

Biomechanical Analysis of a Vertebrate Foot

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While studying the skeletal and muscular systems, students learn that bones are lever systems and memorize the origin and insertion of muscles. Often, however, students don't connect these two concepts. In this workshop (an adaptation of one presented at ABLE in 1981) participants will work with a biomechanical model of a skeletal foot and determine how modifications in the length of the calcaneus or the length of the actual foot can determine whether the foot can maximize either strength or speed. They will then apply the principles derived from the foot analysis to an examination of particular animal skeletons.

Keywords: biomechanical model, lever system, vertebrate foot

Introduction

The goal of this exercise is to provide students with an opportunity to study a biomechanical model of a bone/muscle system so they may better understand the principle of lever systems, muscle origin and insertion, and the relationship between structure and function exhibited in the skeletal system. In an anatomy/physiology class this exercise could be used to extend students' understanding of bones and muscles operating as lever systems; in an evolution class, it could be used to study adaptations in animal skeletons. This exercise does not extend to more complex issues regarding the skeleton-muscular system and movement such as gait, the role of individual toes, or a flexible spine. Consideration of these topics could certainly be based on this activity, supplemented by articles from the extant literature (for example, Hildebrand, 1960; Hildebrand, 1962).

Students do not need extensive knowledge of bones and muscles to carry out this exercise. A basic understanding of origin and insertion of muscle, however, is necessary. Students should also consider the arrangement of the three classes of lever systems prior to beginning the laboratory exercise.

Student Outline

In this laboratory exercise, you will be studying a particular example of a lever in the body, the foot, as it relates to the ankle and lower leg. Before you begin, spend some time with these websites and familiarize yourself with various lever systems and with the related vocabulary.

- <http://www.enchantedlearning.com/physics/machines/Levers.shtml>
- <http://citytechnology.org/stuff-that-works/levers-have-a-lot-of-class>
- <http://biology.kenyon.edu/courses/biol10/lever/typeframe.htm>

In Fig. 1, label these parts: calcaneus, gastrocnemius muscle, in-force, effort arm, out-force, load arm, fulcrum. Terminology used is from the Kenyon web site.

Definitions

Lever – a rod which pivots around a point

Fulcrum – pivot point

Effort arm – the arm of the lever to which the in-force is applied

In-force - the power supplied, in this case by the muscle

Load arm – the arm of the lever whose movement results from the movement of the power arm

Out-force – the force created on the other arm of the lever

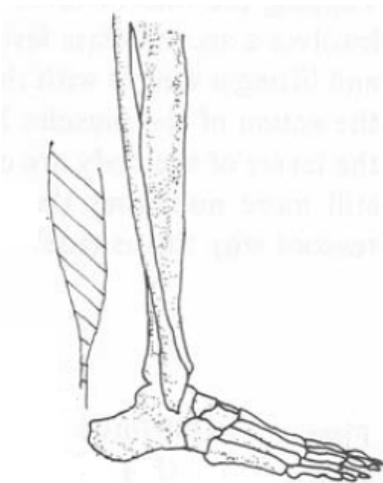


Figure 1. Diagram of the bones and specific muscle of the lower leg.

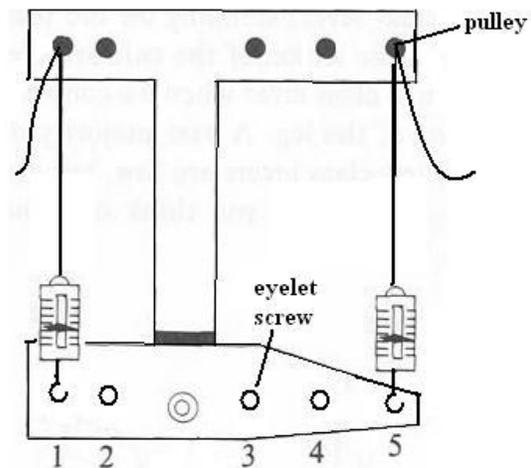


Figure 2. Diagram of the biomechanical foot model.

You will be using a biomechanical model of the lower leg and foot. Label the same parts in the mechanical diagram (Fig. 2): calcaneus, gastrocnemius muscle, in-force, effort arm, out-force, load arm, fulcrum.

Make sure you can explain the operation of both the actual foot and the foot model in terms of lever systems. Make sure you can explain the actual anatomical significance of each of the five foot positions in terms of the length of the calcaneus and the length of the foot.

In this laboratory exercise, you will be comparing the structure of a foot that is designed for force with a foot that is designed for speed.

Determining the Force Mechanical Advantage (FMA)

Force Mechanical Advantage is an indication of the force conversion efficiency of a bone/muscle lever system. A bone/muscle lever system is considered force-efficient if $FMA > 1.0$, because the out-force produced by the muscle is greater than the in-force of the muscle contraction. If the $FMA < 1.0$, the system is force-inefficient, because the out-force is less than the

in-force of the muscle contraction. If $FMA = 1$, the muscle neither gains nor loses mechanical advantage since the two values are equal.

To determine the FMA of the six foot arrangements of the foot lever system, you will first determine the out-force generated by an in-force of 1000 grams in each of the six arrangements.

1. Make sure your spring scales are both set at 0. Set up the foot model so the gastrocnemius insertion is at Position 1 and the end of the foot is at Position 3 (Fig. 2).
2. One member of the group should establish an in-force of 1000 grams on the calcaneus end of the foot by pulling straight down on the string. At the same time, another member of the group should pull straight down on the other string until the foot is perpendicular to the leg.
3. When the foot is perpendicular, check to make sure the in-force is still 1000 g. Then measure and record in Table 1 the out-force generated at Position 3.
4. Repeat for a foot that ends at Position 4, and again at Position 5. Before each new arrangement, check the 0 setting on the spring scales.
5. Move the gastrocnemius insertion to Position 2 and the end of the foot to Position 3.
6. Establish an in-force of 1000 grams.
7. Measure and record the out-force generated at Position 3.
8. Repeat for a foot that ends at Position 4, and again at Position 5.

