</tr>
<tr>
<td>25-50 kg</td>
<td>10 kg</td>
</tr>
<tr>
<td>&gt; 50 kg</td>
<td>20 kg</td>
</tr>
</tbody>
</table>

- **TARGET Correct**
- **Incorrect redo Calibration**

When you click Record, the recording will continue and an append marker labeled “Forearm 1, Increasing clench force” will be automatically inserted – Ignore this marker as we are using a different protocol than was intended for this program. **Press F9 to insert a new marker and type “Segment 1 Dominant Max Fatigue”.** The screen will change to display only the hand dynamometer channel, and a grid using your assigned increment as a division scale will appear so that you can visually review the force level.

Note the maximum clench force so you can determine when the force has decreased by 50% (the maximum force may scroll out of view). Try to maintain the maximum clench force (the forearm will fatigue and the force will decrease). If max force goes off of the screen then treat 12.5 as your 50% target.

The time to fatigue to 50% of maximal clench force will vary greatly among individuals.

When you click Suspend, the recording should halt, giving you time to review the data for segment two.

If all went well, your data should look similar to Fig. 2.8.

![Fig. 2.8 Fatigue](image)

Note that the peak found immediately following the start of the Segment represents the maximal clench force. This example shows the point of fatigue to 50% maximal clench force captured on the same screen, but **your maximum force may scroll out of view.** You may
7. If incorrect, click **Redo** (this will erase the previously recorded data segment) and repeat Segment 1.


**SEGMENT 2 – Dominant Arm Motor Unit Recruitment**

9. Click **Continue and Record**.

10. Clench-Release-Wait and repeat with increasing clench force. **Hold each clench for 2 seconds** – wait 15 seconds to allow recovery between each clench. Targets are 5-10-15-20-25-etc. until max clench achieved.

11. Click **Suspend**.

12. Review the data on the screen.

   - If correct, proceed to recording Segment 3 – dominant arm ½ max fatigue test.

13. If incorrect, click **Redo** (this will erase the previously recorded data segment) and repeat Segment 2.

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use the horizontal (time) scroll bar to view your entire recording.

The data would be **incorrect** if:

- a) You didn’t record past the point of 50% maximal clench force.
- b) **Suspend** was clicked prematurely.
- c) The instructions were not followed.

Click “**Redo**” and have the Subject rest so the arm muscles recover and the fatigue data will be meaningful. When ready repeat Segment 1. Note that once you click **Redo**, the data you have just recorded will be erased.

Scroll back to view your maximum force at the start of the test. Write down the value for 1/2 of your maximum force for use in Segment 3.

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After you click **Continue**, the recording will begin and an append marker labeled “Forearm 1, Continued clench at maximum force” will automatically be inserted – Ignore this marker as we are using a different protocol than was intended for this program. **Press F9 to insert a new marker and type “Segment 2 Dominant Recruit”**.

Repeat a cycle of Clench-Release-Wait, clench and **holding clench for 2 seconds** and **waiting for 15 seconds** after releasing clench before beginning the next cycle. Begin with 5 kg of force and increase by the 5 kg (5-10-15-20-25 for example) for each cycle until maximum clench force is obtained.

The recording should halt, giving you time to review the data.

If all went well, your data should look similar to Fig. 2.7.

- The important aspect for you to review is that the data shows multiple peaks (indicating the clench cycles).
- The data shown is from a Subject who was able to maintain an even force throughout the clench. You should have at least 2 seconds of relatively smooth plateau for each clench.

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If the data appear incorrect then click “**Redo**” and repeat Segment 2. Note that once you click **Redo**, the data you have just recorded will be erased.
SEGMENT 3 – Dominant Arm Muscle Fatigue Test – 1/2 Maximum Force

14. Click Resume.

15. Clench the hand dynamometer to the level of \( \frac{1}{2} \) of your maximum force and try to maintain it.

16. When the clench force displayed on the screen has decreased by more than 75\%, click Suspend.

17. Review the data on the screen. If correct, proceed to recording Segment 4 – Non-dominant Arm Motor Unit Recruitment.

When you click Resume, the recording will continue and an append marker will be automatically inserted – ignore the label on the marker. Press F9 to insert a new marker and type “Segment 3 Dominant Half-max Fatigue”.

Note the maximum clench achieved in segment 1 so you can determine when the force has decreased by 50\% (the 50\% of max force may scroll out of view). Try to maintain the maximum clench force (the forearm will fatigue and the force will decrease).

The time to fatigue to 50\% of your 50\% max clench force will vary greatly among individuals.

When you click Suspend, the recording should halt, giving you time to review the data for segment two.

