Muscle Structure and Exercise Physiology

Objectives: When you complete this lab you should be able to:

Understand the basic anatomy of a muscle.

Be able to recognize several tissue types associated with the musculoskeletal system.

Understand the types of muscle fibers, their capacity for sustained activity and the nature. of metabolism they utilize.

Understand how several body movements are performed by the interaction of muscles, why muscle fatigue occurs, and how temperature affects muscle action.

Introduction:

Human athletic performance has been a source of entertainment, admiration, and curiosity since the dawn of recorded history. Athletes with extraordinary capacities for speed, power, strength, endurance, and stamina are not only recognized for their physical achievements, but they are also likely generate puzzled expressions of amazement such as, "Why is that guy so strong?" "How can she so fast?" and "Could I ever do that?" These questions lie at the very core of human **exercise physiology**, a field that seeks to understand the physiological and biochemical events that occur when a person exercises. As a result of research in this area, we now know a great deal about why athletic performance varies from one individual to another, about the effect of training on muscle function, and about the long-term consequences of performance-enhancing drugs such as anabolic steroids and amphetamines. In this exercise, you will look at several aspects of the musculoskeletal system. It is divided into four units.

- I. Basic muscle structure
- II. Histology
- III. Metabolism and Fiber Types
- IV. Muscle action

The skeletal and muscular systems serve to give us our shape, permit movement, and protect our internal organs. Examine the articulated skeleton and note the shapes of bones that articulate at specific joints, such as the hip or shoulder (spheroidal or ball-and-socket joint), skull (pivot joint with the first vertebra), elbow (hinge joint), knee (condylar joint), wrist (gliding joint) and fingers (hinge joint). Ligaments connect bones to each other and tendons connect muscles to bones.

The diagram of the human muscular system (see attached) shows just how extensive the various muscles are that cover the skeleton. Skeletal muscle is also called voluntary muscle because it is largely under voluntary control regarding contraction. To provide specific body movements, muscles work in what are called **antagonistic pairs** with one muscle contracting while the other is relaxing. When a muscle contracts it pulls on the tendon attached to a bone that lies across a particular joint. This moves the two bones closer or farther apart (e.g. flexion and extension of the arm). Try flexing and extending your arm; with one hand you can feel some muscles tighten (contract) with these movements.

I. BASIC MUSCLE STRUCTURE

Study the following diagram to learn the basic parts of the muscle and how muscles are attached to bones.

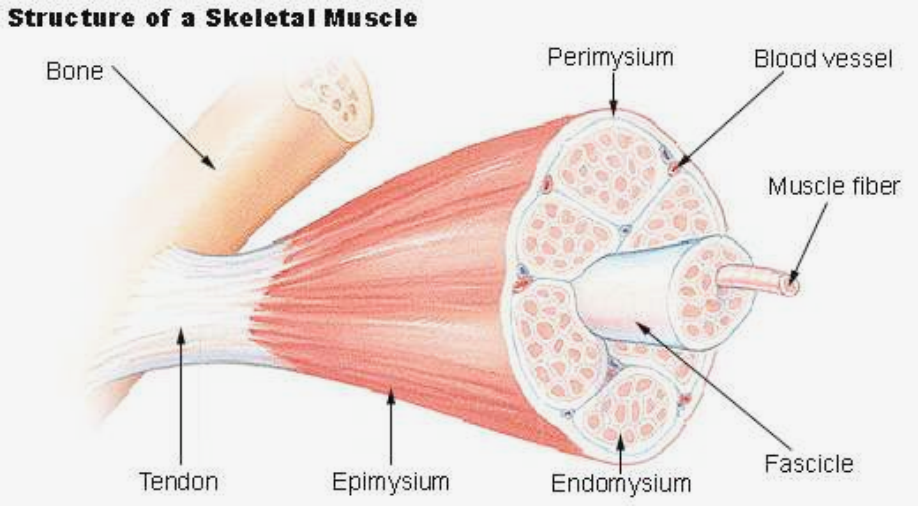


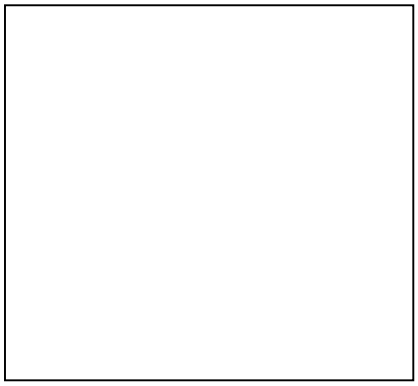
Image source: http://training.seer.cancer.gov/module_anatomy/unit4_2_muscle_structure.html