Table 1. Individual group measurements of out-force generated by constant in-force of 1000 grams in six foot arrangements.

Gastrocnemius insertion position	SMA calculated at various positions		
	3	4	5
1			
2			

9. When all of the groups have recorded their data, calculate the average out-force at each of the six positions and record these in Table 2.

Table 2. Class averages of out-force generated by constant in-force of 1000 grams in six foot arrangements.

Gastrocnemius insertion position	Out-force measured at various positions (g)		
	3	4	5
1			
2			

Using the data in Table 2, calculate the FMA for each of the six foot possibilities using the formula:

$$FMA = \frac{(\text{out-force})}{(\text{in-force})}$$

10. Record your values in Table 3.

Table 3. FMA for six foot arrangements.

Gastrocnemius insertion position	FMA calculated at various positions		
	3	4	5
1			
2			

What is the foot arrangement with the greatest FMA? With the smallest?

Determining the Speed Mechanical Advantage (SMA)

Speed Mechanical Advantage is another indicator of the effectiveness of a bone/muscle lever system. In the best arrangement, the shortening distance of the muscle during its contraction is small compared with the distance moved by the distal, or “business,” end of the bone. A bone/muscle lever system is considered speed-efficient if $SMA > 1.0$, since the muscle is moving the bone’s distal end through a greater arc than its own contraction distance. If $SMA < 1.0$, the lever system is relatively speed-inefficient, since the distance moved by the muscle in contraction is greater than the movement of the distal end of the bone. If $SMA = 1$, the muscle neither gains nor loses mechanical advantage since contraction distance equals the bone movement.

You will use two different methods to determine the SMA. Here is the first method.

11. To determine the SMA, you must first measure the arcs drawn by points corresponding to the two muscle insertion positions and the three foot lengths.
12. To do this, remove the foot from the platform and place it on a large sheet of paper. Carefully mark the position of the pivot point by applying enough pressure on it to leave a mark on the paper. Place a pencil in each of the five holes, one at a time, and move the foot through the full extent of its rotation for each position. Be sure you don’t shift the position of the foot as you do this. When you have drawn all five arcs, lift the foot and mark the position on the paper left by the pivot. Replace the foot in the platform. [Your instructor may provide you with a diagram that results from this procedure instead.]
13. Mark off the arcs as shown in Fig. 3, and then measure the arcs to the nearest 0.1 cm. These arcs are shown as M_1 , M_2 , B_3 , B_4 , and B_5 (where M designates muscle and B designates bone). Record your values in Table 4.

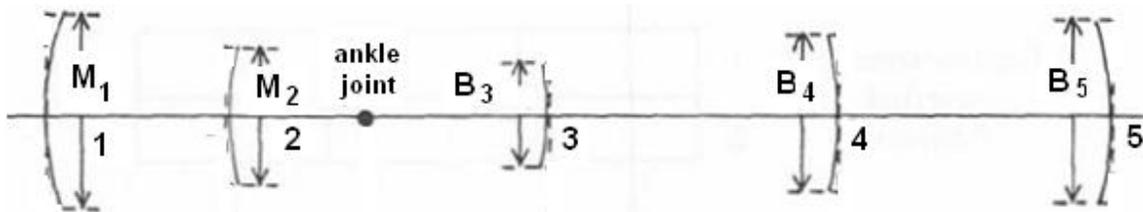


Figure 3. Arcs drawn by positions on the biomechanical foot model. M_1 and M_2 are the contraction distances for the gastrocnemius muscle inserted at positions 1 and 2; B_3 , B_4 , and B_5 are the movements of the ends of the foot at positions 3, 4, and 5.

Table 4. Individual group values for length of arcs drawn by five positions on biomechanical foot model.

Position	Gastrocnemius contraction distance (cm)
1	$M_1 =$
2	$M_2 =$
	Distance moved by distal end of bone (cm)
3	$B_3 =$
4	$B_4 =$
5	$B_5 =$

14. When all of the groups have recorded their data, calculate the average M and B values and record these in Table 5.

Table 5. Class averages for length of arcs drawn by five positions on biomechanical foot model.

Position	Gastrocnemius contraction distance (cm)
1	$M_1 =$
2	$M_2 =$
	Distance moved by distal end of bone (cm)
3	$B_3 =$
4	$B_4 =$
5	$B_5 =$

15. Use the values in Table 5 to calculate the SMA for each foot arrangement. It is computed by this formula:

$$\text{SMA} = \frac{\text{(distance moved by distal end of the bone)}}{\text{(distance of the muscle contraction)}}$$

16. Record these values in Table 6.

Table 6. SMA calculations for six foot arrangements using distal movement distance.

Gastrocnemius insertion position	SMA calculated at various positions		
	3	4	5
1			
2			

What is the foot arrangement with the greatest SMA? With the smallest?

In some situations, it isn't possible to measure the arcs drawn by the rotation of the calcaneus and the end of the foot. Therefore, a second method for determining SMA is necessary.

17. Return to the diagram of the arcs drawn by the five foot positions that you used earlier. Now, follow the diagram shown in Fig. 4 and draw lines that represent the distance from the fulcrum to each arc. Record these values in Table 7.