If all went well, your data should look similar to Fig. 2.8.

18. If incorrect, click Redo (this will erase the previously recorded data segment) and repeat Segment 3.

Click “Redo” and have the Subject rest so the arm muscles recover and the fatigue data will be meaningful. When ready repeat Segment 3. Note that once you click Redo, the data you have just recorded will be erased.

![Fig. 2.8 Fatigue]

Note that the peak found immediately following the start of the Segment represents the maximal clench force. This example shows the point of fatigue to 50\% maximal clench force captured on the same screen, but your maximum force may scroll out of view. You may use the horizontal (time) scroll bar to view your entire recording.

The data would be incorrect if:

- d) You didn’t record past the point of 50\% maximal clench force.
- e) Suspend was clicked prematurely.
- f) The instructions were not followed.

Recording continues...
SEGMENT 4 – Non-Dominant Arm Muscle Fatigue Test - Max

19. To record Forearm 2, position the electrodes on the Subject’s non-dominant forearm. Connect the lead set (SS2L) to the electrodes on the Subject’s non-dominant forearm according to Fig. 2.9 and click OK.

**IMPORTANT**
Make sure the electrode lead colors match Fig. 2.9.

20. You should use the same 5 kg increment as for the dominant arm test.

21. Click Resume.

22. Clench the hand dynamometer with your maximum force. Note this force and try to maintain it.

23. When the maximum clench force displayed on the screen has decreased by more than 75%, click Suspend.

24. Review the data on the screen. If correct, click Stop and proceed with the last portion of the EMG lab – Listening to the muscle potentials.

25. If incorrect, click Redo and repeat Segment 4.

In Segments 4 - 6, you will record Forearm 2, the non-dominant forearm, following the same procedure you used for Forearm 1.

Disconnect the lead set (SS2L) from the electrodes on Forearm 1 and connect to the electrodes on Forearm 2 per Fig. 2.9

Based on your calibrated grip force, the software determines the optimal grid display and force increments.

When you click Resume, the recording will continue and an append marker will be automatically inserted – ignore the label on the marker. Press F9 to insert a new marker and type “Segment 4 Non-Dominant Max Fatigue”.

Note the maximum clench force so you can determine when the force has decreased by 50% (the maximum force may scroll out of view). Try to maintain the maximum clench force (the forearm will fatigue and the force will decrease).

The time to fatigue to 50% of maximal clench force will vary greatly among individuals.

When you click Suspend, the recording should halt, giving you time to review the data for segment two.

If all went well, your data should look similar to Fig. 2.8.

When you click Stop, a dialog box is generated, asking if you are finished with both Forearm recordings. This is simply one last chance to confirm that you don’t need to redo the last recording segment. Click “Yes” to end data recording and automatically save the data. Click “No” to return to a display with a Redo option.

The data would be incorrect if:

a) You didn’t record to the point of 50% maximal clench force.

b) Suspend was clicked prematurely.

c) The instructions were not followed.

Click Redo and have the Subject rest so the arm muscles recover and the fatigue data will be meaningful. When ready, repeat Segment 4. Note that once you click Redo, the data you have just recorded will be erased.

SEGMENT 5 – Non-Dominant Arm Motor Unit Recruitment
26. Click Resume.

27. Clench-Release-Wait and repeat with increasing clench force. **Hold each clench for 2 seconds – wait 15 seconds to allow recovery** between each clench.

28. Click Suspend.

29. Review the data on the screen. If correct, proceed to recording Segment 6 – Non-dominant Arm Muscle Fatigue Test – ½ Max Force.

30. If incorrect, click Redo and repeat Segment 5.

**SEGMENT 6 – Non-dominant Arm Muscle Fatigue Test – 1/2 Maximum Force**

31. Click Resume.

32. Clench the hand dynamometer to the level of ½ of your maximum force and try to maintain it.

33. When the clench force displayed on the screen has **decreased by more than 75%**, click Suspend.

34. Review the data on the screen. If correct, click Stop and proceed with the last portion of the EMG lab – Listening to the muscle potentials.

35. If incorrect, click Redo and repeat Segment 6.
**Listening to the EMG – Audio amplification of your forearm muscle potentials**

36. Subject puts on the headphones.

37. Click **Listen**.

38. As you listen, try a variety of Clench-Release–Wait cycles and watch how the data changes on the screen as you listen to the muscle potentials.

