Biceps Muscle Model

Introduction

This lab will begin with some warm-up exercises to familiarize yourself with the theory, as well as the experimental setup. Then you'll move on to the experiment itself.

Rather than giving you explicit steps to follow at every stage, at times we'll provide you with a problem to investigate and some hints on how to proceed. It will be something of a challenge to figure out how exactly to accomplish each step, but this will be much more like doing science in the real world. We hope you enjoy the process!

Learning outcomes

By the end of this lab, you will be able to:

i. Describe how torque depends on applied force and distance of force from pivot point.

ii. Understand that angle at which a force is applied affects the applied torque.

iii. Use concepts of torque to understand aspects of the human arm.

iv. Relate the biceps muscle force to weight lifted by the hand.

v. Extrapolate a linear model from experimental data

vi. Use experimental results and critical thinking to make predictions about future results

Warm up exercises

Warm up I: Torque

Before you start the main portion of the lab, here are some warm up questions to introduce you to the key concept of torque.

1. A 60 kilogram parent sits on a seesaw, 1 meter to the right of the pivot (as pictured in figure 1). How far to the left should a 30 kilogram child sit in order to balance the seesaw?

   If you're unsure how to approach this problem, try to answer it intuitively. Perhaps you can give a range of possible values?

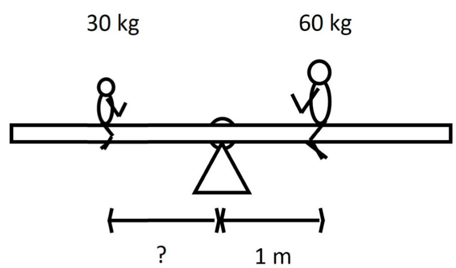


Figure 1: Diagram for warm up problem 1.

2. Now reconsider the previous problem in light of a more formal introduction to torque:

   The torque of each person about the pivot point is the product of the person's weight and the distance of the person (strictly speaking, the person's center of mass) from the pivot. The sign of the torque is positive if it would cause a counterclockwise rotation of the seesaw. The net torque is the sum of the individual torques from each person. To remain at rest, an object like this seesaw must have zero net torque acting on it.

   If you didn't use quantitative reasoning in your answer to the previous problem, go back and do so now.

3. Consider now a slightly modified seesaw setup (pictured in figure 2), with a child of weight W sitting a distance L to the left of the pivot. This time, the seesaw is balanced by the pull from a vertical rope, attached at a distance r to the *left* of the pivot. Assume that $r < L$, meaning the rope is attached between the child and the pivot.

   (a) Before doing any calculations, make a prediction. Do you think the force F will be larger, smaller, or the same as the child's weight W?

   (b) Now do the calculation: Express the upward force F exerted by the rope in terms of W, L, and r.

   (c) Finally, evaluate your prediction in light of the previous result. Remember that r is always smaller than L. Was your prediction correct? If not, are you surprised by this result?

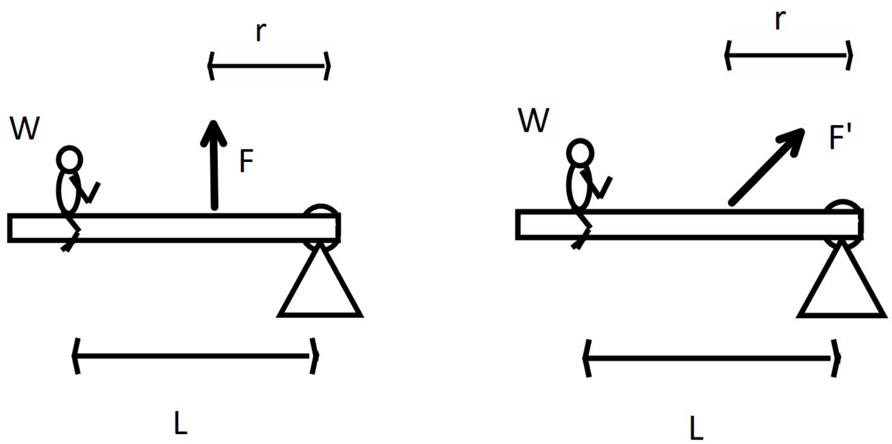


Figure 2: Diagrams for warm up problems 3 (left) and 4 (right).

4. Finally, imagine that the rope balancing the seesaw is at an angle, rather than being vertical (pictured in figure 2). Does the magnitude of this new force F' need to be larger, smaller, or the same size as the previous (vertical) force F in order to balance the seesaw?

   Hint: Remember that the force F' acts along the direction of the rope.

Warm up II: The apparatus

Before we get into equations, take a moment to understand the equipment.

