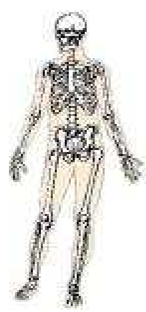
Biomechanics Laboratory



CleveLabs Laboratory Course System Version 6.0

Introduction

The biomechanical properties of muscle allow a person to perform several different types of activities. As you learned in the Electromyography I laboratory session, there are different types of fibers which make up a single muscle. The different types of muscle fibers give rise to different properties of motor units such as their responsiveness and fatigue resistance. In addition to these properties, muscle also has particular biomechanical properties that are a function of the length and velocity at which they contract. More specifically, muscle has length-tension and force-velocity relationships. During this laboratory session, electromyography and a force plate transducer will be used to monitor leg muscles properties during jumping. The force plate will be used to quantify the force generated during the different phases of a jump. Combining the two inputs, you will be able to see which leg muscles are active during the different phases of jumping, and how the different properties of muscle impact the ability to jump.

The legs are comprised of many large muscles that facilitate walking, running, and jumping.

Equipment Required:

- CleveLabs kit
- CleveLabs Course Software
- Nine (9) snap leads and cloth snap electrodes
- Transducer Interface Cable
- Force Plate Transducer
- MATLAB® or LabVIEW™

Background

Physiology of Muscle Contractions

Nearly 40% of the body is composed of skeletal muscle, the type that facilitates everyday movements such as walking, running, and talking. All skeletal muscles are composed of numerous fibers ranging in size from 10 to 80 micrometers. Each of these fibers is composed of even smaller subunits called myofibrils. A typical muscle fiber contains anywhere from several hundred to several thousand myofibrils, which are composed of approximately 1500 myosin and 3000 actin filaments. Myosin and actin filaments are large polymerized protein molecules that are responsible for muscle contraction.

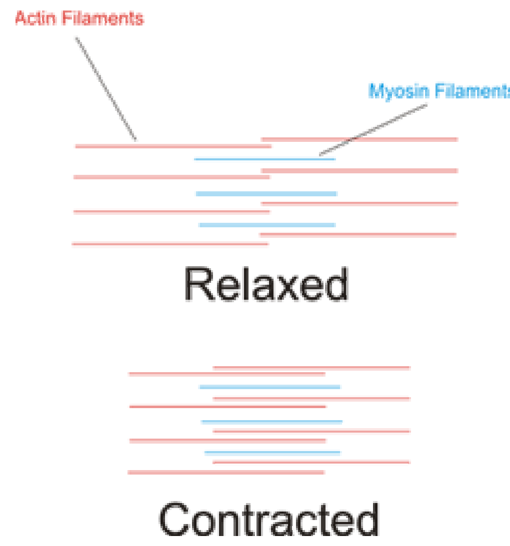


Figure 1. Relaxed and contracted states of a sarcomere.

Muscle contraction occurs in the following steps:

1. An action potential travels along a motor nerve, arriving at muscle fibers.
2. Acetylcholine is released at the nerve ending, which then acts on a local area of the muscle fiber membrane to open acetylcholine-gated channels.
3. Large quantities of sodium ions flow to the interior of the muscle fiber membrane through the opened acetylcholine-gated channels.
4. An action potential is produced by the influx of sodium ions. The action potential travels along the length of the muscle fiber.
5. The action potential depolarizes the muscle fiber membrane and travels deep inside the muscle fiber, causing the release of stored calcium ions into the myofibrils.
6. Calcium ions induce attractive forces between actin and myosin filaments, causing them to slide over one another. This is the contractile process.
7. Almost instantaneously, calcium ions are pumped back out of the myofibril to be stored for the next action potential. Once the calcium ions are pumped out of the myofibril, muscle contraction is ceased.

A visual depiction of a contracting myofibril is shown in Figure 1. This portion of the myofibril is called a sarcomere. When a muscle is fully relaxed, the sarcomere length is approximately 2.2 micrometers. At this length, the actin filaments overlap the myosin filaments and slightly overlap other actin filaments. Additionally, at this length, the sarcomere has the ability to generate the greatest force (tension) of contraction shown in Figure 2.

