

# Electromyography

In this experiment, you will explore the electrical activity of skeletal muscle by recording an electromyogram (EMG) from a volunteer. You will examine the EMG of both voluntary and evoked muscle action and attempt to measure nerve conduction velocity.

---

## Background

A skeletal muscle fiber is innervated by a branch of a motor axon. Under normal circumstances, a neuronal action potential activates all of the muscles innervated by the motor neuron. This activation process involves an action potential and a contraction of the muscle fibers. During a contraction, therefore, there is synchronous activity in a number of fibers in the same muscle. The electrical signal recorded from a contracting muscle is called an electromyogram or EMG. Like the electrocardiogram (ECG), this activity can be detected by electrodes placed on the skin. A voluntary muscle contraction is produced by one or more action potentials in many fibers. The EMG activity is not a regular series of waves like the ECG, but a chaotic burst of overlapping spike-like signals.

In this experiment, you will record EMG activity during voluntary contractions of the biceps and triceps muscles of the arm. The raw EMG signal during voluntary contractions may be processed in various ways to indicate the intensity of EMG activity. In the method used here, the negative-going portions of the EMG are inverted, and then the whole signal is integrated in such a way as to smooth out individual spikes, and make the time course of changing activity much clearer. You will also record EMG signals produced by electrical stimulation of a motor nerve supplying a muscle. The abductor pollicis brevis muscle a member of the thenar muscle group on the palmar surface of the hand. The motor nerve to this muscle (the median nerve) is easy to stimulate at the wrist and elbow.

## Required Equipment

- A computer system
- Chart software
- PowerLab (with built-in Bio Amp or PowerLab and Bio Amp front-end)
- Five-lead Shielded Bio Amp Cable & snap-connect Shielded Lead Wires
- Disposable ECG recording electrodes
- Stimulus Bar Electrode
- Electrode cream
- Abrasive pad/gel
- Alcohol swabs
- Ballpoint pen
- Dry earth strap
- Four books of similar weight (about 1 kg each)

## Warning



Some exercises involve application of electrical shocks to muscle through electrodes placed on the skin. People who have cardiac pacemakers or who suffer from neurological or cardiac disorders should not volunteer for those exercises. If the volunteer feels major discomfort during the exercises, discontinue the exercise and consult your instructor.

## Subject preparation and equipment setup

1. Select a volunteer for the experiment and have that person remove any watch, jewelry, etc. from their wrists.
2. Plug the five-lead Bio Amp cable into the Bio Amp (Figure 1).
3. Plug the lead of the dry earth strap into the Earth connection of the Bio Amp cable. Since this cable only has one connection pin, plug it into the upper post on the shielded Bio Amp cable (Figure 2).

