SECTION 5 - SKELETAL MUSCLES

EXERCISE 5.1 NEURAL CONTROL OF MUSCLE CONTRACTION

Approximate Time for Completion: 30 minutes-1 hour

Introduction

This exercise is designed to introduce students to the dynamics of skeletal muscle contraction and the use of physiological recording instruments. In this exercise, students will pith a frog, stimulate the sciatic nerve, and prepare and operate recording equipment for studying the contraction of the gastrocnemius muscle. With the stimulating electrodes first in the muscle, then under the sciatic nerve, the difference between the threshold voltages required at these two locations (muscle and nerve) can be evaluated.

The prudent use of animals in laboratory exercises is a powerful and effective method for teaching students basic physiological principles in action. Often the instructor does the pithing, handing over the preparation for students to continue the required surgery and to record the contractions. Caution the students to follow the procedures in sequence. If the frog muscle is excessively stimulated early in the lab the energy stores in the muscle may be depleted prematurely. Notice that this exercise is usually done in concert with the next exercise (5.2) since summation, tetanus, and fatigue of skeletal muscle follows the topic nicely and the preparation is already available.

Materials

1. Frogs
2. Surgical scissors, forceps, sharp probes and pins, dissecting trays, glass probes
3. Recording equipment (either a kymograph or an electrical recorder, such as a physiograph), electrical stimulators
4. Alternatively, computerized data acquisition and analysis systems, such as those provided by Biopac and iWorx, may be used.
5. Straight pins bent into Z-shapes, or thin-wired fish hooks (barbless or debarbed) may be used instead; thread
6. Bone clamp (if kymograph is used) or myograph transducer (if Physiograph is used)
7. Frog Ringer's solution: Dissolve 7 g NaCl, 0.15 g KCl, 0.15 g $CaCl_2$, and 0.10 g $NaHCO_3$ in 1 liter of water
8. Alternatively, skeletal muscle exercises may be simulated using the *Physiology Interactive Lab Simulations*: Skeletal Muscle Function (Exercises 1, 2, and 3).

Textbook Correlations: Chapter 12 – Skeletal Muscles; Regulation of Contraction; Neural Control of Skeletal Muscles

Answers to Questions

1. (a) fiber; (b) sarcomere; (c) fibril; (d) filaments
2. action potentials
3. thin; thick
4. calcium ion
5. sarcoplasmic reticulum
6. troponin; tropomyosin
7. Acetylcholine (ACh)
8. See figures 5.1(a) and (b) for sketches. During a twitch each sarcomere is shortened by cross bridges pulling actin over myosin filaments and exerting force on all Z lines simultaneously. With all sarcomeres shortening at the same time, the overall muscle fiber also shortens producing the twitch.

9. Binding to receptors in the motor end plate, the released acetylcholine stimulates the production of end plate potentials that in turn, form action potentials on the muscle fiber sarcolemma. Action potentials travel along the sarcolemma, entering the transverse tubules and promoting the release of Ca^{2+} from the sarcoplasmic reticulum. The Ca^{2+} attaches to troponin, the tropomyosin is shifted out of its inhibitory position, and the cross bridges form between myosin and actin resulting in the muscle contraction.
10. Stimulation of the sciatic nerve had the lower threshold. The sciatic nerve is composed of many axons that innervate all muscle fibers of the gastrocnemius. Since each axon of the sciatic nerve branches to innervate hundreds or thousands of fibers (motor unit concept), less voltage is required to excite the minimum number of fibers required to initiate a recorded contraction. Stimulation of the muscle directly requires a higher voltage to produce the same response.
11. If the blood concentration of Ca^{2+} were increased abnormally the strength of contraction in heart muscle beats should increase accordingly. Since calcium ion couples electrical excitation to muscle contraction it follows that an increase in calcium ion concentration would result in an increase in cardiac contractility.
12. A drug that blocks the action of acetylcholinesterase is inhibiting the degradation of ACh at the motor end plate. The result should be a continued presence of ACh in the motor end plate leading to continual depolarization and sustained firing of action potentials. The result would be a sustained contraction or a spastic paralysis. A drug that blocks ACh receptors on the motor end plate, by contrast, would prevent depolarization and excitation of the motor end plate, leading to a flaccid form of paralysis.

EXERCISE 5.2 SUMMATION, TETANUS, AND FATIGUE

Approximate Time for Completion: 1 hour

Introduction

This exercise is designed to introduce students to important principles of skeletal muscle contraction such as summation, tetanus, and fatigue. In this exercise, a frog gastrocnemius muscle is stimulated with suprathreshold shocks of increasing frequency to demonstrate temporal summation. At high frequency (about 10 shocks per second) tetanus can be demonstrated that will eventually result in fatigue. A similar procedure can be repeated on the forearm muscles of a human subject. Appropriate caution should be used with the human subject and the instructor should supervise this procedure at all times. Discuss the concept of fatigue in frog muscle and in human muscle during these procedures. This exercise can be combined with exercise 5.1, since both experiments use the same frog preparation.

Materials

1. Frogs
2. Equipment and setup used in exercise 5.1
3. Electrocardiograph plates and electrolyte gel
4. Alternative equipment: *Physiogrip,* (Intellitool, Inc.); or Biopac system with hand dynamometer
5. Alternatively, simulated skeletal muscle exercises may be performed using the *Physiology Interactive Lab Simulations*: Skeletal Muscle Function (Exercises 1, 2, and 3).