Skeletal muscle is just one type of muscle found in the body; smooth muscle and cardiac muscle are the other two. When you study the prepared slide of skeletal muscle examine an area that shows muscle fibers both in longitudinal sections and cross sections. Note that each muscle fiber is a single cell, which is quite long, with easily recognizable striations, and multiple nuclei located along the periphery of each fiber. The striations, or striped appearance is due to the arrangement of actin and myosin filaments. In cross section, you can also see the darkly stained nuclei at the outer edge of each fiber. Tendons are a type of dense connective tissue composed of parallel bundles of collagenous fibers. Bone is also a type of connective tissue composed of concentric layers of a mineralized matrix. For contraction to occur muscle fibers must receive nerve impulses and each muscle fiber is innervated by a single neuron. You will examine this connection and the tissues just described in the histology section that follows.

II. HISTOLOGY

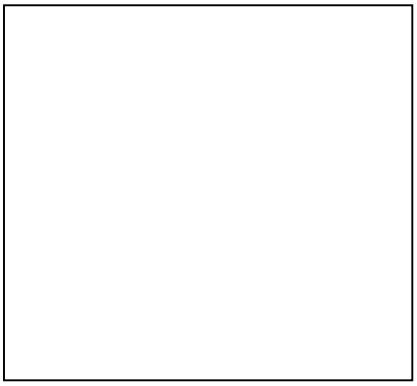
To gain an understanding of the main tissues involved in the musculoskeletal system, you are to view the prepared slides of skeletal muscle, a neuromuscular junction (DEMO), tendon, and compact bone. Make a drawing of each tissue type as indicated below and label the features listed in parentheses ( ).

Materials: compound microscope
Prepared slides of skeletal muscle, tendon, bone
Demonstration scope set up – neuromuscular junction



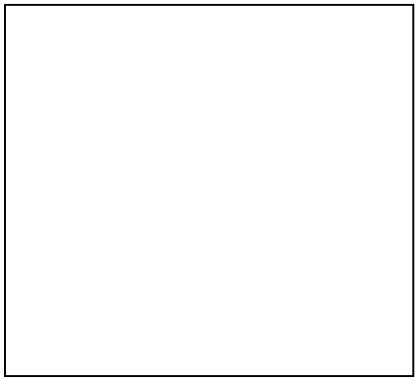
Skeletal muscle, c.s. and l.s.
(**striations, nuclei**)

Mag. _____ X



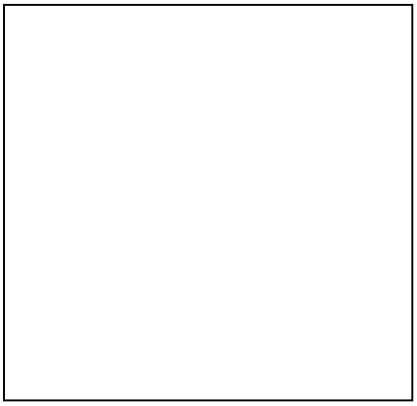
Neuromuscular junction, l.s.
(**muscle cell, motor end plate**)

Mag. _____ X



Tendon
(**collagen fibers and nuclei of fibroblasts**)

Mag. _____ X



Compact bone
(**Haversian canal, lamellae**)

Mag. _____ X

III. METABOLISM and FIBER TYPES

When muscles contract during exercise, they require **ATP** (adenosine triphosphate) in order to function properly. This ATP can either be supplied **aerobically** (with oxygen, through respiration) or **anaerobically** (without oxygen, through fermentation). In general, aerobic metabolism is sustainable over a long period of time, but anaerobic glycolysis has the drawback of producing byproducts (lactic acid in humans, ethanol in yeast) that interfere with metabolism and, in particular, muscle contraction. In a previous lab (Cell Diversity) you learned about anaerobic fermentation by yeast cells. Fundamentally, the process in similar in human muscle tissue but here the byproduct is lactic acid (Figure 1).