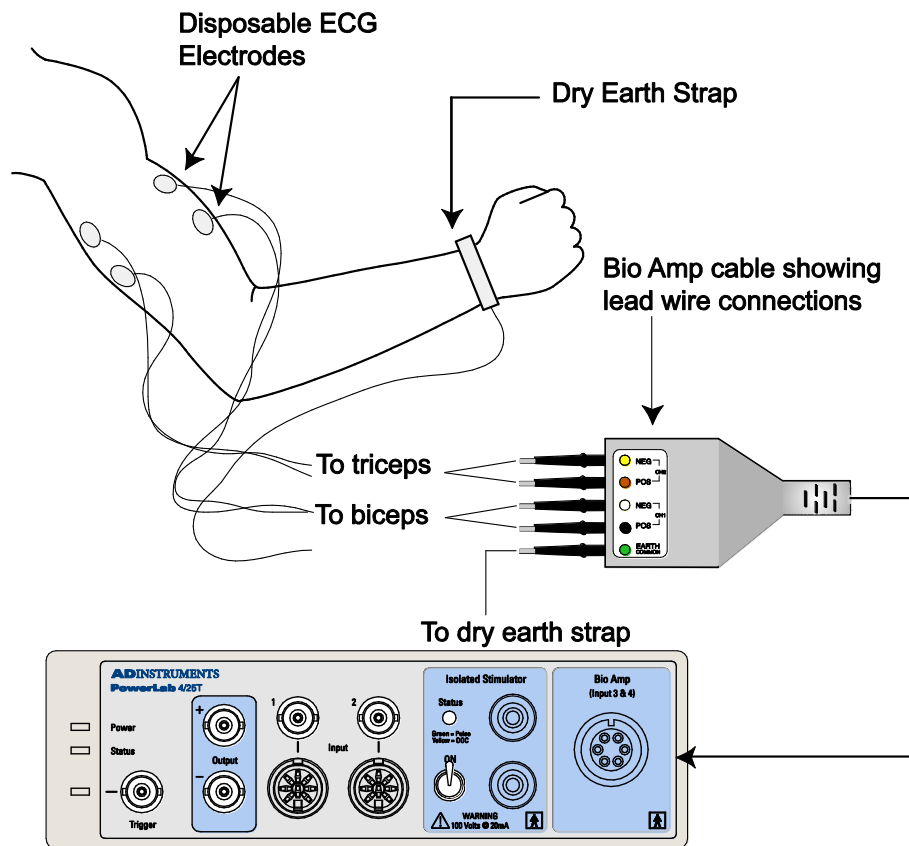


Figure 1. Equipment setup for the EMG experiment, showing the connections for recording EMG from the biceps and triceps muscles.

4. Firmly attach the dry earth strap around the palm or wrist of the volunteer. The fuzzy side of the dry earth strap needs to make full contact with the skin.

## Biological Signals Lab

- Swab the skin with alcohol in each area where electrodes will be placed on the volunteer (Figure 1). With a ballpoint pen, lightly mark two small crosses on the skin overlying the biceps muscle, in the position for the biceps recording electrodes shown in Figure 1. The crosses should be 2–5 cm apart and aligned with the long axis of the arm. *Lightly* abrade the marked skin with an abrasive pad/gel. This decreases the resistance of the outer skin layers and ensures good electrical contact.

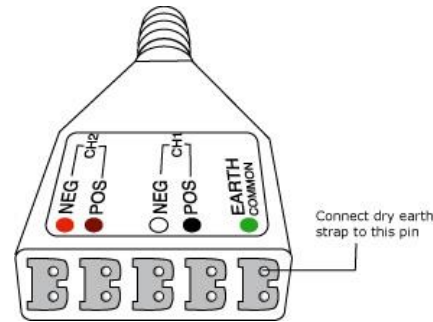


Figure 2. Attach the dry earth strap to the upper pin on the shielded Bio Amp cable.

- Prepare the skin over the triceps for attaching the electrodes as outlined in step 5 for the biceps. The position for the triceps recording electrodes is shown in Figure 1.
- Prepare the disposable ECG electrodes by removing the backing film. Put a *small* amount of electrode cream on the pre-gelled electrode surface. Place the electrodes onto the skin over the crosses so they adhere well.
- Plug the four shielded lead wires into the Bio Amp cable ports for positive and negative, CH1 and CH2.
- Snap the lead wires from Channel 1 on the Bio Amp cable onto the electrodes on the subject's biceps. It does not matter which is positive and which is negative.
- Repeat step 9 for the lead wires on Channel 2 on the Bio Amp cable onto the electrodes on the subject's triceps.
- Check that all electrodes are properly connected to the volunteer and the Bio Amp cable before proceeding.

### Starting the software

- Four channels should be prepared. Channels 1 and 2 show the absolute integrals of the raw EMG signals from the muscles recorded in Channels 3 and 4. Channel 1 should be named "∫ Biceps" (Int. Biceps, Win), Channel 2 "∫ Triceps" (Int. Triceps, Win), Channel 3 "Biceps" and Channel 4 "Triceps".
- Now begin the exercises.

## Exercise 1: Voluntary change in contractile force

### Objectives

In this part of the laboratory, the EMG during voluntary muscle contractions will be recorded and how contractile force changes with increasing demand will be investigated.

