A laboratory exercise is described in which students in a neuroscience, psychobiology, or similar laboratory course record the electromyogram (EMG) from themselves, using surface electrodes (placed on the skin). This exercise is intended to give students a firsthand demonstration that electrical activity is produced within them and to allow the students to use this activity to study biological and psychological concepts. The students study the nature of the EMG (changes with tension and the temporal relationship with limb movement) and the concepts of flexion and extension, reaction time, and the patellar ("knee jerk") reflex. In postlaboratory evaluations, undergraduate introductory neuroscience students indicated that they appreciated the opportunity to record electrical activity from their own bodies. The students found the exercise enjoyable, believed that they had learned from it, and indicated that it should be a regular part of the course. If electrophysiology in animal preparations is already part of the course, this exercise requires minimal additional equipment, some of which is easily constructed and the remainder of which is available inexpensively.


Key words: electromyogram; muscle; reflex; reaction time

The laboratory component of undergraduate neuroscience, psychobiology, and similar courses often includes at least one exercise in electrophysiology that allows students to record electrical activity from living tissue. This type of exercise gives students exposure to electrophysiological techniques and the use of these techniques in answering experimental questions. For example, the students in the Introduction to Neuroscience course at Williams College record action potentials from a cockroach leg to study sensory coding by the nervous system.

One problem with these preparations is that the students do not always fully appreciate that such activity occurs within themselves as well. Thus a valuable addition to such laboratory courses is an exercise that allows students to detect, and use in experiments, electrical signals produced by their own bodies. A limitation is that any such exercise must use noninvasive methods, and thus any electrical activity must be detectable from the skin surface.

Neural activity in the form of the electroencephalogram (EEG) and evoked potentials can be recorded from the human scalp; however, sophisticated equipment is required, as is special treatment of the data (such as the averaging of responses over many trials). Muscles produce another type of electrical activity detectable from the human skin surface, the electromyogram (EMG). The EMG is easily recorded, and if electrophysiology is already part of the course, the basic equipment is available. Only inexpensive elec-
trodes and some readily available and easily constructed additional items are needed.

Among the concepts investigated by the students in this exercise are 1) the nature of the EMG—how it changes with muscle tension, and the temporal relationship between muscle action potentials (which comprise the EMG) and limb movement; 2) flexion and extension; 3) reaction time; and 4) the patellar, or “knee-jerk,” reflex. In addition to providing the students with an opportunity to record electrical activity from their own bodies, these experiments involve students in active learning of ideas that they have been exposed to in lecture courses. For example, the idea that a reflex is considerably faster than a similar voluntary response to a stimulus is a fundamental concept; in this laboratory exercise, this is studied empirically. Furthermore, to encourage critical thinking, the students can be asked to predict and explain results. Thus, for example, they can predict, on the basis of their knowledge of the EMG source, whether a change in this signal will precede a movement or follow it, and then test their prediction.

**EQUIPMENT**

Several companies manufacture surface EMG electrodes (typically silver-silver chloride) with attached leads. These require electrode gel, for skin-electrode continuity, and adhesive disks, for securing the electrodes. General-purpose EMG electrodes work well for this experiment; the miniature electrodes (which are more selective and can be more closely spaced) should be avoided. It is more difficult to maintain good skin contact with these smaller electrodes, and this can lead to increased noise problems; furthermore, the increased recording selectivity provided by the miniature electrodes is not necessary for this exercise. From the electrodes, the signal goes to a preamplifier (Grass P511 was used) set to record activity within a range of $\sim$30–1,000 Hz. The gain should initially be 5,000, with changes made as necessary. The signal is then sent to a storage oscilloscope. A digital scope is useful, but not necessary.

Three other instruments are required: 1) an inexpensive “handgrip” exerciser; 2) a simple “telegraph”-style switch that produces a voltage change when a finger is lifted; and 3) a percussion hammer that triggers an oscilloscope when struck. The switch is easily constructed, as illustrated in Fig. 1A. The percussion hammer, although commercially available, can be constructed less expensively. A simple percussion hammer is available (Carolina Biological Supply, Burlington, NC) and is prepared as shown in Fig. 1B.