1. (a) Label **both** the photograph of the experimental apparatus below and the anatomical drawing of the arm beside it with the following labels:

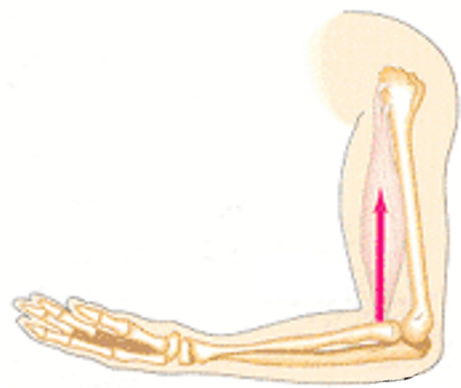
   - upper arm (humerus)
   - elbow
   - forearm
   - hand
   - biceps muscle

   Hint: If you're confused where to start, know that the horizontal bar on the apparatus models the forearm.

   (b) Now compare the photograph of the apparatus with the anatomical drawing. How are they similar and different? Do you think the experimental apparatus does a good job approximating the features of the human arm and biceps muscle? (Be sure to record your group's response to this question, realizing that there's no right or wrong answer.)

2. Label the free body diagram below with the following forces and distances:

   - r: The distance between the elbow and the point where the biceps muscle attaches to the forearm
   - R: The distance between the elbow and the hand
   - H: The force the hand (and anything it's holding) exerts on the forearm
   - B: The force the biceps muscle exerts on the forearm
   - W: The force due to the weight of the forearm, which acts on the center of mass of the forearm (already labeled on the diagram)
   - θ: The angle between the forearm and the direction of the bicep force (already labeled on the diagram)



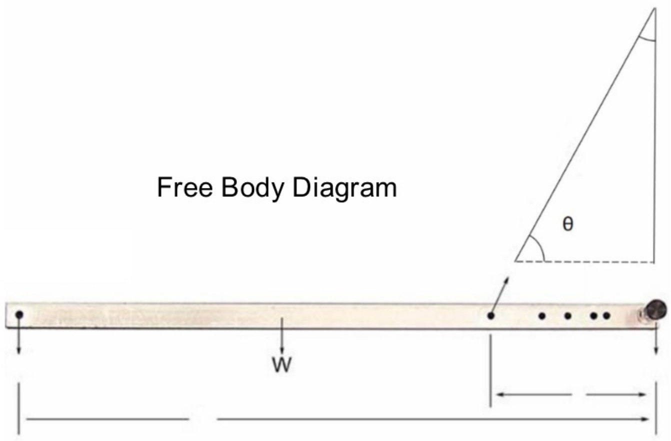
Initial Setup

Before we begin the experiment, we need to ensure the biceps muscle scale is correctly calibrated, as it is common for the scale to become miscalibrated after several lab sections.

1. Remove the forearm bar from the apparatus, so nothing is hanging from the biceps muscle scale.

2. Hang a 1 kg mass from the biceps muscle scale (making sure to use the keeper ring to prevent the mass from falling off).

   If the scale does not read 1 kg, you need to recalibrate it. Do so by turning the 'knurled ring'



at the top of the force scale, in the direction that increases or decreases the force reading as needed, until the scale reads 1 kg.

3. Do not adjust the knurled ring for the remainder of the experiment.

Procedure

Every time a person lifts a weight, throws a ball, or turns a page, there are forces involved throughout the muscular and skeletal systems. We wish to investigate just one example of those forces. Specifically, we'll examine the situation where you're holding a weight in your hand, with your forearm being held horizontal. We'll measure the forces exerted by the biceps muscle.

If you'd like, imagine yourself as a physical therapist or prosthetic limb designer, who wishes to combine physics with some general experimental design skills to determine some of the forces involved in lifting objects.

As we said before, you'll be given quite a bit more freedom in this lab. Part of that means you'll have to think critically about which steps you'll be taking, and you'll have to examine your results to check whether they seem reasonable. When you're making decisions like this, think back to some of the things you've done in the previous labs – many of those choices were made for good reasons, and represent good experimental practices.

1. **In everything that follows, make sure the forearm bar is horizontal.** We're focusing on this case (1) because every experiment needs to focus on specific scenarios in order to make meaningful conclusions, and (2) because keeping the forearm horizontal vastly simplifies both the measurements and the calculations.

2. Before you begin taking data, measure the experimental parameters of your apparatus. That is, measure and record the values of r, R, and W.

Furthermore, if you ever change any of these values in what follows, be sure to measure and record the new value(s).

Note that for the first several steps, you'll be keeping r fixed. It's up to you to choose whichever initial value for r you'd like, but we recommend starting with a fairly large r.

3. Start by measuring the biceps force B for some fixed weight H being held in the hand. Make sure to record this value (with units). Note that the force gauges are labelled with units of mass (kilograms) rather than units of force (Newtons). You need to multiply the mass readings by $g = 9.8\,\mathrm{m/s^2}$ to convert the mass values to their corresponding *weight* values. Note that you may wish to first just record the mass values, and convert to weight using Excel.

$$B = \Big(\text{Biceps gauge reading (in kilograms)}\Big) \times g$$

After doing this, B and H should both be recorded in units of force.