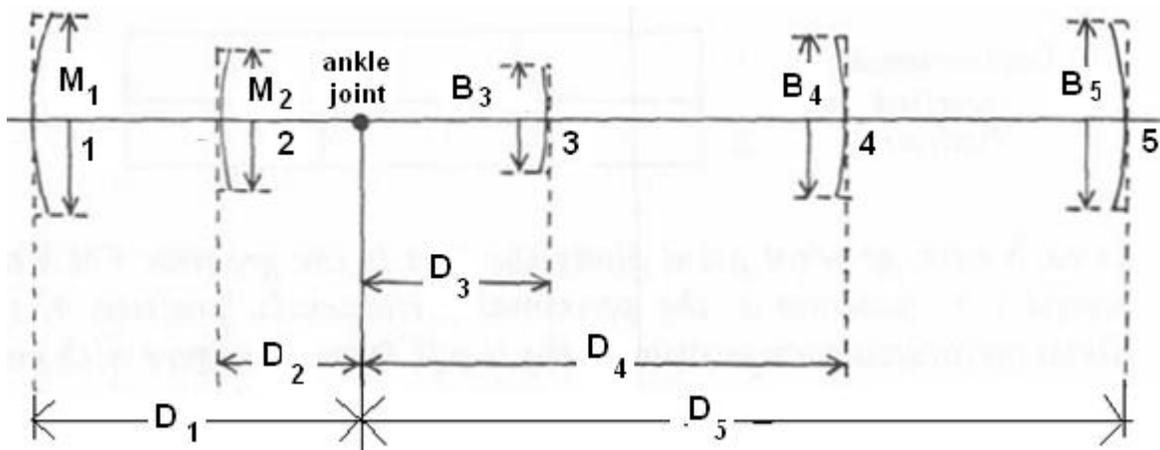


Figure 4. Distance from fulcrum for arcs drawn by five points in biomechanical foot model.

Table 7. Individual group values for distance from fulcrum of arcs drawn by five positions on biomechanical foot model.

Foot Position	Length of effort arm (cm)
1	$D_1 =$
2	$D_2 =$
	Length of load arm (cm)
3	$D_3 =$
4	$D_4 =$
5	$D_5 =$

18. When all of the groups have recorded their data, calculate the average values and record these in Table 8.

Table 8. Class averages for distance from fulcrum of arcs drawn by five positions on biomechanical foot model.

Foot Position	Length of effort arm (cm)
1	$D_1 =$
2	$D_2 =$
	Length of load arm (cm)
3	$D_3 =$
4	$D_4 =$
5	$D_5 =$

19. Use the values in Table 8 to calculate the SMA for each foot arrangement. It is computed by this formula:

$$\text{SMA} = \frac{(\text{length of load arm})}{(\text{length of effort arm})}$$

20. Record the values in Table 9.

Table 9. SMA calculation for six foot arrangements using arm lengths.

Gastrocnemius insertion position	SMA calculated at various positions		
	3	4	5
1			
2			

How do the values you recorded in Table 6 compare with those in Table 9? What does this suggest about the two methods you used to determine SMA? How does this compare with what you found for FMA values? How does the foot arrangement with the greatest FMA compare with the foot with the greatest SMA?

Examining Vertebrate Skeletons

Examine the diagrams of the three partial vertebrate skeletons. Measure the length of the foot and the length of the calcaneus for each leg/foot. Calculate the SMA for each leg/foot. Explain whether each foot/leg is designed for speed or strength, based on your calculations.

Materials

Per Group

- Biomechanical foot model
- 2 spring scales
- Heavy string (nylon, not waxed)
- Ruler
- Diagrams of vertebrate lower leg skeletons (or actual skeletons, if possible)

Notes for the Instructor

The previous workshop, on which this is based, was offered at the second ABLE conference (Glase, et al., 1981) and is available at the ABLE website. Although the directions for the use of the biomechanical foot model have been changed somewhat from the original exercise, the conclusions are the same.

Background for Students

Students do not need extensive knowledge of bones and muscles to carry out this exercise. A basic understanding of origin and insertion of muscle and the name of heel bone and the major muscle involved in foot extension, however, is necessary. Students should also consider the arrangement of the three classes of lever systems. Numerous websites clearly present the necessary background information regarding lever systems, for example:

<http://www.enchantedlearning.com/physics/machines/Levers.shtml>

<http://citytechnology.org/stuff-that-works/levers-have-a-lot-of-class>

<http://biology.kenyon.edu/courses/biol10/lever/typeframe.htm>

The last website is particularly helpful because it uses the terms in-force and out-force that are also used in the activity. The instructor could also refer students to the original ABLE workshop (Glase et al., 1981) where an extensive explanation of the underlying physics principles is provided.

In the **Student Materials**, the instructor may find it helpful to enlarge Figs. 1 and 2 on a separate page to facilitate labeling. The instructor may also require additional verification that students understand the operation of the actual foot and the foot model. Students could be required, for example, to write a one-sentence description of the operation of each, incorporating the terms that are used to label the diagrams. The same type of verification could be prescribed for the question about the length of the calcaneus and foot.

Construction of the Biomechanical Models

The directions for constructing the biomechanical foot model are adapted from the 1981 ABLE directions. They are provided in the **Appendix**.

Conducting the Laboratory Exercise

The steps in the exercise and the resulting calculations can easily be completed in a 3-hour laboratory period. Before students begin the exercise, make sure they understand how to manipulate the foot model. A demonstration of how to do this is very helpful. After the demonstration, check each group to make sure they are working with the foot model correctly. The activity is designed for individual student groups to carry out each stage on their own, and then for the class to calculate averages to use in the analytical portion of the exercise. The data tables in the Student Materials are set up for this approach. Alternatively, each group can carry out the analysis with their own data. It is suggested, however, that in this approach the instructor verify that data are reasonably accurate before a group begins their analysis. In addition, changes must be made in the number and labeling of data tables.

