BIOL 347 General Physiology Lab
Part 1: Grip Strength and Electromyogram (EMG) Activity
Part 2: Stretch Receptors and Reflexes

Objectives

- To determine the relationship between the intensity of EMG activity and the force of a muscle contraction.
- To observe the relationship between length and strength of a muscle contraction and EMG activity in both the dominant and non-dominant forearm.
- To study EMG activity in antagonistic muscles during normal movement.
- To determine conductance time from stimulus to response in the Achilles tendon reflex arc.
- To determine conductance time from stimulus to response in the patellar tendon reflex arc.

Introduction

A motor unit is composed of a motorneuron and all the muscle fibers that are innervated by that motorneuron. In a persistent muscle contraction, like a clench, multiple motor units are firing repetitively throughout the contraction of the muscle. The strength of a muscle contraction is related to the number of motor units in the muscle that are activated during the same time period.

The electromyogram (EMG) recorded during the muscle contraction is seen as a burst of spike-like signals, and the duration of the burst is about equal to the duration of the muscle contraction. The strength of a striated muscle contraction is directly proportional to the amount of electrical activity in the muscle. However, it is difficult to quantify the amount of electrical activity in a muscle unless the raw EMG data is mathematically transformed. One of the most common transformations used is the integration of the absolute values of the amplitudes of the EMG spikes. Through this transformation, it has been found that the area under the graph of the absolute integral of the EMG is linearly proportional to the strength of the muscle contraction.

In this experiment, students will use a hand dynamometer to measure a subject's grip strength as the EMG activities of the forearm muscles used to generate the grip are recorded. The EMG activity will be related to the grip strength by plotting the maximum grip strength as a function the area under the absolute integral of the EMG activity during the muscle contraction. Data recordings will be made from the subject's dominant and non-dominant forearms, and the relative strength and electrical activity of each forearm will be compared to its diameter. Recordings of prolonged grip strength and forearm EMG activity will also be made to determine the rate of fatigue in the dominant and non-dominant forearms.

Studying the vertebrate stretch reflex is a good way to introduce students to the topics of stretch receptors, nerve conduction velocity, electromyograms (EMG), and motor control. Specialized receptors in the muscle respond to stretching of the tendon attached to the muscle, and send signals to motorneurons through a single synapse. The muscle fibers depolarize and twitch in response to the incoming impulse from the motorneuron.

Skeletal muscles have specialized receptors that convey information about muscle length, tension, and pressure to the central nervous system. The sensory receptors responsible for providing information about the length, or the rate of change of the length, of a muscle are called muscle spindles. Arranged in parallel with muscle fibers, the spindles are stretched when the muscle is stretched by an external force. Therefore, these receptors play a significant role in developing antigravity reflexes and maintaining muscle tone. Muscle spindles contain a small bundle of intrafusal fibers that do not contribute to the overall tension of the muscle, but regulate the excitability of the afferent spindle nerves by mechanically deforming the receptors. These fibers are innervated by gamma motor neurons. The majority of a muscle consists of extrafusal fibers, which are innervated by alpha motor neurons and are responsible for developing muscle tension.

When a muscle is stretched, excitation of its muscle spindles causes a reflex contraction of the muscle. This reflex response is known as a stretch (myotatic) reflex. The minimal delay between the muscle stretching and the reflex contraction is due to its monosynaptic pathway. The sensory afferent nerves from the spindles synapse directly with motor neurons; there are no inter- neurons. This pathway constitutes the shortest possible reflex arc.

As an example of the stretch reflex, consider the reflex response that occurs when a person jumps from a low stool to the floor. The extensor muscles of the legs are stretched on landing, lengthening all their muscle spindles. The discharge of the muscle spindles is conveyed to the central nervous system through the fast-conducting afferent axons.

These sensory axons enter the spinal cord through the dorsal root and synapse with the motor neurons of the same extensor muscle. In turn, the motor neurons trigger the contraction of the extensor muscle to oppose the stretch produced by landing, completing the reflex arc.

Students will record electromyograms (EMGs), the summation of asynchronous electrical activity (muscle action potentials) in the multiple fibers in the muscle, and use them to determine the time between the stretch of the tendon and the arrival of the motor impulse at the muscle.