39. Click **Stop**. To listen again, **Redo**.

40. Click **Done**.

41. Remove the electrodes from each forearm.

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**Listening to the EMG is NOT optional. You will be asked to describe this experience in your lab report discussion section.**

You will hear the EMG signal through the headphones as it is being displayed on the screen. The screen will display three channels: CH 1 Force, CH 3 EMG, and CH 40 Integrated EMG. The data on the screen will not be saved. The signal will run until you click **Stop**.

This will end listening to the EMG.

A pop-up window with four options will appear. Make your choice, and continue as directed.

Remove the electrode cable pinch connectors, and peel off the electrodes. Throw away the electrodes. Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours, which is quite normal.
DATA ANALYSIS

Finding your Data Files: When you entered your filename during set-up, a folder with that name was created in this location: C:/Program Files/BIOPAC Systems, Inc./Biopac Student Lab v.4.0/Data Files/ You can copy your data folder to a portable media drive and conduct the data analysis on any computer in the neuroscience laboratory – all of these computers have the BIOPAC software installed on them.

1. Enter the Review Saved Data mode and choose the correct file. Press ALT and click on the red 1 in the upper left to show the EMG Data.

Note Channel Number (CH) designations:

Channel Displays
CH 1 EMG (raw)
CH 41 Clench Force
CH 40 Integrated EMG

Note: This does not go in order on your Excel Sheet. We will do recruitment first, then fatigue.

Analysis of Motor Unit Recruitment – Dominant Arm (Seg.2) and Non-Dominant Arm (Seg. 5)

2. Setup your display for optimal viewing of Segment 1 data.

3. Set up the measurement boxes as follows:

Channel Measurement
CH 1 p-p
CH 1 stddev
CH 1 delta T
CH 41 value

The first data segment was the recording before the first marker. See Fig. 2.11.

The following tools help you adjust the data window:

- Autoscale horizontal Horizontal(Time) Scroll Bar
- Autoscale waveforms Vertical (Amplitude) Scroll Bar
- Zoom Tool
- Zoom Back

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 them. The following is a brief description of these specific measurements.

- p-p: finds the maximum value in the selected area and subtracts the minimum value found in the selected area.
- stddev: displays the standard deviation of the selected area.
- delta T: is the amount of time that you have selected (2 s)
- value: is the numeric value at the right edge of the cursor or selection.

The “selected area” is the area selected by the I-Beam tool (including the endpoints). You need to change from the “arrow” to the I-Beam tool by clicking the button on the right side of the screen (highlighted in white on Fig. 2.11)
4. For segment 2 use the I-Beam cursor to select a 2 second region on the plateau phase of the first clench (Fig. 2.11). Record the measurements on the EXCEL data template sheet available for download on the course laboratory web site.

RAW = ch1 PP measurement
STDev = ch1 stddev measurement

5. Repeat the measurement process on the plateau of each successive clench.

6. Scroll forward to Segment 5 – non-dominant arm increasing force clenches and set up your display for optimal viewing.

7. Repeat the measurement process for Segment 5 – non-dominant arm increasing force clenches.

Analysis of Arm Muscle Fatigue Test and ½ Max Fatigue Test – Dominant Arm (Seg. 1 and 3) and Non-Dominant Arm (Seg. 4 and 6)

8. Scroll back to Segment 1 – dominant arm muscle fatigue test and set up your display for optimal viewing.

9. Use the I-Beam cursor to select a point of maximal clench force immediately following the start of the segment (Fig. 2.12). Record the maximal clench force (value, CH 41) for the dominant arm on the EXCEL datasheet. The cells are the last on the right-side.

Calculate 50% of the maximum clench force. (=Dfatigue/2)

Data Analysis continues…
10. Find the point of 50% maximum clench force by using the I-beam cursor and leave the cursor at this point.

11. Select the area from the point of 50% clench force to the point of maximal clench force by using the I-beam cursor and dragging. (Fig. 2.13).

Record the time to fatigue (CH 1 delta T) measurement in the appropriate cell on the EXCEL sheet.

12. Scroll to **Segment 4** and set up your display for optimal viewing.

13. Repeat the measurement of maximal force and time until 50% of maximal force for **Segment 4 – Non-dominant Arm Muscle Fatigue Test**.

14. Repeat the measurements for **Non-dominant Arm Muscle Fatigue Test Segments 3 and 6**.

Record the values in the spreadsheet.

15. Exit the program.

16. Save your Excel file and copy or enter your individual data into the GROUP datasheet linked to a Google Doc on the lab website.

Your data must be entered into the Group Data sheet on GOOGLE DOC by the deadline found on the lab website. There is a link to the Google Doc on the lab website.

**Fig. 2.13 showing area max-50%**

Segment 4 begins at the fourth append marker, labeled “Segment 4.”

**END OF DATA ANALYSIS**