A Faraday cage to shield out electrical noise should not be necessary. If there is considerable noise, the ground connection should first be checked. An electrode attached to the wrist and connected to the proper amplifier input serves as the ground. An electrode such as those used for the EMG recordings may be sufficient for this purpose (as it was with the disposable electrodes used here); however, a ground electrode with a very large surface area may further reduce the noise level. Another potential cause of excessive 60-Hz noise is poor electrode-skin contact. This can occur if insufficient electrode gel has been used (or, when using the disposable electrodes, if the gel has dried) or if the electrode has pulled away from the adhesive. If the noise remains after all of the electrodes have been checked, the 60-Hz filter on the amplifier can be activated (if the amplifier is so equipped). The use of such filters is not recommended in EMG experiments because they filter out part of the EMG signal (6); however, no fine analysis of the signal is done in this exercise, and so this loss is fairly inconsequential to the experimental results.

**Electrode Placements**

Three recording sites are used, each requiring three electrode placements: two placements for differential EMG recording, and one for ground. The two forearm sites are based on descriptions by Davis as reported in Lippold (13); the quadriceps site is from Hale et al. (8).

These surface recordings detect activity from more than one muscle. Rather than identifying all the possible muscles that may contribute to the recordings, the nomenclature of “forearm flexors” and “forearm extensors” is used for the electrode placements on the arms. Likewise, the leg muscles relevant to this exercise are identified as the quadriceps.
Forearm flexors. The electrodes for this site are attached to the ventral (bottom) surface of the forearm. With the forearm held with the palm of the hand up, the two EMG electrodes are placed on an imaginary line running diagonally across the entire length of the forearm, from the outer edge of the wrist (just below the thumb side of the hand) to the inner, most posterior part of the forearm. One electrode is positioned at a point on this line one-third of the way from the posterior part of the forearm, and the second electrode is placed on this line ~5 cm (distances are based on the electrode centers) from the first, toward the wrist. The ground electrode is placed on the wrist.

Forearm extensors. The electrodes for this site are attached to the dorsal (top) surface of the forearm. With the arm held with the palm of the hand down, the two EMG electrodes are placed on an imaginary line running straight back along the surface of the forearm, from the outer edge of the wrist (just below the little finger side of the hand) to the outer, most posterior part of the dorsal surface of the forearm (near the elbow). One electrode is placed at a point on this line one-third of the way from the posterior part of the forearm, and the second electrode is placed on the line ~5 cm from the first, toward the wrist. The ground electrode can be left in place from the forearm flexor placement.

Quadriceps. On the dorsal (top) surface of the leg, the point approximately one-half the distance between the hip and the knee, along the midline, is located, and one electrode is placed anterior (toward the knee) and one posterior (toward the body) to this point, ~3 cm apart. The ground electrode is placed on the wrist.

EXPERIMENTS

Basic concepts such as motor units, flexion, extension, and simple reflexes should be discussed before the laboratory exercise is done. The following points regarding the EMG should also be stressed. 1) The muscle action potentials, which comprise the EMG, occur before the actual contraction of the muscle; it is the processes initiated by these potentials that lead to the contraction. 2) The surface EMG represents the...
Temporal partitioning of a skeletal response to a stimulus. The first component is the time from stimulus to a change in the electromyogram (EMG) from the muscles mediating the response. In the case of a spinal reflex, this first component is the spinal reflex latency, and for a voluntary reaction, it is the supraspinal response initiation time (“supraspinal” reflects the involvement of the brain). The second component is the electromechanical delay and represents the time required for the processes occurring between the muscle action potentials and the movement.

The first component represents the time from the stimulus to a change in the EMG from the muscles required for the response. For reflex time, this component is the spinal reflex latency. The EMG change in this case occurs at the end of a reflex arc that has a single synapse in the spinal cord. For reaction time, this first component is the supraspinal response initiation time. The involvement of the brain (hence, “supraspinal”) is required for the response as well as for detection of the stimulus.

The second component is the time from the EMG change to an overt response; this is the electromechanical delay (for both reflex and reaction times). It includes the time required for the processes leading up to muscle contraction and the time required for sufficient contraction to result in a detectable movement.