There are a few aspects of the exercise that need the instructor's specific attention. Make sure:

- The spring scales are set to zero before students begin.
- The attachment of the spring scale on the foot corresponds with the same pulley on the top horizontal bar.
- Students keep the in-force constant at 1000 g and read the out-force.
- Students pull the strings straight down and not at an angle to the "leg".
- The foot is perpendicular to the leg when the out-force is determined.

Student groups record their data in Table 1 at the board. An easy way to accomplish this in an organized manner is to copy the table on the board, but divide each data "block" as shown below. Each group can record their data in the same position in each data "block" and avoid confusion.

A	B	C
D	E	F

Figure 5. Diagram of how student group data can be entered.

Once all the student data is recorded, ask students to study the values and look for patterns. They should observe two: values should decrease from left to right across each row; values in the top row should be larger than corresponding values in the bottom row. Any values that don't fall into these two patterns should be re-measured. The instructor may want to discuss reasons for data variability at this point. When the students establish that all the values fall into the two patterns, the class calculates an average for each foot arrangement. Averages should be rounded to the nearest whole number.

These values are entered in Table 2 in the student handout. The instructor may want to discuss significant figures at this point.

Students sometimes have a difficult time understanding the relationship between a constant in-force of 1000 g and various out-force values. A helpful analogy to use here deals with a savings account. In-force is the amount of money deposited in the account and out-force is the amount in the account after a period of time (assuming no withdrawals have been made).

Make sure the students understand the basic design of a strong foot: long calcaneus, short foot.

Two different methods are used to determine the SMA of the foot model. The first requires the measurement of the arcs drawn by the rotation of the foot at the ankle. While this is possible with the model, it is impossible to accomplish with an actual foot. Therefore, a second method is also employed. It's not necessary that students recognize the need for both methods right away.

The first step for the determination of SMA is drawing the arcs (#12) drawn by full rotation of each of the five positions of the foot model. The incorporation of a stand for the foot model makes this step somewhat difficult for students to do. An alternative to this step is for the instructor to carry out these steps on large (14 x 17) paper and photocopy the results for each student group. Before the students begin their measurements of the arcs and lever arms, they can label their diagram to correspond with Fig. 3.

If students are drawing the arcs themselves, each group should definitely record their values at the board and check for accuracy. If they are working with the instructor-provided handout, this may not be necessary. An advantage to recording the values at the board and calculating averages, however, is that ensuing discussions all refer to the same values.

Students have a difficult time understanding the relationship between the distance traveled by an end of the foot model and speed. A helpful analogy to use here deals with a marching band turning a corner (Fig. 6). The person marked X in the diagram only has to march in place when the turn is made, but the person marked Y has to be much faster than any others in the row because of the greater distance that he must cover in the same amount of time.

Another way of illustrating this is to hold a meter stick in

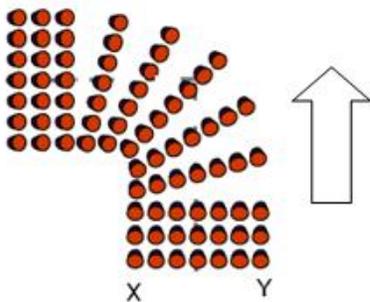


Figure 6. Diagram of marching band to use in analogy.

your fist about $\frac{1}{4}$ of the way along its length and rotate the stick vertically, using your hand as the fulcrum. Ask the students to think about how quickly the two ends of the stick move to “keep up” with each other.

The meter stick can also be used to help students to understand the underlying principle of the second method for determining the SMA. Hold the meter stick at various positions (exaggerating the distances helps), rotate it around the hand-fulcrum, and ask students what determines how fast the ends of the meter stick move. The answer, of course, is the distance from the fulcrum.

Students may run into some difficulty drawing the lines in # 17. For this reason, it might be helpful to start with group measurements and then calculate class averages.

Make sure the students understand the basic design of a fast foot: short calcaneus, long foot.

To illustrate the relationship between FMA and SMA, the students can construct a graph in Excel (or similar program) as shown in Fig. 7.

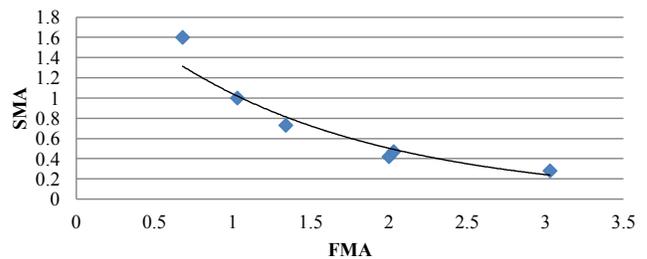


Figure 7. Relationship between SMA and MA for 6 foot arrangements

If actual vertebrate skeletons are not available for this exercise, suitable diagrams can be found in Hildebrand (1960) or online. Students frequently have difficulty making the transition to working with skeletons, diagrammatic or actual. If this is the case, ask them to locate the ankle on each leg/foot. Once that landmark is determined, the other measurements are relatively simple. Make sure they measure along the actual structural part of the foot, however, and don't measure the line that connects the two points, as shown in Fig. 8. They will be able to calculate the actual SMA of the feet.

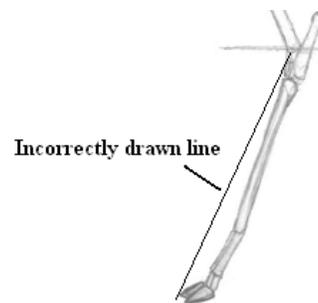


Figure 8. Illustration of incorrectly drawn line on diagram of deer leg.