### Procedure

- Have the volunteer sit in a relaxed position, with their elbow bent to 90° with the palm facing upwards. They should use their other hand to grasp the wrist of the recorded arm.
- Ask the volunteer to make a strong contraction of the biceps muscle, by trying to bend the recording arm further and resisting this movement with their other arm. Observe the signal.

## Biological Signals Lab

3. Repeat the same steps for the triceps signal in Channel 4 (Triceps). The volunteer can make a strong contraction of the triceps muscle by trying to straighten out the recorded arm and resisting this movement with their other arm.
4. Click Start. Have the volunteer perform a maximum contraction of their biceps and then triceps muscles. Click the Stop button to stop recording, and check that the integrated signal traces are clearly visible in the Chart window. If not, adjust the **Y-axis scaling** so that they are visible.
5. The volunteer should once more sit in a relaxed position, with their elbow unsupported and bent to 90° with the palm facing upwards.
6. Click Start to resume recording. After a few seconds, place one book (or a similar weight) on the hand of the subject. Enter a **comment** in the data trace called "one book". Leave the book in place for two to three seconds to record the change in the EMG, and then remove it. Repeat this process for two, then three, then four books, to give a series of increasing weights, adding a **comment** each time.
7. Click Stop and observe the data. The waveforms should look something like those in the Chart window in Figure 3.

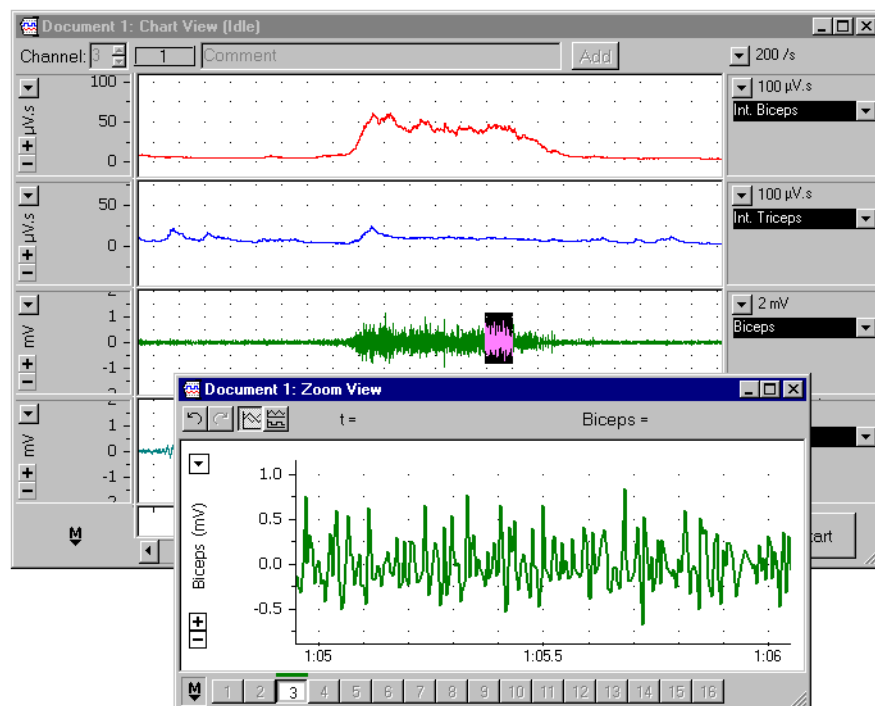


Figure 3. Burst of EMG activity of bicep muscles while supporting a weight: Channel 1 (Int. Biceps) is the integrated signal; the Zoom View shows part of the raw EMG activity in the biceps muscle.

## Exercise 2: Alternating activity and co-activation

### Objectives

In this part of the laboratory, the activity of antagonist muscles and the phenomenon of co-activation will be examined.