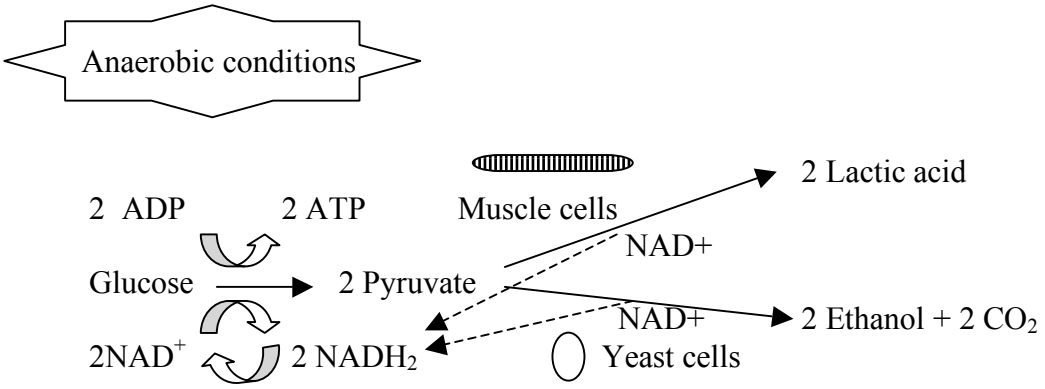


Figure 1. Anaerobic metabolism in yeast cells and human muscle tissue.

While glucose is the energy source for most cellular activity, the cell cannot use it as an intact molecule. The chemical bonds must be broken and the energy converted through a series of enzymatic pathways; glycolysis (which occurs in the cytoplasm) and the Krebs cycle and oxidative phosphorylation (which occur in the mitochondria). These pathways generate 36 molecules of ATP. In the very last step of the electron transport chain, molecular oxygen (from what we breathe) is reduced to metabolic water. The basic equation associated with aerobic metabolism follows:

$$C_6H_{12}O_6 + O_2 \rightarrow \rightarrow \rightarrow ATP + CO_2 + H_2O + \text{heat}$$

(glucose) (glycolysis, Krebs cycle, and oxidative phosphorylation)

Aerobic respiration: When oxygen is available, glucose can be reduced to carbon dioxide (CO_2) and water (H_2O), resulting in the production of 36 molecules of ATP. This is what happens during aerobic exercise using muscles that are designed for aerobic metabolism.

Fermentation: When you exercise intensely over a short period of time, your muscle cells will be starved for oxygen and will switch over to anaerobic metabolism (fermentation), with lactic acid as a byproduct. As with yeast, the net gain of ATP is low, just two molecules, but the regeneration of NAD+ allows the process to continue until the accumulation of lactic acid interferes with metabolism.

MUSCLE FIBER TYPES

Many exercise physiologists believe that one of the most important factors determining athletic performance is the cellular composition of the contracting muscles. Muscle cells, which are called **fibers**, can be broadly classified into categories based on their structural and metabolic characteristics. Consider the biceps muscle in the upper arm. This muscle tissue is composed of distinct fiber types that play a critical role in determining the muscle's performance capacity.

Three main fiber types are commonly identified, although further subgroupings are known. For our purposes, we will focus on the three major types described here. **White, fast-twitch, glycolytic** fibers (**FG**) are generally quite large in diameter and can generate energy rapidly for quick, powerful contractions. White fibers rely on anaerobic metabolism to produce ATP and become fatigued with the accumulation of lactic acid, a noxious by-product that interferes with muscle contraction. Consequently, white, fast-twitch fibers are generally activated in short-term sprint or "power" activities, as they fatigue rapidly. **Red, slow-twitch**, **oxidative** fibers (**SO**) are smaller in diameter, and generate a greater yield of ATP by aerobic metabolism and without the formation of lactic acid. As the name implies, red, slow-twitch fibers contract less rapidly and powerfully, but they are not easily fatigued and are well suited for prolonged exercise. In addition to these two types, a third intermediate fiber type, fast, oxidative-glycolytic (FOG), shares both the oxidative and glycolytic pathways and is intermediate in size as well when compared to red and white fibers (it is sometimes referred to as "pink" fibers). These characteristics are summarized below in Table 1.