Two reflexes in a human subject will be studied: the Achilles tendon reflex, and the patellar tendon (knee- jerk) reflex. Conduction times and nerve velocities for each reflex arc will be determined and compared. The effect of pre-existing tension in the effector muscle, or motor activity in other muscle groups, upon reflex responses will be measured. The coordination of motor activity in antagonistic muscles will also be studied.

Procedure

Set-up of Equipment and Electrodes

1. Plug the AAMI (5-lead electrode) connector into the Channel 1 and 2 inputs on the iWorx unit. Connect the hand dynamometer to the input of Channel 3 on the iWorx unit.
2. Have your test subject remove all jewelry from their wrists. For this first experiment have the subject use their dominant arm.
3. Using the alcohol swab, clean and scrub three regions on the subject's arm where the electrodes will be placed:
   - Near the wrist
   - Middle of the forearm
   - Approximately two inches below the elbow
4. Place the electrodes in the aforementioned locations.
5. Attach the electrodes as follows:
   - The red "+1" lead is attached near the elbow
   - The black "-1" lead is attached to the middle of the forearm
   - The green "C" lead, the ground, is attached to the wrist
6. Click on the LabScribe icon on the desktop.
7. Click on the **Settings** menu and select **EMG-GripStrength-LS2** settings file.
8. The settings should appear on the screen.

Calibration of the Hand Dynamometer

1. Gather a stack of five textbooks.
2. Place the hand dynamometer on the bench-top.
3. Click the **Record** button on the Main Labscribe window. Record for ten seconds.
4. Continue to record as you place the stack of textbooks on the bulb of the hand dynamometer. Once the recording is stable, record for ten additional seconds. Then click the **Stop** button.
5. Using the scale in the lab, weigh your stack of textbooks.
6. Use the **Display Time** icon to adjust the display on the window, so that the time before placing the textbooks on the hand dynamometer until stabilizing after their placement is visible.
7. Click the **2-Cursor** icon on the toolbar. Place one cursor on the area that corresponds to before the weight was applied and place the other cursor on the section of the recording after the weight was applied.
8. **Click** on the down arrow on the **Force** (CH3) channel. Select **Units** from the pull down menu. Type zero (0) in the box next to the voltage value of the first cursor. Type the weight of the stack of the textbooks (in kg) in the box next to the voltage value of the second cursor. Type the unit "kg" in the **Name** box. Click the **OK** button.

EMG Intensity and Force

1. The subject should sit quietly with his/her dominant forearm resting on the bench-top. Explain the following procedure to the subject:

   The subject will clench his/her fist around the hand dynamometer bulb four times: each clench should last two seconds, followed by a relaxation period of two seconds. Each clench should be progressively stronger.

2. Click the **Record** button to begin recording. Type "Increasing Clenches" in the comment line to the right of the **Mark** button. Press the **Enter** key on the keyboard. The subject should start the procedure that was outlined in the previous step. After the final two-second relaxation click the **Stop** button to end the recording.
3. Click the **AutoScale** buttons for the **EMG** (CH 1), **EMG Integral** (CH 2) and **Force** (CH 3) channels.
4. Save your work.
5. Adjust the time on the main window display to show all four of the subject's clenches.
6. Click the **2-cursor** icon on the toolbar. Place the two cursors on either side of the four clench cycles displayed in the main window. Click the **Analysis** icon on the toolbar to send this data to the analysis window.
7. Look for the Area and Mean functions on the analysis bar. If these functions are not shown then click on the add function button and add them.
8. Place the two cursors on the Analysis window at either end of the maximum force plateau, for the first clench, on the **Force** channel (CH3). Record your value for **Mean** in Table 1.
9. Repeat these procedures to get **Area** and **Mean** for all four clench cycles. Record the data in Table 1.

EMG Intensity and Fatigue in Dominant Arm

1. The subject should sit quietly with his/her dominant forearm resting on the bench-top. Explain the following procedure to the subject:

   The subject will clench the hand dynamometer bulb as tight and as long as possible in an attempt to fatigue the muscles in the forearm. When the subject's clench force falls below 50% of the maximum, the procedure will be stopped.