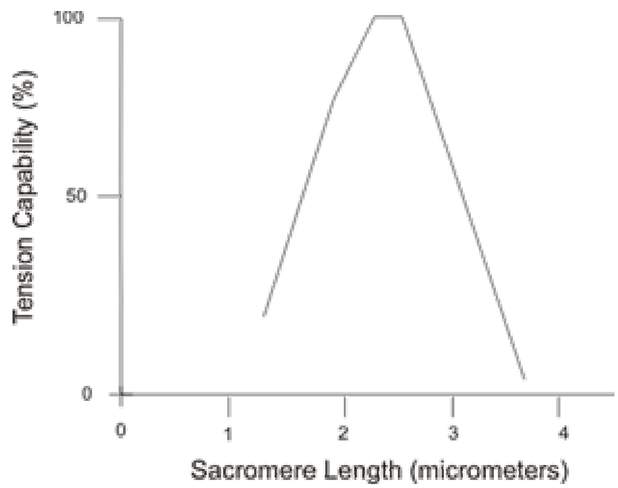
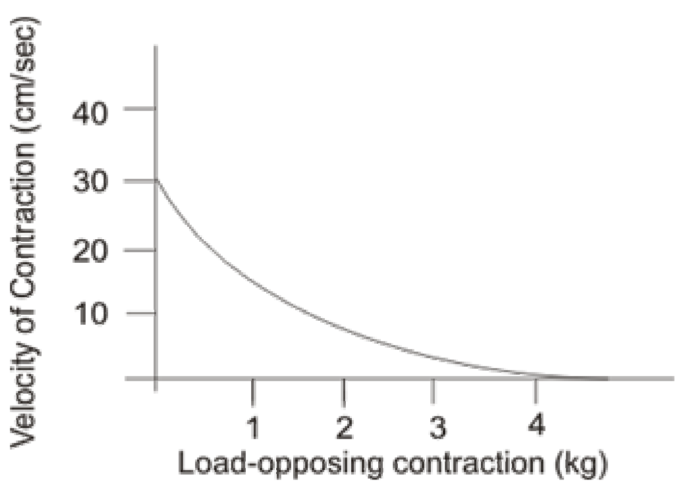


Figure 2. Length-tension diagram for a single sarcomere

A muscle can contract at the greatest velocity when it is contracting against no load. On average, a muscle under no load can fully contract in approximately 0.1 seconds. However, when a load is applied to a muscle, the velocity of its contraction decreases significantly. The graph shown in Figure 3 depicts this contraction load versus the velocity that the muscle can contract. When a load is applied to a contracting muscle, the contractile force is opposed. This opposition reduces the net force available used to increase the velocity of contraction, hence a slower contraction. If the load increases to the point where it equals the maximum force that a muscle can exert, no contraction occurs.



Biomechanical Modeling

Biomechanical modeling is often utilized in research applications to calculate muscle output forces for given conditions. This modeling is usually completed using computer simulations. While it can be important to complete experiments with human subjects, biomechanical modeling and simulations are of great benefit. First, it can be very costly and time consuming to complete experiments with human subjects. Additionally, there are some experiments that may be very invasive or need to be repeated over and over while changing the parameters. By completing computer simulations, experiments can be run faster and at less cost. Therefore, there is great value to creating biomechanical models that can run simulations to test hypotheses without actually having to experiment on human subjects. One very popular muscle model integrated in biomechanical modeling is the Hill type model. The Hill type model for muscle takes into account the contractile elements of muscle, excitation parameters, and length-tension and force velocity properties. Utilizing this type of model you can predict the force output of a muscle based on several input parameters including neural activation, the current muscle length, the current muscle velocity and the size of the muscle.

There are several different types of models that can be developed. In some cases, a user may want to input the muscle forces and have the model output the endpoint forces that are generated at the hands or feet. In other cases, a user may want to specify the endpoint forces that someone would generate and have the model calculate which muscles need to be activated and at what levels. In generating these inverse kinematic models there are many solutions that could satisfy end point forces for given constraints. Therefore, there is often optimization criteria built into the model to allow selection of a unique solution. For example, one such optimization criterion is to minimize the stress on the muscles to create a given endpoint force.

Types of Muscle Contractions

There are three different types of muscle contractions. A concentric muscle contraction means that the length of the muscle is shortening as the muscle is generating force. An example of this would be someone lifting a dumbbell with his or her arm by flexing at the elbow. The biceps muscle length shortens as it contracts to lift the weight up during the curling exercise.

An eccentric muscle contraction means that the length of the muscle is lengthening as the muscle is generating force. You can create an eccentric contraction by slowly lowering the dumbbell after you have completed a biceps curl. As you slowly lower the weight, the biceps muscle is lengthening, but is still contracting to create the force to oppose the weight of the dumbbell.

Finally, an isometric contraction occurs when the muscle is contracting while it is held at a fixed length. An example of this is if you are holding a dumbbell in your hand with your elbow at a fixed angle. If the arm is not moving, then the muscle is holding a sustained isometric contraction to balance the weight.