Sample Data

The numbers in the tables correspond with the numbers in the **Student Materials**.

Table 2. Sample out-force values.

Gastrocnemius insertion position	Out-force measured at various positions (g)		
	3	4	5
1	1600	730	420
2	1000	470	280

Table 3. Sample data for FMA for six foot arrangements.

Gastrocnemius insertion position	FMA calculated at various positions		
	3	4	5
1	1.60	0.73	0.42
2	1.00	0.47	0.28

Table 5, 7. Sample data for six foot arrangements

Position	Gastrocnemius contraction distance (cm)	Length of effort arm (cm)
1	$M_1 = 5.3$	$D_1 = 7.7$
2	$M_2 = 3.5$	$D_2 = 5.1$
	Distance moved by distal end of bone (cm)	Length of load arm (cm)
3	$B_3 = 3.6$	$D_3 = 5.2$
4	$B_4 = 7.1$	$D_4 = 10.3$
5	$B_5 = 10.6$	$D_5 = 15.3$

Table 6. Sample data for SMA for six foot arrangements.

Gastrocnemius insertion position	SMA calculated at various positions		
	3	4	5
1	0.68	1.34	2.00
2	1.03	2.03	3.03

Acknowledgments

I am indebted to the authors of the original ABLE activity, which I have used for over 20 years.

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Appendix

We modified the design of the biomechanical foot model from the original (Glase et al., 1981):

- Because it was difficult to use the model when it was lying flat, we constructed a wooden platform in which the foot model can be stood up.
- Because the eyelet screws in the top bar introduced substantial friction, we replaced them with small pulleys.
- The original directions called for paperclips to attach the spring scales to the eyelet screws. We find that these are not necessary and connect the spring scales directly with the eyelet screws on the foot.

The biomechanical foot model has three parts: the biomechanical foot, the brace, and the platform.

Constructing the Biomechanical Foot

The three components—the foot, brace support, and platform—are constructed separately and then assembled. See below for supplies needed, separate instructions for constructing the three components, and instructions for final assembly.

Supplies Needed:

- 4 ft section of 1 x 3 in standard stock pine board. (Although the dimensions of the stock are given as 1 x 3 in and are referred to as such by suppliers such as Home Depot, Lowe's, and lumber yards, the actual dimensions are $\frac{3}{4}$ in x 2 $\frac{1}{2}$ in.)
- 8 ft section of 1 x 4 in standard stock pine board. (Again, actual dimensions are $\frac{3}{4}$ in x 3 $\frac{1}{2}$ in.)
- (5) 1 $\frac{1}{4}$ in galvanized roofing nails
- (5) plastic pulleys. (Various sizes of pulleys suitable for this application can be purchased from Ward's Natural Science, catalog # SB28836M.)
- Drywall Screws
 - (2) 1 in
 - (11) 1 $\frac{1}{4}$ in
 - (6) 1 $\frac{1}{2}$ in
 - (4) 2 in
- (6) 1 $\frac{1}{8}$ in eye screws
- (1) 1 $\frac{1}{2}$ x $\frac{1}{4}$ in lag bolt, with nut and washer
- (4) rubber feet, $\frac{3}{4}$ in diameter, with $\frac{1}{2}$ in, x # 10 panhead screws

We estimate the cost of materials for each biomechanical foot model would be ~ \$15.00 (excluding the spring scales). The spring scales are available for ~ \$10.00 each from

<http://www.learningresources.com/product/spring+scales-+1000+g+-+2.2+lb.do?sortby=ourPicks&sortby=&&from=Search>.

Constructing the Foot

The pulley bar and movable foot are both 10 in long; the leg is 16 $\frac{3}{4}$ in. A 2 $\frac{1}{2}$ in wide x $\frac{3}{8}$ in deep section is cut from one lateral side of the pulley bar, 2 $\frac{1}{2}$ in from one end (Fig. 9).

Five pulleys are attached to the opposite lateral side of the pulley bar using galvanized roofing nails, $\frac{3}{4}$ in from the top edge of the board and in the positions shown in the diagram. Pre-drill the holes so that the nails do not split the wood of the pulley bar. It may be necessary to drill out the center holes of the pulleys somewhat, to easily accommodate the nails so that the pulleys will turn freely. The tips of the nails will protrude through to the opposite side of the pulley bar. File these tips down flush with surface of the wood using a metal file.

The front surface of the bottom 3 in of the leg is cut out to a depth of $\frac{3}{8}$ in. The lower end of this cut-out section is then symmetrically tapered from its initial width, starting 2 $\frac{3}{16}$ in above the bottom of the board, to a width of $\frac{3}{4}$ in at the very bottom. Round off the lower corners of the taper. See Fig. 10. Drill a $\frac{1}{4}$ in diameter hole through the wood, centered laterally within the taper and 1 $\frac{1}{4}$ in from the end of the board. Use (2) 1 in drywall screws to attach the pulley bar to the top of the leg, so that the top of the leg is flush with the top of the pulley bar in the cut-out section.