2. Click the **Record** button on the Main window. Record a baseline for a few seconds, then have the subject clench the hand dynamometer bulb as described in the previous step. Click the **Autoscale** buttons on all three recording channels. Continue to record until the subject's clench force falls below 50% of the maximum, instruct the subject to release the bulb and then click **Stop**.
3. Save this file.
4. Use the tape measure to determine the circumference of the widest part of the subject's dominant forearm. Record the data in Table 2.
5. Adjust the screen time in the Main window so that the complete recording of this experiment can be seen.
6. Click the **2-cursor** icon on the toolbar. Place one on the relaxation period that proceeds the fatigued exercise. Place the second cursor to the right of the point when the subject released the bulb. Click the **Analysis** icon on the toolbar to send this data to the analysis window.
7. Place one cursor on the relaxation period before the maximum contract and one cursor on the peak of the muscle contraction. The difference in amplitude (V2-V1) is the maximum clench force of the subject. Record this value in Table 2.
8. Divide the maximum clench force by two to get the half-maximum clench force. Enter this value in Table 2.
9. To determine the time it takes the subject's forearm to fatigue, move one cursor to the peak of muscle contraction and the other at the point where the V2-V1 is equal to the half-maximum clench force. Once these cursors are in the correct positions, the T2-T1 value is the time it takes the subject's forearm muscles to fatigue to half of their strength. Record this value in Table 2.

EMG Intensity and Force in the Non-Dominant Arm

1. Repeat the procedure for EMG Intensity and Force in the Dominant Arm, however use the subject's non-dominant arm. Record this data in Table 1.

EMG Intensity and Fatigue in the Non-Dominant Arm

1. Repeat the procedure for EMG Intensity and Fatigue in the Dominant Arm, however use the subject's non-dominant arm. Record this data in Table 2.

EMGs in Antagonistic Muscles

1. Plug the AAMI (5-lead electrode) connector into the Channel 1 and 2 inputs on the iWorx unit.
2. Using the alcohol swab, clean and scrub three regions on the subject's upper arm where the electrodes will be placed:
   - Below the shoulder
   - Middle of the biceps
   - Above the elbow
   - Upper portion of the triceps
   - Middle of the triceps
3. Attach the electrodes as follows:
   - The red "+1" lead is attached below the shoulder
   - The black "-1" lead is attached middle of the biceps
   - The green "C" lead is attached just above the elbow
   - The white "+2" lead is attached to the upper portion of the triceps
   - The brown "-2" lead is attached to the middle of the triceps
4. Click **Record** to begin recording. Type "No weight" in the comment line to the right of the mark button and press the **Enter** key on the keyboard.
5. Ask the subject to bend and extend their arm slowly. Type "bend" in the comment line and press **Enter** key each time the subject bends his/her arm.
6. Click **Stop**.
7. Repeat this experiment, lifting a heavy weight or book bag. Type a comment to identify this portion of the record.
8. Click **Record** to begin recording. When finished, click **Stop**. Save the file and answer the questions at the end of this lab while looking at your data.

EMG Recording and Reflex Time in the Achilles Tendon Reflex Arc

1. Plug the AAMI (5-lead electrode) connector into the Channel 1 and 2 inputs on the iWorx unit.
2. Using the alcohol swab, clean and scrub three regions on the subject's arm where the electrodes will be placed:
   - Near the ankle
   - Fundus of the calf muscle
   - Three inches below the back of the knee
3. Attach the electrodes as follows:
   - The red "+1" lead is attached near the back of the knee
   - The black "-1" lead is attached to the fundus of the calf muscle
   - The green "C" lead, the ground, is attached to the ankle
4. Plug the plethysmograph cable into the Channel 4 (Tap) input on the iWorx unit. Place the plethysmograph on the side of the head of the patellar hammer. Attach it to the head with its Velcro strap. As the patellar hammer strikes the tendon, the plethysmograph will emit a signal that is recorded on Channel 4. The signal will serve as a mark for when the tendon was struck.
5. Click on the LabScribe icon on the desktop.
6. Click on the **Settings** menu and select **AchillesStretchReflex-LS2** settings file.