Temporal partitions similar to these have been used in studies on reflex (8, 9, 10, 12, 14) and reaction (1, 4, 5, 8, 11, 15) times.

If there are two people per station, one can be the subject for the forearm sites experiments and the other for the quadriceps site experiments.
the back of the wrist (extension) to determine for which movement more EMG activity is observed.

**Predicted results.** There should be more activity during flexion compared with extension. Muscles (and muscle groups) can only move a limb in one direction. Because these electrodes are on the ventral surface of the forearm, activity (leading to contraction) in the muscles under these electrodes would be expected when the hand moves toward the front of the wrist (flexion). This is evident in the sample data shown in Fig. 3A.

**Force and EMG**

**Concepts addressed.** This exercise demonstrates what happens to the EMG as the force exerted by muscles is increased.

**Procedure.** The handgrip exerciser is slowly squeezed, with the oscilloscope at a slow speed (500 ms/div), and any change in the EMG is noted.

**Predicted results.** The prediction is that there will be an increase in the peak-to-peak amplitude (from the peak of a negative wave to the peak of the next positive wave) of the surface EMG as the exerciser is squeezed. There is an increase in the frequency of muscle action potentials within motor units and an increased number of active motor units as muscle tension is increased, and this electrical activity sums. The increase in the EMG amplitude is illustrated in Fig. 3B.

**FOREARM EXTENSORS**

**Extension**

**Concepts addressed.** As in the flexion exercise, this exercise demonstrates that different muscle groups perform flexion and extension.

**Procedure.** The arm is held with the elbow by the side of the body and the forearm extended with the fingers curled into a loose fist. The hand is slowly moved toward the front of the wrist (flexion) and then the back of the wrist (extension) to determine for which movement more EMG activity is observed.

**Predicted results.** There should be more activity during extension compared with flexion. Because these electrodes are on the dorsal surface of the forearm, activity (leading to contraction) in the muscles under these electrodes would be expected when the hand moves toward the back of the wrist (extension).

Note: The focus during the wrist extension (and the earlier flexion) should be on what happens as the hand moves from the midline position because, for example, during extreme flexion there may be EMG activity in the extensors due to these muscles in the
antagonist position becoming active to stabilize the wrist (2). If desired, the students can demonstrate this for themselves.

Temporal Relationship Between EMG and Movement

Concepts addressed. This experiment addresses the issue of the timing of the EMG change relative to movement of a finger.

Procedure. The hand is placed palm down with the forefinger on the switch. The output of the switch goes to one channel on the oscilloscope and the EMG to the other channel. With the sweep speed at 20 or 50 ms/div, one person starts a sweep of the oscilloscope and the subject quickly lifts the forefinger. This step may need to be repeated to get both the EMG and finger lift on the oscilloscope. (If the oscilloscope allows you to see the “pretrigger” period, then the channel with the output of the switch can be used to trigger the scope.) The students determine whether the EMG change occurs first, the finger movement occurs first, or both occur simultaneously.

Predicted results. The prediction is that the EMG change precedes the finger lift. It is the muscle action potentials, which comprise the EMG, that lead to the process of contraction. Figure 4 shows sample data for this experiment, with the change in the EMG clearly proceeding the lifting of the finger. This illustrates the electromechanical delay described in Fig. 2.

Note: When doing this and the next experiment (reaction time), the EMG change preceding the finger lift is easiest to discern if the hand and forearm are relaxed, with minimal baseline EMG activity, before the finger is lifted.

Reaction Time

Concepts addressed. This experiment is an investigation of reaction time, which is the time required to make a voluntary response after a stimulus. Specifically, reaction time is determined here as the amount of time required for a subject to lift a finger after the hammer strikes the table. Weiss (15) divided reaction time into two components corresponding to the supraspinal response initiation time and the electromechanical delay, illustrated in Fig. 2 (Weiss used the terms “premotor time” and “motor time,” respectively.) He was trying to determine whether variables, including motivation, that influence reaction time have their major effects on the events occurring between the stimulus and the change in the EMG, or in the events occurring between this change and the overt response. Others have since done similar analyses to examine the effects of such variables as fatigue (11), temperature (1), and ethanol (4) on the two components. Here, the students observe the reaction time variability that occurs over trials and then determine which of the two components, the supraspinal response initiation time or the electromechanical delay, accounts for most of this variability.