Table 1. Comparison of Muscle Fiber Types.

	Slow, Oxidative	**Intermediate**	**Fast, Glycolytic**
Fiber color	Red	Pink - red	White
Predominant metabolic pathway	Aerobic	Aerobic	Glycolysis
Contraction speed	Slow	Fast	Fast
Rate of fatigue	Slow	Intermediate	Fast
Mitochondria	Many	Many	Few

It is widely known among sport physiologists that the "fiber-type"[1] of elite, world-class athletes is a reliable predictor of performance in athletic events. Sprinters, weight-lifters, wrestlers and others that rely on short, powerful bursts of muscle activity generally have a predominance of _____ -twitch fibers, whereas marathon runners, cross-country skiers, cyclists, and other endurance athletes have a greater abundance of _____ - twitch fibers.

Less widely appreciated is the extent to which these principles of human exercise physiology apply to other animals and their capacity for exercise. Organisms with predominantly white, fast twitch fibers (FG) also use anaerobic metabolism during exercise. They are capable of producing very high levels of muscle power output (e.g., fast sprints and strong bites), but these animals exhaust quickly. Other animals with a greater abundance of red, slow-twitch fibers (SO), which rely on aerobic metabolism, are capable of producing a moderate level of power for long periods of time. The principal disadvantage for "aerobic animals" is that aerobic metabolism is an expensive system to maintain; it requires a large, active heart, an elaborate vascular system to deliver oxygen, and numerous mitochondria in the muscle cells to produce large quantities of ATP. The high costs of maintaining these features are reflected in the higher rates of metabolism when the animal is at rest. "Anaerobic animals" avoid these energetic costs

[1] A person's fiber-type is determined by removing a small muscle tissue sample and analyzing it for the relative proportion of fast-twitch and slow-twitch fibers.

and have relatively low resting metabolic rates, leaving more energy available for growth and reproduction. However, they are incapable of any behavior that entails moderate or high levels of muscle activity for prolonged periods of time.

Many vertebrate animals posses both fiber types, but usually one type predominates over the other. This translates into the animal's ability to be either a sprinter (i.e., moves quickly but can only do so for short distances) or better at endurance (i.e., is able to travel long distances at steady paces). You are already familiar with this by the "white meat and dark meat" of chicken and turkey. How frequently do chickens fly? How much time to they spend running around? What about other birds, such as ducks and geese? Would you expect these birds to have the same distribution of white and red fibers?

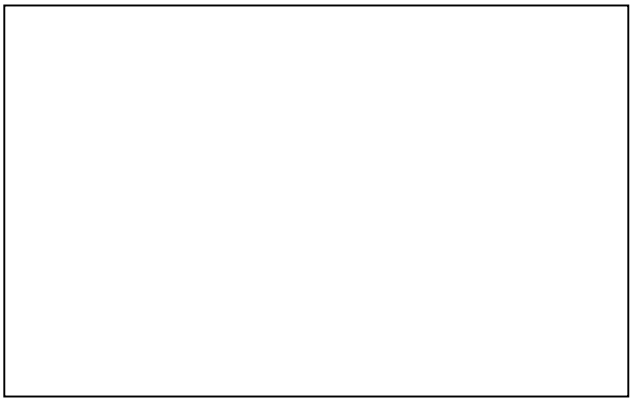
Other good examples are seen in fish. Examine the pieces of tuna, flounder, and swordfish to note these differences in red and white fibers. Comment on a) the predominance of fiber types in all three species and b) how this may relate to where they live and the nature of their swimming activity.

Tuna:

Flounder:

Swordfish:

In the space provided, make a sketch of the swordfish section indicating the location of the **red** and **white** fibers.



Cross section of swordfish steak

In reference to the swordfish, answer the following:

- What is the significance of the location of these two fiber types?

- Which of these fiber types is active during normal swimming?

- What happens in terms of muscle activity when the fish is hooked to a fishing line and fighting to avoid capture?

- Determine the relative amounts of the two different muscle types in the swordfish section by estimating the surface area of each type (red, white).

- What do these estimates tell you about the relative contribution of aerobic and anaerobic metabolism to total muscle power output?