7. The settings should appear on the screen.
8. Have the subject sit at the end of the bench-top with their thighs supported, but with their lower legs hanging free.
9. Tap the Achilles tendon with the head of the rubber hammer. The Achilles tendon is located above the heel and connects the gastrocnemius muscle to the tarsal bone of the foot. A few trials should produce a consistent contraction of the gastrocnemius muscle and a downward movement of the foot (plantar flexion). The opposite, upward movement is dorsoflexion.
10. When ready click **Record**. Ask the subject to move their foot up and down, alternating between the plantar flexion and dorsoflexion. Click **Autoscale** on both the **EMG Calf** (CH 1) and **Tap** (CH 4).
11. Tap the Achilles tendon to elicit the stretch reflex. Record ten trials using the same tapping force.
12. Click **Stop** when finished. Save the file.
13. Mark the recording and repeat the above procedure using a different tapping force (stronger/weaker). Again save your recording when finished.
14. Click on the **2-Cursor** icon on the toll bar. Position the cursors so that the recordings for a single tap and twitch are between the two lines. Click the **Analysis** icon on the toolbar to send this data to the analysis window.
15. Use the mouse to click and drag one cursor to the beginning of the plethysomograph spike to the Tap channel and the second cursor to the beginning of the EMG spike on Channel 1. The time interval (T2-T1) is the reflex time of the subject's stretch reflex. Record this time in Table 3.
16. Repeat this measurement for all ten trials at both the regular tapping force and the stronger/weaker force. Record the data in Tables 3 and 4.
17. Take the mean of these trials and enter this in Table 3 and 4. Also, measure the distance from the fundus of the calf muscle to the site of sensory motor synapse in the spinal cord (assume this location is just above the hip bone on the spinal cord). Multiply this measurement by two to get the total length of the nerve path.
18. Even though this stretch reflex is known as a monosynaptic reflex, the pathway includes the neuromuscular synapse as well. Assume that synaptic transmission takes 0.5 msec (with there being two synapses within the reflex pathway) and that the conduction velocity is around 85 m/sec (estimate based of the ranges of speeds of the two types of neurons involved. Use the measured pathlength and these two constants to measure the subject's neuromuscular junction delay :

$$conductionvelocity\left(m/\sec\right) = \frac{Total\ pathlength(mm)}{\left(Meanreflextime(m\sec) - (synaptictransmissiondelay + nueromuscularjunctiondelay)\right)}$$

EMG Recording and Reflex Time in the Patellar Tendon Reflex Arc

1. Plug the AAMI (5-lead electrode) connector into the Channel 1 and 2 inputs on the iWorx unit.
2. Using the alcohol swab, clean and scrub three regions on the subject's arm where the electrodes will be placed:
   - The knee
   - 12 cm above the knee on the quadriceps muscle
   - 22 cm above the knee on the quadriceps muscle
3. Attach the electrodes as follows:
   a. The red "+1" lead is attached 22 cm above the knee on the quadriceps muscle
   b. The black "-1" lead is attached 12 cm above the knee on the quadriceps muscle
   c. The green "C" lead, the ground, is attached to the knee
4. Plug the plethysmograph cable into the Channel 4 (Tap) input on the iWorx unit. Place the plethysmograph on the side of the head of the patellar hammer. Attach it to the head with its Velcro strap. As the patellar hammer strikes the tendon, the plethysmograph will emit a signal that is recorded on Channel 4. The signal will serve as a mark for when the tendon was struck.
5. Click on the LabScribe icon on the desktop.
6. Click on the **Settings** menu and select **PatellarStretchReflex-LS2** settings file.