# Biological Signals Lab

## Procedure

1. The volunteer should sit in a relaxed position, with their elbow bent to 90° with the palm facing upwards. They should use the other hand to grasp the wrist of the recording arm.
2. Ask the volunteer to activate the biceps and triceps alternately. The biceps muscle can be activated by trying to bend the recording arm further and resisting this movement with the other arm. The triceps muscle can be activated by trying to straighten out the recorded arm and resisting this movement with the other arm. The volunteer should practice this alternating pattern until it feels like both muscles are being equally activated in turn.
3. Click Start to begin recording. Ask the volunteer to use the alternating pattern of activation for 20 to 30 seconds.
4. Click the Stop button and examine the data. The waveforms should look something like those in Figure 4.

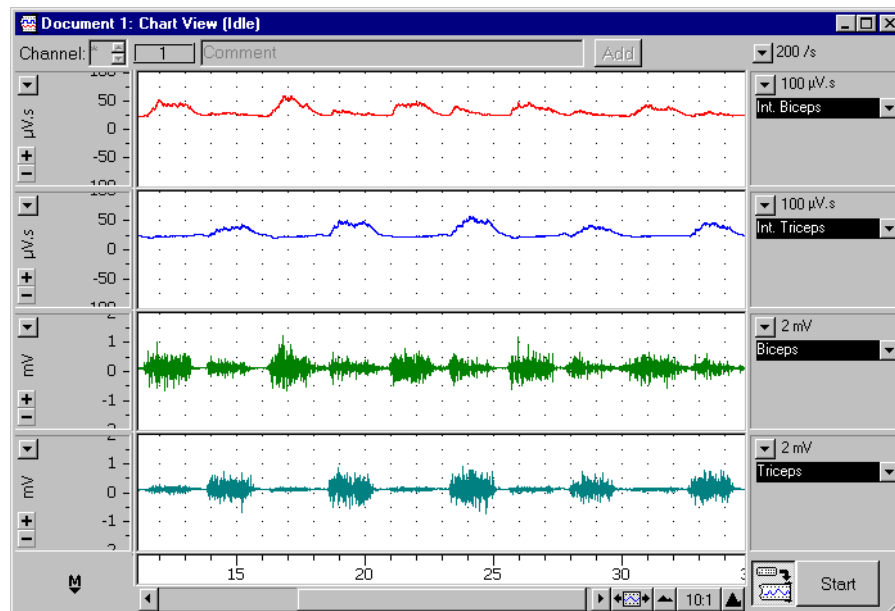


Figure 4. A Chart recording of EMG, showing coactivation.

5. Choose Save from the File menu to save the recording.

## Exercise 3: Evoked EMG



Please read the following instructions through carefully before continuing with this exercise. Note that muscle contraction and sensations such as tingling or brief pain, are associated with nerve stimulation.

## Objectives

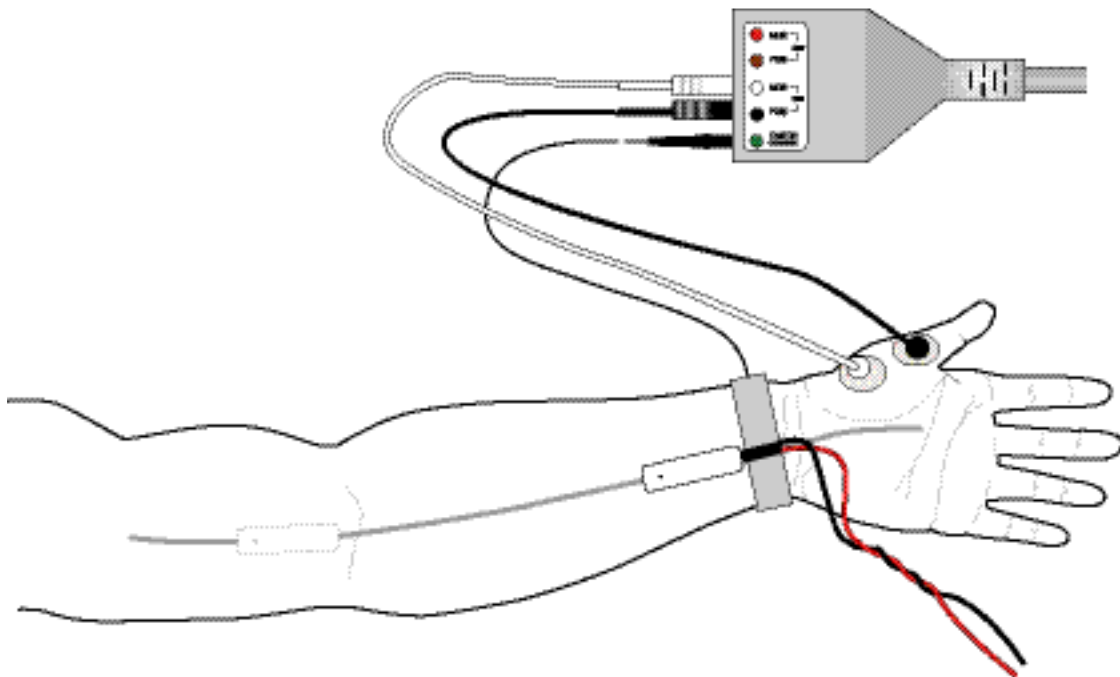
In this exercise, EMG responses evoked by stimulating the median nerve at the wrist will be recorded.