Procedure. The EMG and switch outputs are left on separate oscilloscope channels, and the hammer is connected to the oscilloscope trigger. The subject sits with eyes closed and forefinger on the switch. Another student strikes the hammer on the table or other surface (using the “pointed” part of the hammerhead, and not the switch), and the subject lifts the finger rapidly on hearing the strike. (If more than one oscilloscope sweep occurs per hammer strike due to “bounce” in the switch, the oscilloscope can be set to “single sweep”). On the oscilloscope, three times are determined: reaction time (hammer strike—when the oscilloscope is triggered—to finger lift), the supraspinal response initiation time (hammer strike to start of change in EMG activity), and the electromechanical delay (start of change in EMG activity to finger lift). Students do 10 trials and plot the means ± SE of reaction time and its components. They then plot a scatter graph of reaction time for the 10 trials versus...
each of the two components and calculate correlation coefficients to determine which component is better correlated with reaction time; Botwinick and Thompson (5) did a similar analysis to address the issue of which reaction time component accounts for most of the reaction time variability. The present experiment takes advantage of the reaction time variability that tends to occur across trials; no variables are manipulated. The basic question that is addressed is whether this variability is mainly due to processes occurring between the occurrence of the stimulus and the muscle action potentials or between the muscle action potentials and the lifting of the finger. This will be reflected as a greater correlation between that particular component and the total reaction time. Alternatively, both processes could be making equal contributions to the variability in the reaction time, in which case the two correlations will be about the same.

**Predicted results.** The prediction is that the supraspinal response initiation time will be more highly correlated with the reaction time. This first component includes the time required to detect and respond to the stimulus. This component will be influenced by any psychological variables—attention, for example—that may vary from trial to trial. The second component—the electromechanical delay—is largely a biochemical and physical process, and less trial-to-trial variability would be expected. The sample data (Fig. 5) show that the supraspinal response initiation time is more highly correlated with the reaction time.

**QUADRICEPS**

**Reflex Versus Reaction Times**

**Concepts addressed.** This experiment serves to investigate whether the time required for a response to a stimulus—jerk of the leg (or, in this case, the EMG change preceding this) in response to a tap—varies depending on whether it is a reflex or a reaction.

**Procedure.** Students should bring short pants to wear for this experiment. The subject sits with the leg with the electrodes crossed over the other leg, and the experimenter strikes the hammer on the patellar tendon just below the kneecap, triggering the oscilloscope and eliciting a knee jerk. Ten trials are given this way and ten more trials are given in which the hammer is struck at a point near the tendon, which does not elicit a reflex; the subject jerks the leg when detecting the tap. For each trial, the time between the stimulus and the EMG change is measured. For the first 10 trials, this represents the spinal reflex latency; for the second 10 trials, it is the supraspinal response initiation time (Fig. 2). The means ± SE are plotted. The purpose of this exercise is to determine whether one of these time periods is greater than the other, and if so, which one is greater.

**Predicted results.** The reaction, unlike the reflex, requires brain involvement and thus should take considerably longer. The sample data in Fig. 6, A (raw data) and B (plotted data), show this. This experiment is essentially an empirical test of a similar idea discussed in a textbook by Carlson (7).

**EVALUATION OF EXERCISE**

This exercise was performed in the 1996 fall semester in the Introduction to Neuroscience course at Williams College. All students had previously performed laboratory exercises on the dissection of the sheep brain, Golgi staining of the rat cerebellum, and sensory coding in the cockroach. Twenty of the ninety-three students in the course chose the EMG exercise for the last laboratory session (they had 2 other options: an exercise on hippocampal long-term poten-
tiation or an exercise on hemispheric and gender differences in frontal cortex EEG). The 20 students were distributed over 3 laboratory sections. There were usually two (and never more than 3) students per setup. The exercise took approximately two hours, including a brief lecture to explain the EMG. The students were required to write a laboratory report, the grade of which comprised 10% of their total grade for the course.