The 10 in board used for the foot has holes drilled in it at a height of $\frac{3}{4}$ in from the bottom edge of the board and the following distances from the “heel” end of the board: $\frac{1}{2}$ in, 1 $\frac{1}{2}$ in, 5 $\frac{1}{2}$ in, 7 $\frac{1}{2}$ in, and 9 $\frac{1}{2}$ in. (Fig. 11). To allow mobility of the movable foot in the ankle region, a $\frac{3}{8}$ in-deep, V-shaped groove is cut from the back surface of the foot, as shown in Fig. 12. Note that the angles of the groove are not symmetrical, with a slightly wider angle facing the toe portion of the foot (30°) and a slightly lesser, steeper, angle facing the heel portion (20°) (Fig. 13). A $\frac{1}{4}$ in hole is drilled through the face of the foot, vertically centered within the tapered groove and 1 $\frac{1}{4}$ in from the bottom of the board. Five 1 $\frac{1}{8}$ in eye screws are placed $\frac{5}{8}$ in directly

above each of the five drilled holes in the foot. An additional $1\frac{1}{8}$ in eye screw is placed in the bottom edge of the board, in the center of the section corresponding to the bottom of the tapered V-groove. Attach the foot to the bottom of the leg using the $\frac{1}{4}$ in lag bolt, washer, and nut, with the head of the bolt at the back surface of the leg-foot connection, as also shown in Fig. 13. The biomechanical foot, with its three components, is now complete.

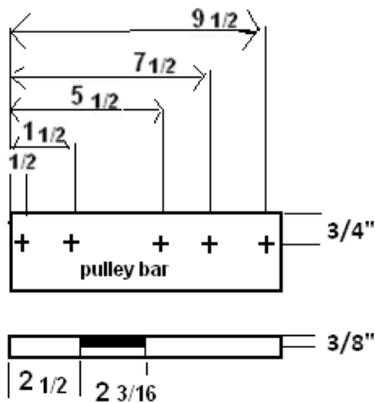


Figure 9. Diagram of how to prepare the pulley bar of the biomechanical foot model. The portion shown in solid black is cut out.

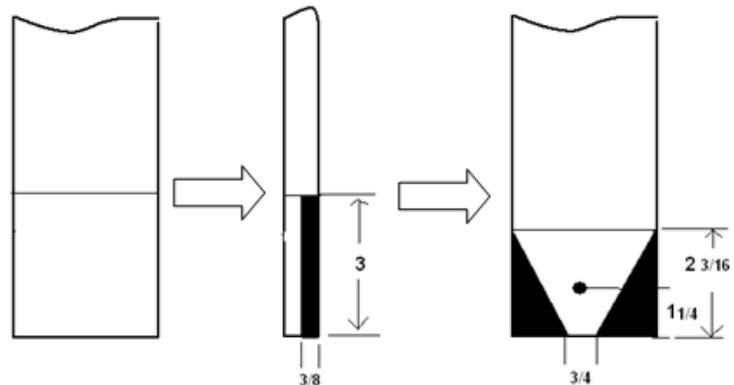


Figure 10. Diagram of how to prepare the leg of the biomechanical foot model. Only the distal portion of the leg is shown. The portion shown in solid black is cut out.

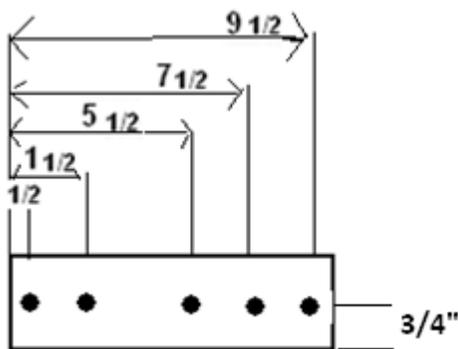


Figure 11. Diagram of placement of holes in movable foot.

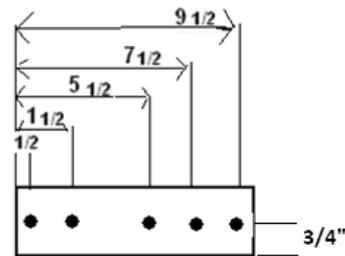


Figure 12. Diagram of removal of portion from back of movable foot. The cut-out portion is shown in black.

Constructing the Brace and Platform

The component pieces of the brace and platform are cut from 1 in x 4 in board. Sections for the brace are 13 in, 6 in, and $5\frac{3}{8}$ in long. The three pieces of the brace are assembled with (5) $1\frac{1}{4}$ in drywall screws as shown in Fig. 14. The leg is then attached to the brace with (3) $1\frac{1}{4}$ in drywall screws, as shown in Fig. 15.

The platform consists of six sections of 1 in x 4 in board cut to the following lengths: two 12 in, two $9\frac{3}{4}$ in, one $4\frac{5}{8}$ in, and one $1\frac{5}{8}$ in. Attach boards F, G, H, and I as shown in Fig. 16, using (4) 2 in drywall screws, in the pattern shown, sandwiching boards H and I between F and G according to the dimensions in the diagram. Attach the resulting assembly to boards D and E, using (6) $1\frac{1}{2}$ in drywall screws, in the pattern shown in Fig. 16. Attach the rubber feet to the bottom surface of boards D and E, centered about $\frac{3}{4}$ in from the ends of the boards, using the $\frac{1}{2}$ in x # 10 panhead screws supplied with them.