During jumping, leg muscles go through both a concentric and eccentric phase. As the person squats, the muscles go through an eccentric phase in which the muscles store energy that can be released. Once the person lowers his/her center of gravity to the bottom of the squat, there is much potential energy that is stored in the muscles. While at the bottom of the squat, some of that potential energy begins to dissipate. Therefore, the sooner that the concentric phase of the jump begins after the eccentric phase, the more energy will be available to propel the person's center of gravity upward.

Biomechanical Kinematics

According to Newton's 3rd Law of Motion, for every action, there is an equal and opposite reaction. Due to gravity, objects are in constant contact with the ground. This interaction creates forces generated by both the object and the ground. For example, during human motion, such as when a step is taken, a force is generated. The equal and opposite force created by the ground in response to this step (or any other force) is called the ground reaction force. In order to quantify the forces generated during human motion, researchers utilize force plates. Measuring the ground reaction force with a force plate provides valuable insight into diagnosing movement disorders, analyzing gait patterns, and studying sports performance.

Several biomechanical kinematic parameters can be measured or calculated when a person jumps. A person exerts a particular force on the ground when he/she jumps, as measured by the force plate transducer. The force measured by the force plate is the normal force (F_n). By knowing the mass of the person, you can calculate the acceleration that a person generates. When standing still on the force place, the force measured is given by $F_n = mg$, which is the person's weight. When the person jumps, acceleration can be found using the relationship $F_n - mg = ma$. By integrating acceleration, you can compute the velocity of the person at take off.

The following formulas may be useful in your data analysis:

Force = mass * acceleration;	1 N = 1 kg * m/s^2
1 lb = .4536 kg	1 N = .2248 lbs of force
1 lb = 4.448 N	Gravity = 9.81 m/s^2

Experimental Methods

Experimental Setup

During this laboratory session you will record four channels of EMG from your lower extremities. You will record one channel from your calf muscle and another from your quadriceps muscle on each leg.

1. Your BioRadio should be programmed to the “LabBiomechanics” configuration. The software will automatically do this when you enter the laboratory session.

2. For this laboratory you will need to use nine snap electrodes from the CleveLabs Kit. Remember that the electrode needs to have good contact with the skin in order to get a high quality recording. The surface of the skin should be cleaned with alcohol prior to electrode attachment. For the best recordings, it is best to mildly abrade the surface with pumice or equivalent to minimize contact resistance by removing the outer dry skin layer. Attach two electrodes about one inch apart above each muscle you are recording from. The muscles include the quadriceps and calf muscles in each leg (Fig 4). Attach one electrode to the bony part of one knee to use as the ground electrode.

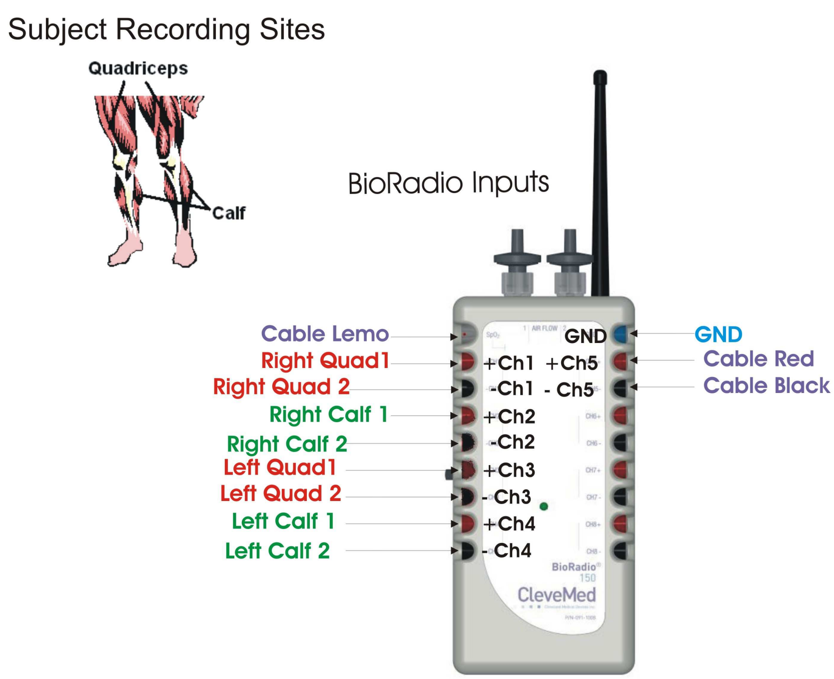


Figure 4. Experimental setup for the Biomechanics Laboratory session.