## Biological Signals Lab

### Procedure

Continue with the same volunteer or choose a new one. Things should be set up as described previously, with the Bio Amp cable plugged into the Bio Amp socket on the PowerLab, and the dry earth strap wrapped around the palm or wrist of the volunteer and connected to the Earth connection of the Bio Amp cable.

1. Disconnect the recording electrode leads from Channel 2 sockets of the Bio Amp cable, and remove their electrodes from the triceps of the subject. Remove the electrodes from the biceps of the subject, but leave their leads connected to Channel 1 sockets of the Bio Amp cable.
2. To set up recording, select Experiments Gallery from the File menu and open the settings file "**EMG Evoked Settings**". After a short time, the Chart View on the computer screen should be set up, with a single displayed channel (Channel 3, "EMG").



*Figure 5. Electrode connections for recording from the abductor pollicis brevis muscle, and stimulation of the median nerve at the wrist and elbow.*

3. With a ballpoint pen, lightly mark two small crosses on the skin overlying the abductor pollicis brevis muscle, in the position for the recording electrodes shown in Figure 5. The crosses should be 2–3 cm apart. Lightly abrade the marked skin to reduce its electrical resistance.
4. Obtain two new disposable ECG electrodes and trim the adhesive pad slightly so they will fit as shown in Figure 6. Place a very small amount of electrode cream on the gelled surface of the electrode and attach them onto the skin over the crosses. Use adhesive tape to fasten the electrode wires immediately adjacent to the skin electrodes.

**Note:** The polarity of the electrodes must be as shown in Figure 6, with the negative electrode closer to the wrist.

## Biological Signals Lab

5. Connect the bar stimulus electrode to the Isolated Stimulator output of the PowerLab or Stimulus Isolator: the red (positive) connector to the red output and the black (negative) connector to the black output.
6. Place a small amount of electrode cream on the two silver pads of the stimulating bar.
7. Place the bar stimulus electrode over the volunteer's median nerve at the wrist (the approximate placing is shown in Figure 5). The bar stimulus electrode should lie along the axis of the arm, with the leads pointing towards the hand — a red (positive) dot on the back of the electrode should be on the far end of the electrode from the hand. Set the stimulator switch on the PowerLab unit to the "**ON**" position (up). Note that the Isolated Stimulator only becomes active during sampling — it is switched off internally at all other times.
8. Choose the **Stimulus Isolator** command (Windows) from the Setup menu to bring up the Isolated Stimulator dialog window and ensure that the settings are the same as in Figure 6.