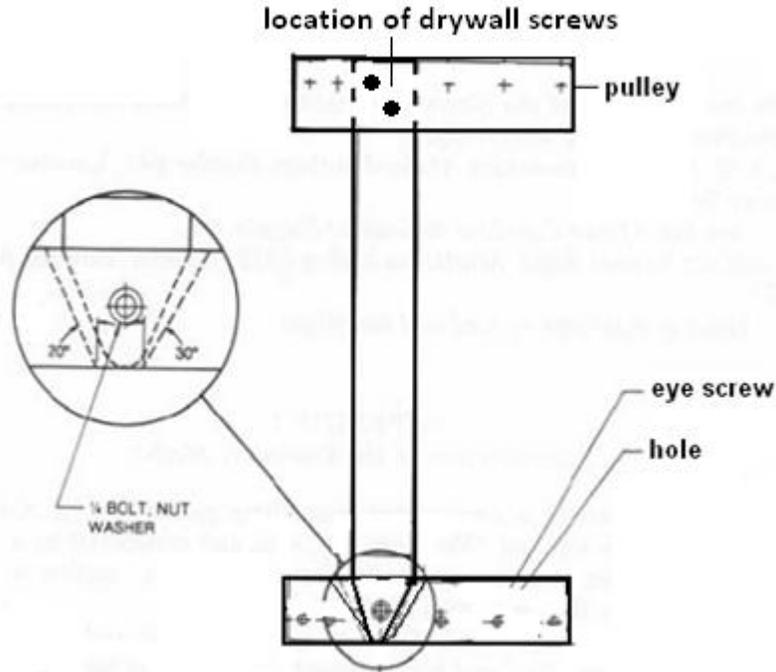


Figure 13. Diagram of how to prepare the movable foot of the biomechanical foot model and attach it to the leg.

Assembling the Completed Parts

Use (3) 1 ¼ in drywall screws to attach the completed foot model to the completed brace, as shown in Fig. 15. The foot model/brace assembly is then simply inserted into the gap located in the center of the completed platform, pushing the vertical board of the brace squarely and fully into the gap until it bottoms out. The foot model/brace assembly can be removed from the platform to facilitate easier storage when not in use.

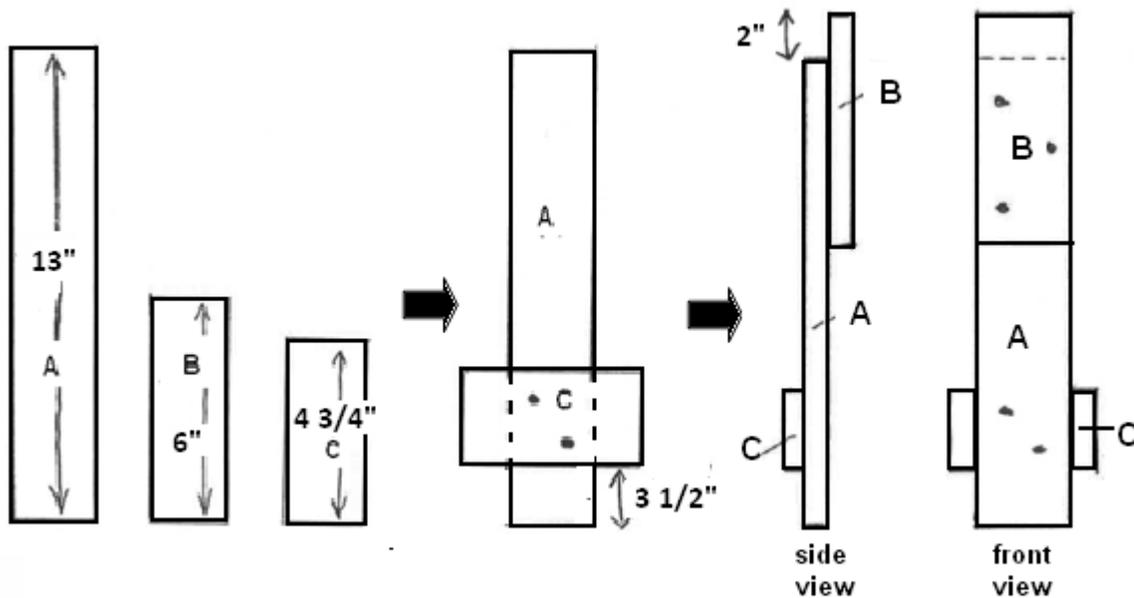


Figure 14. Diagram showing assembly of the brace.

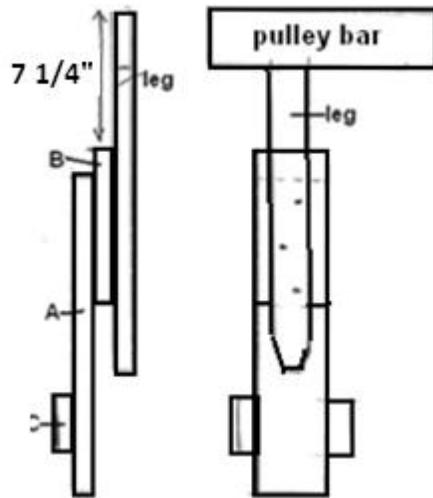


Figure 15. Diagram showing attachment of leg to brace. To simplify the view, the movable foot is not shown.