7. The settings should appear on the screen.
8. Have the subject sit at the end of the bench-top with their thighs supported, but with their lower legs hanging free.
9. Tap the patellar tendon with the head of the rubber hammer. The patellar tendon is located just below the knee
10. When ready click **Record**. Tap the patellar tendon to elicit the stretch reflex. Record ten trials using the same tapping force.
11. Click **Stop** when finished. Save the file.
12. Now record five trials when the subject voluntarily contracts their quadriceps.
13. Record another five trial when the subject contracts their quadriceps muscle more/less than before.
14. Now record five trials with the subject in the Jendrassik Maneuver (hands cupped and interlocked in front of their chest with elbows pointing out). The subject creates an isometric contraction as they attempt to pull their hands apart. Save the file.
15. Click on the **2-Cursor** icon on the toll bar. Position the cursors so that the recordings for a single tap and twitch are between the two lines. Click the **Analysis** icon on the toolbar to send this data to the analysis window.
16. Use the mouse to click and drag one cursor to the beginning of the plethysomograph spike o the Tap channel and the second cursor to the beginning of the EMG spike on Channel 1. The time interval (T2-T1) is the reflex time of the subject's stretch reflex. Record this time in Table 5.
17. Repeat this measurement for all trials and record in the appropriate tables.
18. Move the first cursor to the baseline of Channel 2 prior to the reflex response and move the second cursor on the peak of the integral channel. Record the V2-V1, or strength of the motor response of the reflex. Record the data in the appropriate tables.

Table 1: EMG Intensity and Force

	Dominant Arm				**Non-Dominant Arm**			
	Cycle 1	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
Area								
Mean Force								

Table 2: EMG Intensity and Fatigue

	Dominant Arm	**Non-Dominant Arm**
Circumference (cm)		
Maximum Clench Force		
Half-maximum Clench Force		
Time (s) to Half-maximum Clench Force		

Table 3: Achilles Tendon Reflex Times- Normal Tap

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
Reflex Time										

Mean Reflex Time: ___________________

Total Length of Nerve Path: ___________

Neuromuscular Junction Delay: __________________

Table 4: Patellar Tendon Reflex Times and Strength

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
Reflex Time										
Strength										

Mean Reflex Time: ___________________

Table 5: Patellar Tendon Reflex Times and Strength with Contraction

	With Contraction					Experimental Contraction				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Strength										

Table 6: Patellar Tendon Reflex Times and Strength in Jendrassik Position

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Reflex Time					
Strength					

Mean Reflex Time: ___________________

EMG Intensity and Force Questions and Conclusions

1. Do muscle fibers have a refractory period like nerve fibers?

2. Does the amplitude for the EMG signal and force of contraction increase because a finite number of fibers are firing more often, or because more fibers are recruited to fire as the intensity of signals in the motorneurons increase, or a combination of these two?

EMG Intensity and Fatigue Questions and Conclusions

1. Is there a difference in the maximum forces generated by the dominant and non-dominant arm forearms?

2. Is there a relationship between the circumference of the forearm and the maximum force developed? Explain.

3. How does the time to fatigue to half-strength in the dominant forearm compare to the same parameter in the non-dominant forearm?

EMGs in Antagonistic Muscles Questions and Conclusions

1. Where does myogram activity occur when the arm is extended away from the shoulder? When the arm is flexed (towards the shoulder)?

2. Does EMG activity increase or decrease when more weight is moved? What is the relationship between motorneuron activity, EMG, muscle performance and work?

3. If the weight is held at arm's length, does EMG activity increase, decrease or remain constant for the duration of the experiment?

4. Why would muscle activity increase if the load being lifted is constant?

Reflex Time in the Achilles Tendon Reflex Arc Questions and Conclusions

1. Which muscles are involved in plantar flexion and dorsiflexion of the ankle?

2. Is the reflex time consistent or does it change?

3. Traditionally, neuromuscular junction delays are around 30-45 msec, but they can vary greatly (beyond that range). How does your experimental value compare with that accepted range, and what do you think causes such a large variance of the neuromuscular delay compared to the essentially universal delay of the synapse?

Reflex Time in the Patellar Tendon Reflex Arc Questions and Conclusions

1. Compare the average reflex times of the Achilles and patellar reflexes. What factors contribute to the differences between these times?

2. Is the patellar reflex inhibited or enhanced by voluntary muscle activity in the quadriceps?

3. Is the patellar reflex facilitated during the Jendrassik Maneuver? Speculate on the mechanism of enhancement or inhibition.

4. Besides excitatory inputs from stretch receptors, what synaptic inputs might influence the activity of spinal motorneurons?