Note: H corresponds to the weight held by the hand – that is, the weight hanging off the forearm bar. It does *not* include the weight of the forearm, which is separately accounted for in W. (W, in turn, does not include the weight held by the hand.)

4. Now devise and carry out a procedure for measuring (and recording) the force B for different weights H. Make sure to explicitly write out the steps of the procedure. If you find you need to modify the procedure as you carry it out, that's okay – but be sure to change the written version to correctly reflect the steps you really carried out.

5. After taking several measurements (you can choose a number which seems reasonable), use your data to extrapolate a relationship between the biceps force B and the weight H in the hand: First, argue that your data shows a linear relationship between B and H. Then, write an explicit formula for B as a function of H. *Hint: In case this terminology is a bit unfamiliar, it might help to know that* $y(t) = \Big(10\,\mathrm{m}\Big) - \Big(4.9\,\mathrm{m/s^2}\Big)t^2$ *is an example of an explicit formula for y as a function of t (for a certain physical situation).* Make sure you specify the units of all quantities involved. Hint: You've performed similar steps in previous labs. Think back to any time you graphed your data and fit a trendline to the graph.

6. Choose a new value for H – one that you haven't measured yet, but that you are able to measure. Before you measure B, use your model to predict the biceps force B for this new value of H.

7. Now use the apparatus to measure B for this value of H. How does it compare to the prediction from your model? (Calculate the percent deviation.) If the two values don't exactly agree, do you think this is okay? Do you think it tells us our model is wrong? Why or why not?

8. Is your formula for B as a function of H consistent with the concepts of torque explored in the warmup problems? Why or why not?

Varying model parameters

Now that you've gained a bit of familiarity with the apparatus by taking some measurements, let's take a step back and think a bit more about what's going on.

9. Using a combination of your intuition for how your own arm works, and the knowledge of torque you developed in the warm up exercises, predict how the biceps force change when we increase each of the following parameters.

Fill in your own copy of the charts below, answering with "increases", "decreases", "stays constant", or "something else". (If you choose something else, explain why you chose that.)

Parameter change	Effect on B
$\uparrow R$	
$\uparrow W$	
$\uparrow r$	

10. The way our apparatus is set up, the easiest of the above parameters to vary experimentally is r. Devise and carry out an experiment to determine the effect that increasing r has on the biceps force B. Make sure to record the data that leads you to this conclusion. Do your results agree with your prediction in part 9?

Comparing results to theoretical predictions

In a previous step above, you experimentally determined a formula for the biceps force B as a function of the weight H in the hand. Now we'll compare this model to the one the theory predicts.

It turns out that we can analyze the torques acting on the forearm to determine a formula for B vs H. You actually have all the tools needed to do this from the warm up exercises at the beginning of this lab, and we encourage you to give it a try! But in the interest of time, we'll just provide you with the formula, which is as follows:

$$B = \left(H + \frac{W}{2}\right)\frac{R}{r\sin\theta}$$

11. Now that we have this theoretical model, we can use it to predict what the slope and vertical intercept of your graph of B vs H should be. First, use the theoretical model to predict the slope and vertical intercept of your graph in terms of symbols (i.e., variables) only. Next, plug in the actual parameter values that correspond to your experimental apparatus to get a numerical value for these theoretical coefficients (with units!). How does this prediction compare with your actual slope and vertical intercept?

Note: If you need to find the angle θ, you can do so by measuring two sides of the right triangle formed by the upper arm, the forearm, and the biceps muscle. You can then use the appropriate inverse trig function to find θ.

12. Using the formula above for B as a function of H, revist your predictions from part 9. That is, argue whether the formula given to you above agrees or disagrees with the predictions you made before.

Wrapping up

13. Note: This problem involves a bit of reading, but it should help you understand the importance of a key concept, which will help you on your homework and exams.

Imagine you and a friend wanted to predict the biceps force by directly analyzing the torques involve in the apparatus. You and your friend determine that the experimental parameters for your apparatus are $R = 50\,\text{cm}$, $r = 25\,\text{cm}$, $W = 2.5\,\text{N}$, $H = 2.5\,\text{N}$. Your friend attempts to use the theoretical model to predict the value of the biceps force. He claims that the torque exerted by the biceps must be equal and opposite to the torque exerted by the weight in the hand plus the weight of the arm itself, which is equal to $HR+WR/2$, in the counter clockwise direction. Furthermore, your friend claims that the torque due to the biceps is Br, in the clockwise direction. Since the torques must be equal and opposite, we have $Br = HR+WR/2$.

You read the biceps gauge and find it reads about 0.85 kilograms. Solve the equation above for B, and plug in the values of the experimental parameters given above. Does the resulting value for B agrees with the measured biceps force?

If your prediction is not consistent with the experimental result, go back and figure out what was wrong with your friend's argument above.

Was there a key torque concept your friend forgot to take into account?