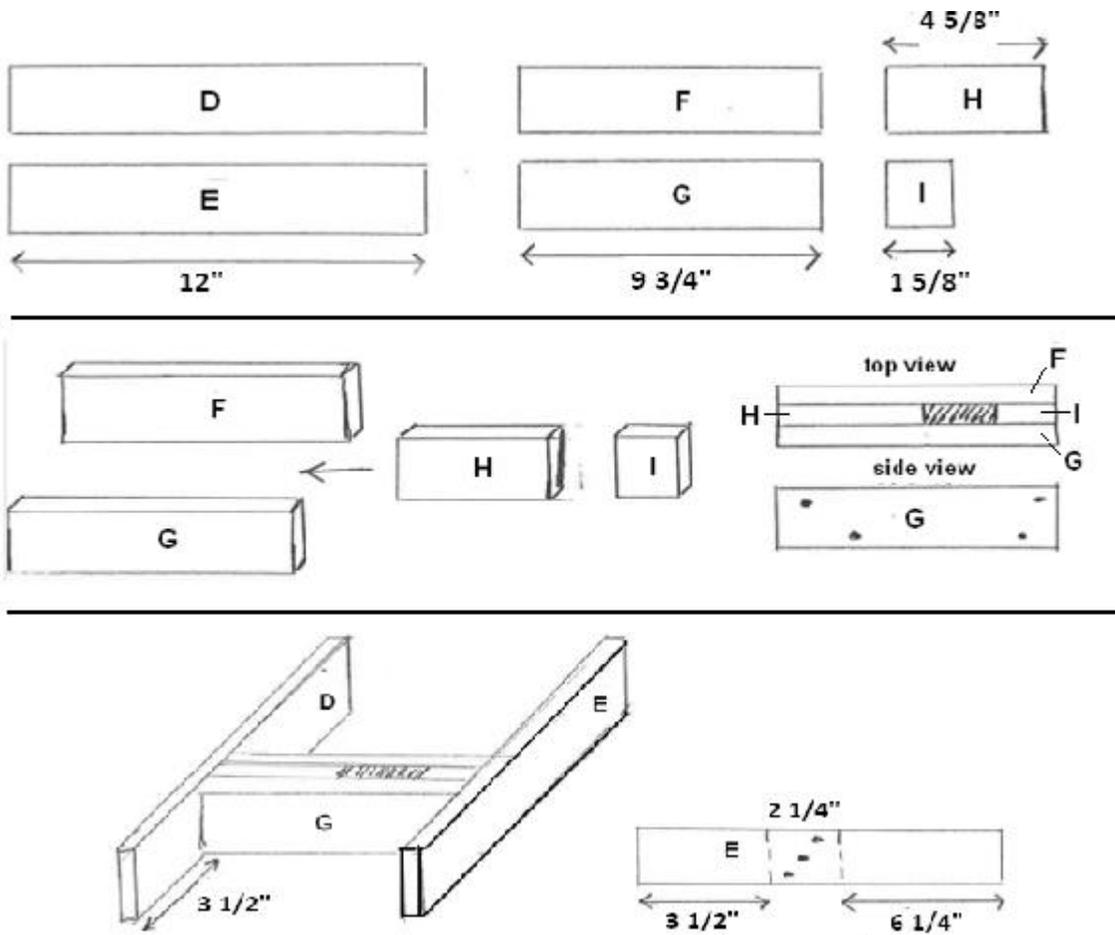


Figure 16. Diagram showing assembly of the platform.

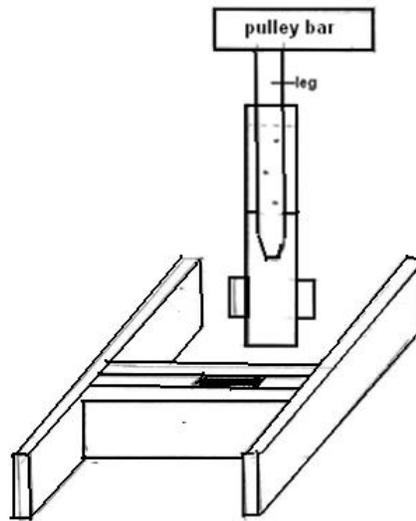


Figure 17. Diagram of assembly of entire biomechanical foot model.

The schematic for construction of the biomechanical foot model (without the brace and platform) as shown in Glase et al. (1981) is shown in Fig. 18.

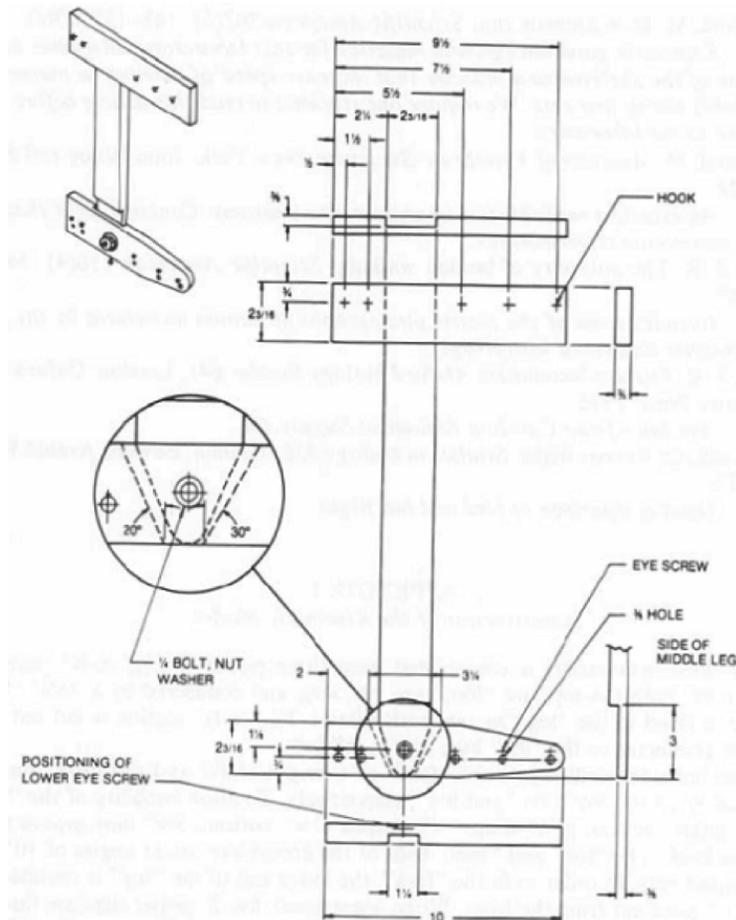


Figure 18. Diagram of foot model as shown in Glase et al. (1981).