Of the 20 students who performed the EMG exercise, 17 opted to evaluate it. These evaluations (on a scale of 1 to 7) were done immediately at the end of the session, before the students wrote up their results. The lab was evaluated along three dimensions.

1) Enjoyment, with $1 = $ not at all enjoyable and $7 = $ very enjoyable ($4 = $ indifferent): mean $= 6.2$, range $= 5–7$. Although this should not be the main criterion by which a lab exercise is judged, students obviously will be more involved in experiments that they enjoy doing.

2) Learning from the exercise, with $1 = $ I learned nothing from doing this laboratory exercise and $7 = $ I learned a lot from doing this laboratory exercise ($4 = $ I learned a moderate amount from doing this laboratory exercise): mean $= 5.2$, range $= 4–6$. This is a self-report measure of learning and thus is not as valid as test scores, etc. However, it does indicate that the students seemed to believe that the exercise was worthwhile.

3) Whether the exercise should be continued as part of the course, with $1 = $ I think that this laboratory exercise should definitely be dropped from the course and $7 = $ I think that this laboratory exercise should definitely be a part of this course ($4 = $ I really have no opinion either way): mean $= 5.8$, range $= 5–7$. This was the first time that this exercise was done, and this item was included as a way to gauge the students' overall opinion of it and to give some indication of whether it should remain as part of the laboratory course.

There was also space on the evaluation form for comments regarding the exercise. Of the 16 students answering the question, “What did you like most about today’s lab?”, eight included as at least part of the answer that they enjoyed the use of human subjects. These responses included “it was interesting to use our own bodies,” “being hooked up to a computer,” and “[as] student subjects we saw how these motor systems functioned in ourselves (as opposed to cockroaches, rats, etc.).”

**DISCUSSION**

One goal of this exercise was for the students to gain an appreciation for the idea that the electrical processes they have heard and read about in courses, and perhaps observed in animal preparations, are occurring in their own bodies. The student comments cited previously demonstrated that they did enjoy the opportunity to observe this activity. Another goal was for the students to engage in active learning. One student did indicate in the laboratory evaluation that he or she “…enjoyed seeing a somewhat ‘practical’

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**FIG. 6.** Knee jerk as a reflex and as a reaction. A: oscilloscope traces from quadriceps. Top trace: EMG response of a subject to a tap on the patellar tendon (reflex). Bottom trace: EMG response when subject voluntarily moved the leg after feeling a tap near the tendon (reaction). B: means ± SE of supraspinal response initiation time and spinal reflex latency. Ten trials were given for both conditions.
application of the material learned in class," and another found it "...interesting to see the correlation between the APs and movement." A third goal was to encourage critical thinking. As a method for accomplishing this, the students were required to write a laboratory report on this exercise to describe and offer explanations for their findings, which did require them to think about the data. However, what could have aided this would have been to provide a worksheet the week previous to the exercise (along with the laboratory description) in which the students would be required to predict the results and offer explanations of the predictions. (They could be allowed to modify these after the laboratory lecture, and before doing the experiments, in the event that the lecture clarified any poorly understood concepts). The predictions could then be incorporated into the lab reports.

The experiments are described here in a procedurally logical order. However, for a postlaboratory assignment (whether a list of questions to answer or a laboratory report), it would be best if the results were organized in a conceptual manner. Thus the experiments on muscle tension and the temporal relationship of the EMG to movement could be grouped together because both investigate aspects of the nature of the EMG. The flexion and extension experiments could similarly be grouped in a postlaboratory assignment.

Although this does work extremely well as a laboratory exercise, the instructor and one or two students could do all or part of it as a demonstration, perhaps to supplement another laboratory exercise.

This exercise is relatively inexpensive, requiring minimal additional equipment over that found in a typical neuroscience laboratory. The use of the percussion hammer, designed for studying reflexes, to also produce the stimulus and trigger the oscilloscope for the reaction time experiment eliminates the need for an additional apparatus for this purpose. Furthermore, there are no expenses for animal care because the subjects take care of their own housing and feeding.

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References