Rewritten Biceps Lab

LEGEND:
* [Black text] – Regular text
* Question or action the students need to take (Mostly for ease of instructor understanding)
* Tip for TAs or answer to student question. Will be removed from student version of the lab.
* [These green or orange boxes] – comments on what needs to be done, etc. Not part of the lab for students.

Overall TODO list: (In addition to items scattered throughout the text)
* **Just tell them the model is linear**

Introduction

This lab will be different from the others you've done so far. First, we'll have some warm-up exercises to familiarize yourself with some of 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

Warm up I: Torque

Note: These questions would probably work better if the students could actually perform some of these mini-experiments. I'm planning to talk to those in charge (not Marty, but others) to ask whether we have the materials needed to investigate the balance of torques on a simple lever-fulcrum system (like the one in the `https://www.dropbox.com/sh/i3iftgdflca6yj0/AAA37zsDuMN591__i-oPnjiSa/Suite\%20II/Instruction/Student_Materials/01_Torque/Tutorial_01_Torque.doc?dl=0` open source tutorial activity). **Such an apparatus will not be available this quarter, but it may work for next quarter** – depending on the resources already in place.

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. How far to the left should a 30 kilogram child sit in order to balance the seesaw? If you haven't seen this type of problem before, try to answer it intuitively. Perhaps you can give a range of possible values?

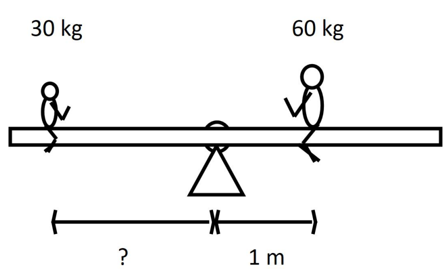


Figure 1: Diagram for warm up problem 1.

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, 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. Express the upward force F exerted by the rope in terms of W, L, and r.

4. Finally, imagine that the rope balancing the seesaw is at an angle, rather than being vertical. Knowing the force balancing the seesaw acts along the rope, does the magnitude of this new

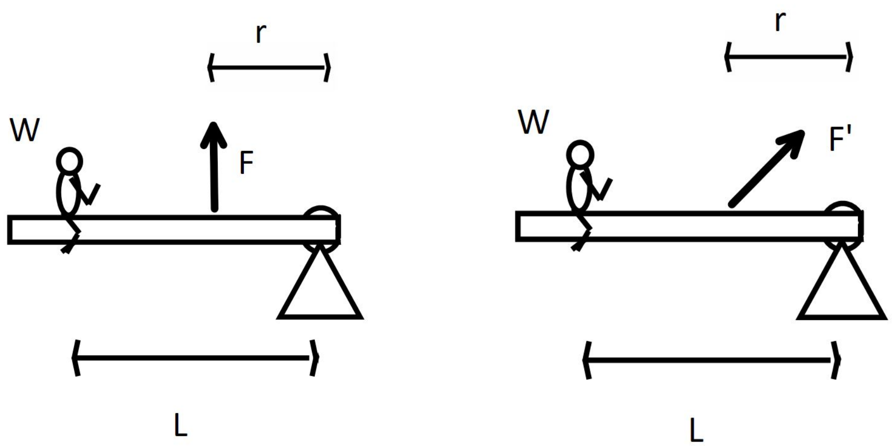


Figure 2: Diagrams for warm up problems 3 (left) and 4 (right).

force F' need to be larger, smaller, or the same size as the previous (vertical) force F in order to balance the seesaw?

Warm up II: The apparatus

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

1. Label the photograph of the apparatus below with the following labels:

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

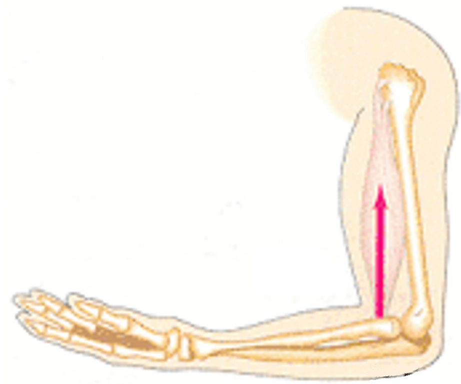
    Be sure to reference the anatomical picture of the arm in case any of these features of the apparatus are unclear.

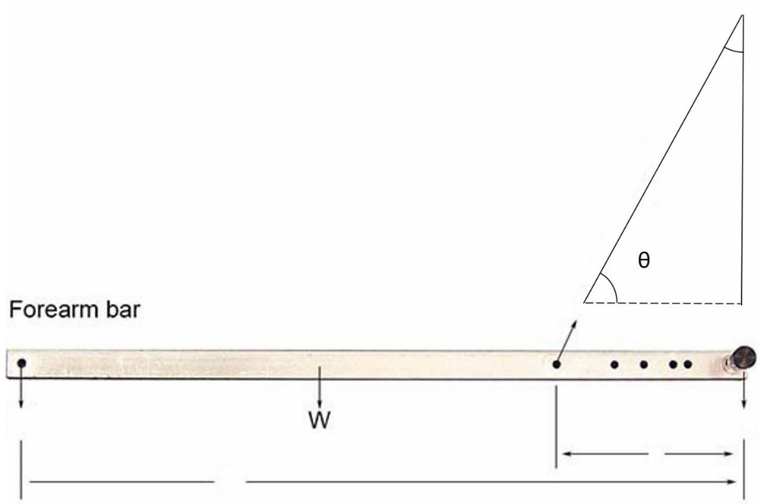
2. Label the free body diagram below with the following forces and distances:

    - 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
    - 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)





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).

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.

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

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.

The idea is that they need to realize to make a graph to do this. Then they just need to fit a trendline to the data, and realize the 'formula' is just the equation of the line.

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.

Before you move on to the next step and make the measurement, have your TA approve your prediction and reasoning.

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?

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.

8. 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
$\uparrow R$	
$\uparrow W$	

Parameter change	Effect on B	Effect on value of B when $H = 0$	Effect on $\Delta B/\Delta H$
$\uparrow r$			

Consider two of the quantities above, (a) the value of B when $H = 0$ and (b) $\Delta B/\Delta H$. Do either or both of these quantities correspond to the slope and/or vertical intercept of your graph?

9. 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 as well as on the slope and the vertical intercept of the graph. Make sure to record the data that leads you to this conclusion. Do your results agree with your prediction in part 8?

They should choose a new value for r, then re-enact their procedure to determine $B(H)$ for this new r value. **It might be difficult for them to realize that they don't want to find** $B(r)$ – doing so does answer the first question, but it doesn't tell them anything about the slope or the vertical intercept.

Subtlety: Changing r changes the angle as well. It might be worth TAs mentioning this to students, but note that it shouldn't really affect their answers much, at least for the values of r allowed by the apparatus.

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:

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

10. Now that we have this theoretical model, we can use it to predict what the slope and vertical intercept of your graph 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?

Do the theoretical predictions above agree with the predictions you recorded in the chart above, regarding how the biceps force and linear equation parameters change when increasing certain apparatus parameters?

Wrapping up

11. 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 $R = 50\,\text{cm}$, $r = 25\,\text{cm}$, $W = 250\,\text{g}$, $H = 250\,\text{g}$. 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 he forgot to take into account? Your friend forgot to consider the angle at which torque is applied. Note: I predict some students will try to replace r with $r/2$, since that's what it might look like is done for W. **The key torque concept** your friend forgot was to consider **the angle at which the force is applied**.