Analyzing Muscle Fiber Types:

Various histochemical methods are employed to distinguish fiber types and today you will examine images of one such staining method and determine the fiber type composition of the muscle tissue. The procedure uses an enzyme reaction in the mitochondria (succinate dehydrogenase, SDH) and a colored compound, which turns purple as a result of this reaction. This assay can distinguish oxidative fibers from less oxidative fibers (essentially red from white). Basically, the more mitochondria that are present in a muscle fiber, the darker it will appear in the stained section. Predict which fiber type will have the greater abundance of mitochondria, FG or SO? _____

Materials: Image of histochemical analysis of fiber types
Ruler
Calculator

Study the laminated image. Identify the three fiber types (FG, FOG, and SO), which are easily recognizable by their staining characteristics. This particular image is from the gastrocnemius muscle of a frog (locate this muscle on your own leg). Why do you think it makes sense that several fiber types are present in this muscle?

Complete Table 2. Count the number of fibers for each type and calculate the frequency as a percentage. In this tissue section, does one type predominate? Which type?

Table 2. Comparison of Stained Fiber Types.

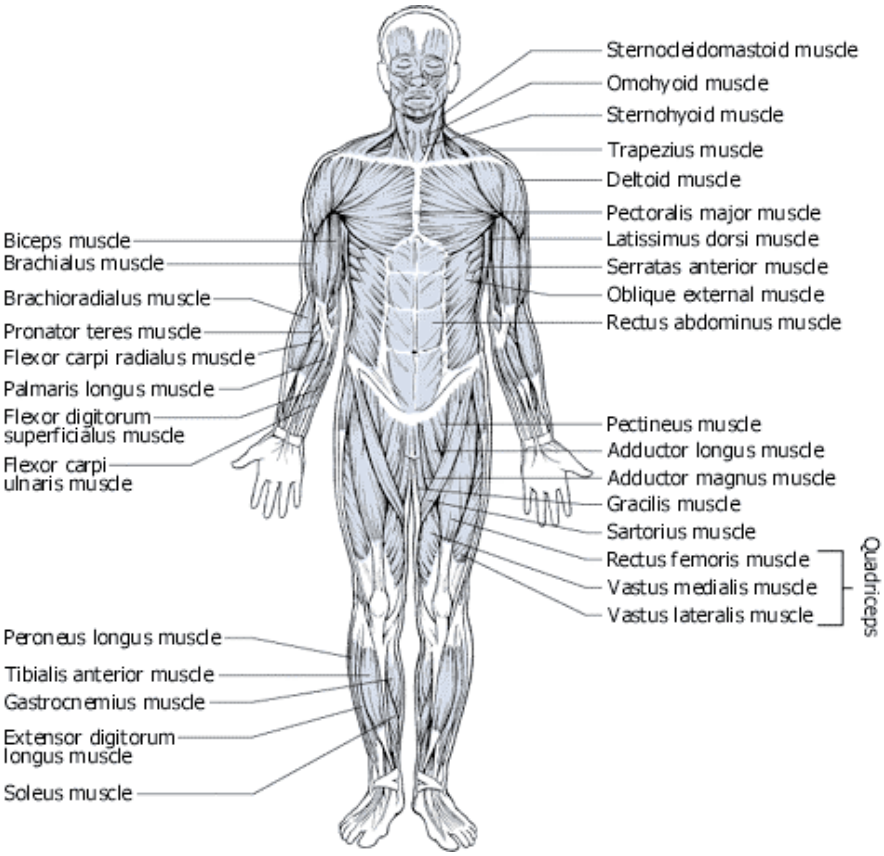
Muscle Fiber type	SDH Stained fiber color	Approximate Fiber diameter, μm	Number of fibers present	Frequency of fiber type (%)
Red, slow, oxidative (SO)				
Pink, fast oxidative (FOG)				
White, fast, glycolytic (FG)				
Total number of fibers counted				100%

IV. MUSCLE ACTION: Muscles of the human body vary in shape and size. While most are somewhat elongated in shape, others may be trapezoidal and a few circular. The thick fleshy part of the muscle is called the belly. You can easily relate to this by feeling the muscle of you upper arm and back of your lower leg. Many (but not all) muscles are directly connected to bones. The tapered ends of these muscle are connected to bone by **tendons** (a type of dense connective tissue).