**Note:** In this exercise, Chart will record for a fixed duration of 0.05 s and then automatically stop.

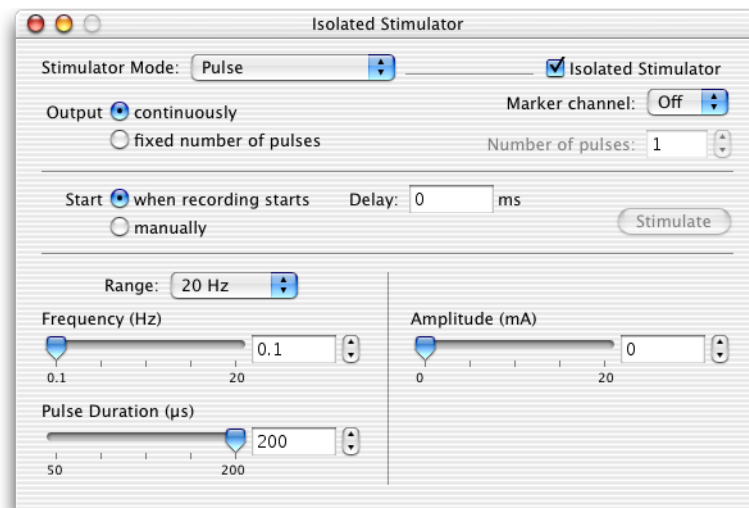


Figure 6. Isolated Stimulator dialog showing the settings for the start of Exercise 3.

9. Increase the pulse current in the Isolated Stimulator dialog to 8 mA by clicking the arrows or dragging the slider control. Move the Isolated Stimulator dialog to a convenient position that does not obscure the view of the Chart View.
10. Click Start to apply a stimulus and record the response. Apply mild pressure to the bar stimulus electrode to ensure that the nerve is stimulated and that the electrode doesn't move around during the exercise. Adjust the electrode to find the best position for stimulation.
11. If no response, increase the pulse current a little. Some subjects may fail to show any response with the stimulating position shown in Figure 6. In these subjects the abductor pollicisbrevis is innervated by the ulnar nerve instead of the median nerve (an example of anatomical variation). If so, try stimulating the ulnar nerve.
12. From the Isolated Stimulator dialog, increase the amplitude up to 20 mA in 2 mA increments, and record the response to a stimulus at each amplitude.

13. The responses should increase with increasing stimuli until a maximal response is reached, after which increasing the stimulus does not further increase the response amplitude.
14. Turn the stimulator switch on the PowerLab unit off (in the down position).
15. Choose Save from the File menu to save the recording.
16. Remove the bar stimulus electrode and mark the spot in between the pressure imprints on the skin.

### **Exercise 4: Nerve conduction velocity**

#### **Objectives**

In this exercise, nerve conduction velocity will be measured from the difference in latencies between responses evoked by nerve stimulation at the wrist and the elbow. This exercise should be done immediately after Ex. 3.

#### **Procedure**

1. From the File menu, choose **New**. Make sure the previous data file has been saved. Open a new blank file with the same settings used in the previous file. A new file should appear with a single displayed channel (Channel 3, "EMG").
2. Position the bar stimulus electrode on the medial aspect of the front of the elbow (Figure 5). The electrode requires firmer pressure at the elbow than at the wrist because the nerve is deeper in the tissues. The orientation of the electrode should be the same as for wrist stimulation, with the cathode (the end with the leads) closest to the hand.
3. To set up stimulation, choose the **Stimulus Isolator** command (Windows) or the **Stimulator** command (Mac OS) from the Setup menu. The Isolated Stimulator dialog appears. Set the current amplitude to 8 mA and close the Isolated Stimulator dialog.
4. Set the stimulator switch on the front of the PowerLab to the "**ON**" position (up). In Chart, click Start to initiate a stimulus and record it. Do this several times, using these low-amplitude pulses to help to find the best position for the electrode. If no response, increase the stimulus current amplitude.
5. Once the best position for the bar stimulus electrode has been found, open the Isolated Stimulator dialog and increase the amplitude to 15–20 mA. Close the Isolated Stimulator dialog.
6. Click Start to record a waveform. Repeat this step three times.
7. Set the stimulator switch on the front of the PowerLab to the "**OFF**" position.
8. Remove the bar stimulus electrode and mark the spot in between the pressure imprints on the skin. Remove other electrodes from the volunteer.
9. Choose Save from the File menu to save the recording.