Textbook Correlations: Chapter 12 – Motor Units; Contractions of Skeletal Muscles; Muscle Fatigue

Answers to Questions

1. (a) A twitch is one complete excitation-contraction-relaxation cycle of a muscle.; (b) Summation is produced by the asynchronous twitching of different muscle fibers; (c) If the summation of fiber twitches occurs sufficiently rapidly (at a high frequency), there will be no visible relaxation phase between successive twitches. The total muscle response as recorded will be smooth and is known as tetanus.
2. tetany; hypocalcemia and alkalosis

3. The rapid, asynchronous firing of different muscle fibers results in the summation of twitches. In this way, some are in the process of contraction while others are in the process of relaxation. By adding a second contraction onto a previous twitch, summation is achieved. The more motor units involved and the larger number of muscles per unit activated the greater the strength of the muscle contraction produced.
4. Sustained contractions *in vivo* are produced by rapid asynchronous activation of different motor neurons and their motor units. Stimulation of different motor neurons in the spinal cord at slightly different times results in a maximal response of the muscle. However, in the body some motor units will rest while others contract to sustain the contraction. In the isolated muscle (*in vitro*), tetanus was achieved by increasing the frequency of stimulation to the muscle. At lower frequencies summation occurred but at higher frequencies the muscle was contracting maximally and unable to relax, resulting in a straight-line recording, or tetanus.
5. With continued exertion of the biceps muscle, the muscle will begin to fatigue and the muscle will start to weaken. Muscle fatigue appears to be due to an accumulation of extracellular potassium ions. This depolarizes the muscle fiber membranes and interferes with the ability of the fiber to produce action potentials. If the contraction continues, lactic acid may accumulate from anaerobic respiration of glucose, decreasing the muscle pH and perhaps interfering with the normal storage and release of calcium ions from the sarcoplasmic reticulum. The firing of pain receptors (nociceptors) may be related to either the increased potassium and/or to the decrease in pH.
6. With continued exertion the biceps muscle will fatigue, lose strength, and begin to shake. Holding the weight steady involves the alternate stimulation of multiple motor units in the biceps muscle. While some units are firing, other motor units are relaxing and thus able to maintain the bent elbow for a longer time. With time, however, individual fibers within motor units begin to release potassium and anaerobic metabolic products such as lactic acid and carbon dioxide. These changes progressively worsen as the exercise continues causing the fibers within larger motor units (mainly fast-twitch but easily fatigued fibers) to weaken while other motor units strain to maintain the lift. The biceps will shake as locally fatigued fast-twitch fibers and units fail to contract when stimulated. This loss of strength resembles the fatigue that is seen during the summation, tetanus, and fatigue exercise during continued high frequency stimulation of the gastrocnemius muscle.

EXERCISE 5.3 ELECTROMYOGRAM (EMG)

Approximate Time for Completion: 30 minutes

Introduction

The electromyogram (EMG) measures the electrical activity of a superficial muscle during contraction. This exercise vividly demonstrates that electrical stimulation is required *in vivo* during muscle contraction. It is very important to thoroughly cleanse the skin with an alcohol swab before applying the EMG electrodes. This exercise could be combined with exercises 5.1 and 5.2 to demonstrate the difference between electrical stimulation of a muscle and the electrical recording of a muscle.

Materials

1. Physiograph or other electrical recorder and high-gain coupler
2. EMG plates, disposable adhesive paper waters for EMG plates
3. Electrolyte (ECG) gel or paste, alcohol swabs
4. Alternative: Biopac system equipment for EMG I and EMG II (Lessons 1 and 2)

Textbook Correlations: Chapter 12 – Motor Units; Contractions of Skeletal Muscles; Alpha and Gamma Motoneurons

Answers to Questions

1. agonist; antagonist
2. Muscle contraction that result in the shortening of the muscle length is called isotonic because the force of contractions remains relatively constant as a body part or bone is moved. Examples of isotonic contractions include walking, talking, or lifting a chair.
3. In isometric muscle contractions the length of the muscle remains constant and no movement is seen. Postural muscle contractions are examples of isometric contractions.
4. A motor unit is the single motor neuron axon and all muscle fibers that it innervates.
5. recruitment
6. electromyogram
7. Refer to figure 5.12 for a motor unit. The smaller motor unit would produce the weakest contraction. The combined smaller and larger motor units would together produce the strongest contraction. The larger motor unit alone would result in a contraction with intermediate strength.
8. See answers to questions 2 and 3.
9. The biceps and triceps brachii are antagonistic muscles. During arm flexion the activity of the triceps is inhibited and during arm extension the activity of the biceps muscle is inhibited. In this way, flexion stretches the extensor muscles, whereas extension stretches the flexor muscles. "Making a muscle" results in no movement of the arm since both biceps and triceps muscles are stimulated simultaneously. This is an example of an isometric contraction.
10. Motor units are recruited from smaller to larger when increasing effort is required. Therefore, the smaller motor units (with slow-twitch fibers) would be used early in the lift with the larger motor units (with fast-twitch fibers) called in as more force is required to continue the lift. The EMG recording is sensitive to the total electrical activity that occurs under the recording electrodes, the amplitude of the EMG is larger when a heavier weight is being lifted. Since the EMG provides a real-time visual display of muscle stimulation, it can be used as a form of biofeedback to reinforce the effort spent attempting to contract specific muscle groups during the lift.
11. Using the EMG to monitor the muscle exertion, a stroke victim could be trained to use the proper writing muscles of the non-dominant arm and hand. By moving the electrodes from muscle to muscle, the resulting EMG would reward the victim as a form of operant conditioning (positive feedback) when the proper muscles are stimulated with the correct amount of strength and the handwriting improves.