Most muscles of the body work in groups to perform a specific body movement. The area on a bone where a muscle is firmly attached is called the **origin** and the point of attachment to the bone it moves is called the **insertion**. The contraction of specific muscles results in an action and that action is often described in terms of "antagonistic pairs" of muscles. The main muscle that is responsible for a specific movement (or action) is called the **agonist** (or prime mover); the muscle that opposes it is called the **antagonist**. When one muscle contacts to produce a motion, its opposing muscle is relaxed. This will become clearer as you perform some of the actions listed below. Some basic types of body movements are flexion/extension (arm or leg), depression/elevation (jaw), and dorsiflexion/plantar flexion (foot).

Materials: Articulated human skeleton
Charts of the Human Skeletal and Muscular systems

A. Perform the movements listed in Table 2 and, with your lab partners, determine the main muscles involved.



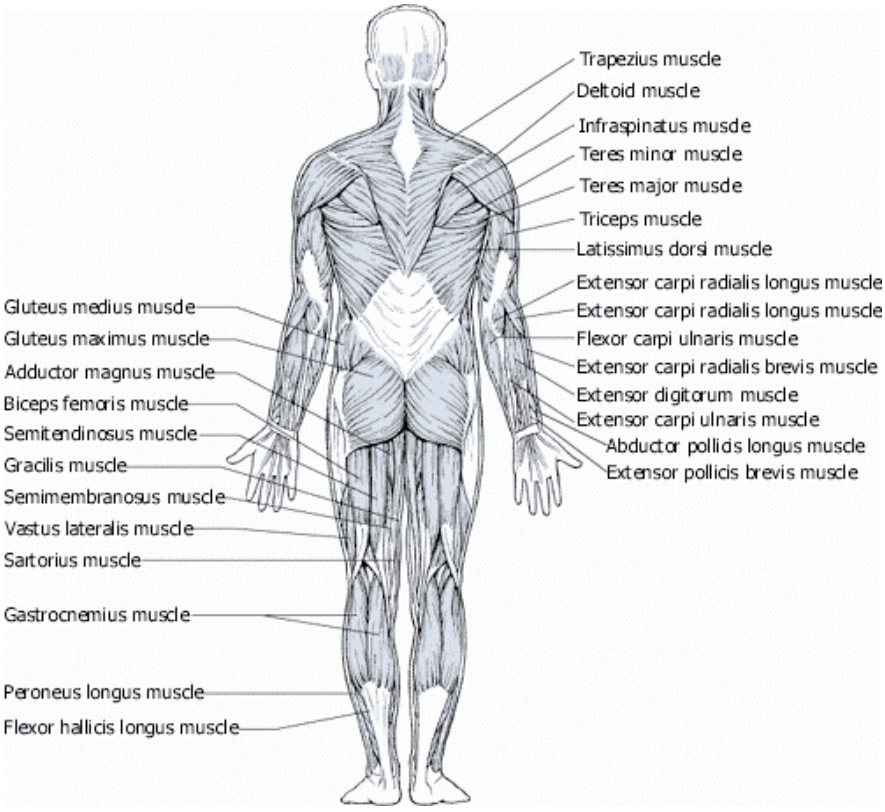


Image source: http://staff.tuhsd.k12.az.us/gfoster/standard/bbones.htm

Table 2. Muscle Actions in the Human Body

Action	**Muscle(s) involved**	**Location (bone hints)**
Toe lift (dorsiflexion)		Origin: tibia Insertion: foot bones
Toe press (plantar flexion)		Origin: femur Insertion: heel bone
Arm curl (forearm flexion)		Origin: scapula and humerus Insertion: radius
Forearm extension		Origin: scapula and humerus Insertion: ulna
Wink your eye*		
Yawn: Depress the jaw		Origin: lower mandible Insertion: hyoid
Close mouth: Elevate the jaw		Origins: temporal bone; maxilla & zygomatic arch Insertions: mandible

* Note this is a sphincter-type muscle.