### Analysis

#### Exercise 1: Voluntary change in contractile force

1. Scroll through the recorded data and note the changes in activity in the raw biceps channel (Biceps). Note also that placing weights on the hand gives rise to little or no activity in the triceps muscle. Select a small part of the "Biceps" activity and examine it in the Zoom View. The raw EMG signal is composed of many up and down spikes.
2. Note the relationship between the raw trace (Biceps) and integrated trace (Int. Biceps). The height of the integrated trace reflects the overall activity of the raw EMG signal, and gives a simpler view of the muscle's electrical activity.
3. Measure the amplitude of the integrated trace as weights were added and removed by using the Marker and Waveform cursor. The height of the trace correlates with the force produced by the muscle. Record these results in Table 1 of the Data Notebook.

#### Exercise 2: Alternating activity and coactivation

1. Scroll through the recorded data and observe the EMG traces for both the biceps and triceps. Note the large-scale alternation of activity in the biceps and triceps.
2. Note that when the biceps muscle is activated forcefully, there is a minor increase of activity in the triceps. Correspondingly, there is a minor increase of activity in the biceps trace when the triceps is activated. This phenomenon is called "coactivation". Its physiological meaning is not well understood, although it perhaps serves to stabilize the elbow joint.
3. Use the **Marker** and **Waveform Cursor** to measure and record the EMG peaks during coactivation for biceps and triceps in Table 2 of the Data Notebook.

#### Exercise 3: Evoked EMG

1. Use the scroll bar at the bottom of the Chart View window to review data blocks recorded with stimulation at the wrist.
2. Drag over a suitable waveform to **select** it, then choose **Zoom View** from the Windows menu or click the Zoom View button in the Tool bar. The waveforms should look something like those in Figure 7.
3. In the **Zoom View**, measure the latency of a single waveform in the data display area (the size of the waveform is of no consequence). The latency is the time elapsed from the start of the stimulus pulse — the start of each block of data — to the start of the evoked response. Place the Waveform Cursor at the point where the response begins. The latency value can then be read directly from the time display at the top of the Zoom View. Record the latency value in Table 3 of the Data Notebook.

## Biological Signals Lab

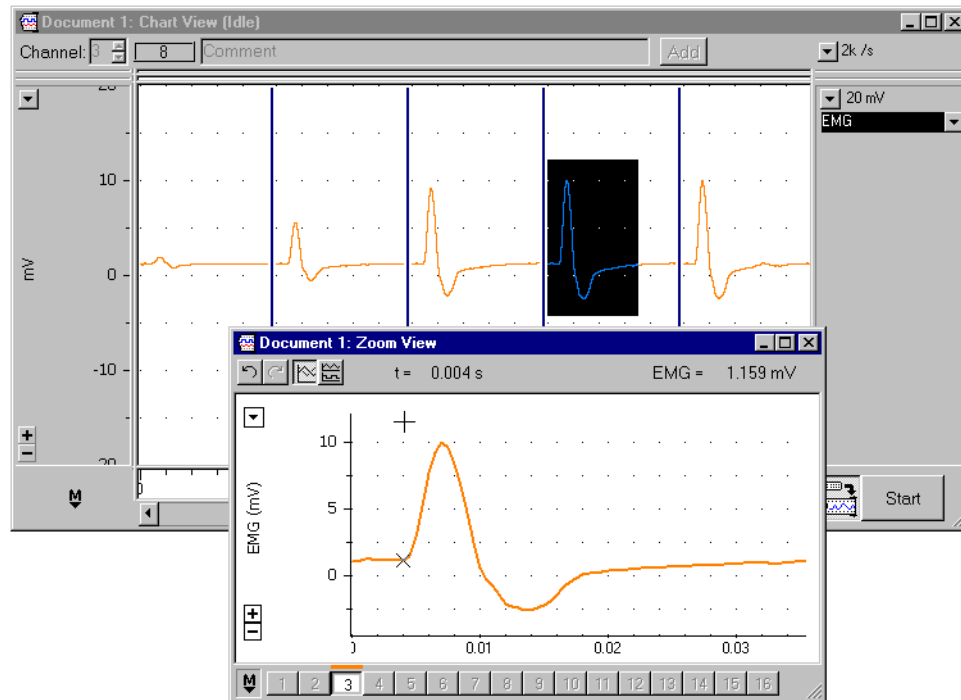


Figure 7. A series of data blocks with EMG responses (M-waves) evoked by median nerve stimulation at the wrist; the Zoom View shows how the latency is measured.