3. After the electrodes have been placed on the subject, connect one snap lead to each electrode. Then, connect those snap leads to the harness inputs for channels 1, 2, 3, 4 and the ground using the picture above as a reference (Fig 4). The leads on the harness are stackable allowing one snap lead to be plugged into more than one connector lead.

4. Make sure to tape up any slack from the electrode leads to the person's leg. This will help to minimize any motion artifact created by inductance on the lead wires.

5. Plug the force plate into the transducer interface cable. The switch at the top of the force plate should be set to -200 to +850 range setting.

6. Plug the lemo connector on the transducer interface cable into the lemo input on the BioRadio. Plug the red lead from the transducer interface cable into the +5 input on the BioRadio. Plug the black lead from the transducer interface cable into the -5 input on the BioRadio.

Procedure and Data Collection

1. Run the CleveLabs Course software. Log in and select the "Biomechanics" laboratory session under the Advanced Physiology subheading and click on the "Begin Lab" button.

2. Turn the BioRadio ON.

3. Click on the BioRadio data Tab and then on the green "Start" button. Four channels of EMG and one channel of force data should begin scrolling across the screen.

4. With no load on the force plate, click on "Zero Force Sensor". This will remove any offset from the transducer.

5. First, instruct the subject to stand still on the force plate to obtain the force he/she is generating in Newtons. Using this number, calculate his/her mass in kilograms. You will need this input parameter for further analysis.

6. Now, begin saving a data file and instruct the subject to squat and then stop at the bottom of the squat. You should call this data file "squat".

7. Now, instruct the subject to jump on the force plate a total of three times. Each jump should be saved as a separate data file. The first jump should be a small vertical jump with a file name of "smalljump". The second should be a medium

vertical jump with a file name of "mediumjump". The third should be a vertical jump as high as he/she can with the filename of "highjump".

8. Now, instruct the subject to jump off of the force plate. Save this file as "jumpoff". Now, instruct the subject to jump back on the force plat and save this file as "jumpon".

9. Now click on the "Kinematics" data tab. This will allow you to compute the acceleration and velocity of the subject during jumping. The top plot shows the force that the subject is generating on the force plate. The second plot is the acceleration of the subject, derived from Newton's 2^{nd} Law. The third plot shows the integral of the acceleration which yields the velocity of the subject.

10. The subject should not be standing on the force plate. First, enter the mass of the subject in kilograms.

11. Now the subject should stand still on the force plate. Once the subject is standing still on the force plate, click on the "Reset Kinematics" button. This should set the velocity to zero. Now, instruct the subject to jump to the three heights as described in step 7. By integrating the acceleration, you will measure the velocity of the subject at takeoff and landing. Due to an inexact measurement of subject mass, the velocity trace will likely drift due to continuous integration of acceleration until it is reset.

Data Analysis

1. Using MATLAB, LabVIEW, or the Post Processing Toolbox process and plot the EMG data for each of the three jump trials.

2. Print out your plots and mark where the eccentric phases and concentric phases of the jumps were in each of the plots. Using the data from the "squat" trial may help you to distinguish the phases of jump.

3. Explore any correlations between the magnitude of the EMG and the magnitude of the jump.

4. Using MATLAB or LabVIEW, open the three jump data files. Plot the force plate measurement for each trial. Then calculate and plot the acceleration, velocity and position of the subject for each of the trials. This is similar to what the software interface achieved, however you will need to take the double integral of the acceleration to obtain position.

Discussion Questions

1. Describe how a muscle contraction occurs.

2. Why are biomechanical models important?

3. How does the length of a muscle impact its force generating ability?

4. How does the velocity of a muscle impact its force generating ability?

5. What ion is responsible for creating an attraction between the actin and myosin heads?

6. During your experiments which muscles (calves or quadriceps) are more active in different phases of jumping?

7. Where is potential energy stored for a jump? If too much time is taken between the eccentric and concentric phase of jump, where is the potential energy dissipated?

8. What was the velocity of the center of gravity of the subject at each of the different jump levels?

9. Was there a correlation between the magnitude of EMG and the level of jump in your results?

10. What was the take off velocity in each of your trials? Did the take off velocity correlate to the height at which the subject jumped?

References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Kandel ER, Schwartz JH, Jessel, TM. Essentials of Neuroscience and Behavior. Appleton and Lange, Norwalk, Connecticut, 1998.

3. Jenkins B. David. Hollinshead's Functional Anatomy of the Limbs and Back, 7th Edition. WB Saunders Company, Philadelphia, 1998.