B. The Effects of Muscle Fatigue on Muscle Function

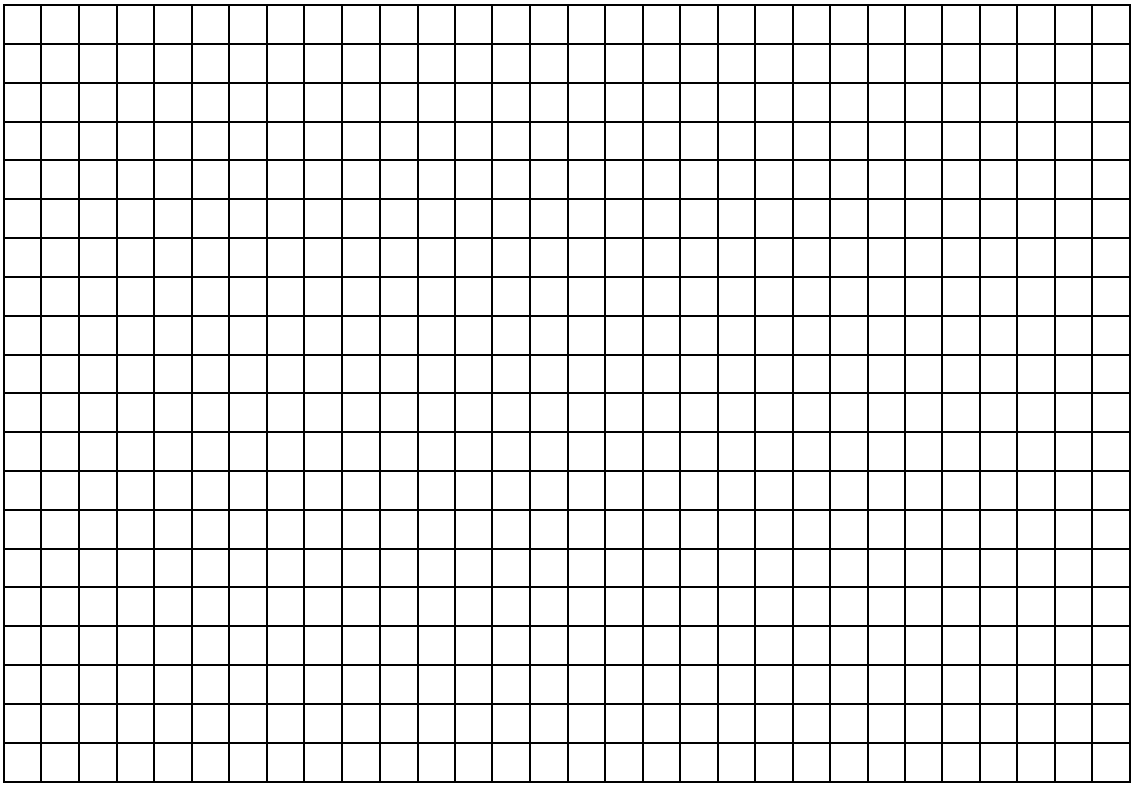
Materials: Hand grip exerciser
Timer

Use a handgrip and compress the grip **completely** counting the number of times you can do this in **15 seconds**. Repeat this activity as many times as you can without resting. In the table below, record the number of closures you make for each 15-second trial. Compile that of your lab partners as well.

Effect of muscle fatigue on hand contractions using a handgrip exerciser.

Trial #	Your data: # of closures	Partner 1: # of closures	Partner 2: # of closures	Partner 3: # of closures
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

1. **Plot the data:** Compare the number of contractions completed for each trial.



2. Based on your data, and that of your partner's and/or classmates, discuss if any of you participate in activities that require extensive use of the fingers (e.g. typing, play piano or guitar, etc.). Does this have a relationship to the results?

3. What is the relationship between muscle fatigue and fiber type? Do you think there are more red (SO) or white (FG) fibers in the hand muscles?

4. What insights can you develop about fiber typing of the muscles involved? Which of your classmates appears to have a higher concentration of red (oxidative) fibers and which appear to have predominantly white (glycolytic) fibers?

C. The Effects of Heat and Cold on Muscle Function:

Materials: Ice
Pen or pencil

1. Write your signature 3 times under the column labeled "Normal".

2. Hold some ice in your writing hand for a few minutes; write your signature 3 times under the column labeled "Cold".

3. Place your hands under warm running water for a few minutes. Massage your hands and write your signature 3 times under the column labeled "Warm".

NORMAL	COLD	WARM

1. What did the changes in temperature do to your hand muscles?

2. How do you explain this effect?

3. Why do you think dancers wear leg warmers and major league pitchers wear jackets before pitching?