### Exercise 4: Nerve Conduction Velocity

An estimate of the nerve conduction velocity is obtained from the extra time required for the nerve impulse to reach the muscle, when stimulation is at the elbow, as compared to the wrist.

1. Measure and record the distance between the marks at the elbow and at the wrist. This is the distance between stimulation sites.
2. Drag in the Chart View to **select** a waveform and then choose **Zoom View** from the Window menu. In the Zoom View, use the same steps as outlined for wrist stimulation to measure the latency of a single waveform. Record the latency value in Table 3 of the Data Notebook.
3. Using the conduction velocity equation given below, calculate the nerve conduction velocity of the subject:

$$\text{Velocity} = \frac{\text{Distance between stimulation sites (mm)}}{\text{Difference between latencies (ms)}}$$

The units of velocity are mm/ms or, equivalently, m/s. Record the calculation in Table 4 of the Data Notebook.

## Data Notebook

**Table 1. Effects of weight resistance on EMG amplitude.**

Weight (or # of books)	Biceps EMG amplitude (mV)	Triceps EMG amplitude (mV)

**Table 2. Coactivation between biceps and triceps.**

Active muscle	EMG amplitude in "active" muscle (mV)	EMG amplitude in opposite muscle (mV)
Biceps		
Triceps		

**Table 3. Stimulus latencies at different stimulation sites.**

Stimulus Location	Latency (ms)
Wrist	
Elbow	

**Table 4. Determination of nerve conduction velocity.**

Latency difference (ms)	Distance between stimulus points (mm)	Nerve conduction velocity (m/sec)

## Results

### Exercise 1: Voluntary change in contractile force

Place a copy of the Zoom window showing the raw EMG and integrated trace from your biceps muscle. Explain your observation.

### Exercise 2: Alternating activity and coactivation

Place a copy of the Zoom window showing the integrated traces from the biceps and triceps during coactivation. Explain your observation.

### Exercise 3: Evoked EMG activity

Place a copy of the Zoom window showing a representative trace of an evoked EMG from the abductor pollicis brevis muscle. Indicate on the trace the stimulus artifact, latent period, and start of response. Explain your observation.

### Exercise 4: Nerve conduction velocity

Fill in the table below. Note: for the last column, you will have to convert your units to meters per second.

Distance between stimulation sites (mm)	Time difference between latencies (milliseconds)	Nerve conduction velocity (mm/milliseconds)	Nerve conduction velocity (m/sec)

## Conclusions

Answer the following questions using complete sentences.

- 1) Unlike the discrete waveform from an electrocardiogram, the electromyogram waveform is irregular. Why do you suppose this is?
- 2) How did the EMG trace change when you added weights to your arm? What do your results indicate?
- 3) Describe co-activation. Why do you think this phenomenon occurs?
- 4) Describe the meaning of the latent period in your trace from evoked EMG activity. Did latency change with increasing stimulus amplitude?
- 5) Based on your results and calculations for nerve conduction velocity, how long would it take for a nerve impulse to travel from the spinal cord to the big toe? Assume that the distance traveled is one meter.

### **Study Questions**

1. Write a paragraph defining the electromyogram, and how it relates to a muscle contraction.
2. Briefly discuss what you expect to learn from this experiment.
3. Briefly describe the techniques you will use to measure your EMG, and explain the difference between a raw EMG signal and an integrated trace.
4. List the physiological events that occur between delivery of the stimulus and the start of the recorded response.