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 verstion 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)

More practical considerations

* Actually write the warm up problems
* Replace α with $90° - \theta$, and add θ to diagrams, in order to emphasize connection to the angle usually referenced in torque calculations.
* **Just tell them the model is linear**
* Consider guiding students through derivation of B vs H equation. (Note that there's a question at the end which almost gets there, and requires students to think critically about the derivation.)
* Supplement pictures of apparatus with biological pictures. Possibly ask students to do fill-in-the-blanks for both sets of pictures.
* Ask students to estimate the 'experimental parameters' associated with their own arms. Maybe ask how the force compares for someone with a shorter arm. R, r, W all smaller, H, θ remain the same. Less torque due to bicep, but also less torque due to hand force and weight of arm. If r and R decrease in proportion, it takes the smaller person slightly less biceps force to lift the same amount of weight.

More on the meta side

* Be careful (and consistent) with word choice. E.g.: parameters, models, formulas.
* Think about specific learning outcomes
* Think about how well lab accomplishes learning goals/outcomes
* Make the procedure easier for students to read – break into numbered bullet points
* Consider creating sample sheet on which to write data, or just a list of all the specific tasks the students need to perform. Note that this list might work well while I'm overseeing this lab, but future TAs will likely want to modify it.

(Rough) **Learning goals** – gain familiarity with/understanding of the following:
* Basic static torque – distance and magnitude of force
* Angle in torque – make sure to really emphasize this
* Torque applies to human arm
* Biceps force is linear in force on hand
* Emphasis on what a linear model looks like
* Understad what it's like to apply a theoretical model to a complicated real-world situation (like a human arm). Understand that this will [always] be an approximation, and that we need to figure out how good an approximation our model is.

Comment from Shanna: Add these to main text:
"By the end of this lab, you will be able:
1. Describe how torque depends on applied force and distance of force from pivot point.
2. Determine how angle of applied force increases or decreases applied torque
3. Use concepts of torque to understand aspects of human arm.
4. Relate bicep muscle force to weight lifted by hand.
5. Extrapolate linear model to make predictions?
6. Recognize the benefits and limitations of a applying a basic physics model to a real-world situation (like a human arm)."
Adjust wording to reflect what was in lab learning outcomes document, if possible. Only include those that explicitly ask the student to show these by answering a question.

Some notes on word choice:
Still deciding
* Experimental parameters
* Parameters vs coefficients in equations
* Formula vs equation vs function
* Apparatus vs experimental setup
* Real world situation vs application vs ?

Decided upon (though subject to discussion)
* 'Model' will always refer to a mathematical model. Distinguish between experimental models [experimentally determined models] and theoretical models
* Vertical intercept, vs y-interecept or B-interecept

Introduction

Comment from Shanna: Recommend emailing students in advance to get them excited. :) Add something like "Because it generally takes longer to devise your own steps, you will notice this lab has significantly fewer parts."

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!

Warm up

Comments on warm up:
* Assume students don't know anything about torque (it's very likely they won't know anything)
* Give activity which guides them through torque
* Possibly just take from open source tutorial
* Ok, open source tutorial requires them to do experiment that we don't have resources set up for (though we could relatively easily set them up, especially in a future quarter)

Comment from Shanna: Mastering physics may have a good activity

Warm up I: Torque

A lot of these problems can be taken with minimal modification from the UMD open source tutorial on torque (and the corresponding HW assignment) [click colored text for links], which focus on static torque , especially on things like levers

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 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.

Outline of some warm-up questions

1. Balancing weights on a ruler atop a fulcrum
   a. Two equidistant weights on opposite side of pivot
   b. Double one weight's distance; ask how much weight needs to be added and to which side
2. Replace one of the weights with an arbitrary force pointing downward
3. Replace arbitrary force with a cable at an angle (positioned like bicep)

Need to figure out how to introduce quantitative relations
* $\tau \sim rF$ (for orthogonal force)
* $\tau \sim rF \sin\theta$

Ideally, we'd have a simple mini-experiment for them to play with, to help this introduction to torque. This is almost certainly possible for a future quarter.

Comment from Shanna: Make two versions of this lab – for this and next quarter

Warm up II: The apparatus

Before we get into equations, take a moment to understand the equipment. Fill in the blanks on the diagram below, from among the following choices: upper arm (humerus), elbow, forearm, hand, and biceps muscle.

TODO – Block out the labels in the picture of the apparatus, and replace with blanks – similar to a diagram one might fill in for a biology course. Blanks include upper arm (humerus), elbow, forearm, hand, and biceps muscle.

Do something similar for extended free body diagram (?)

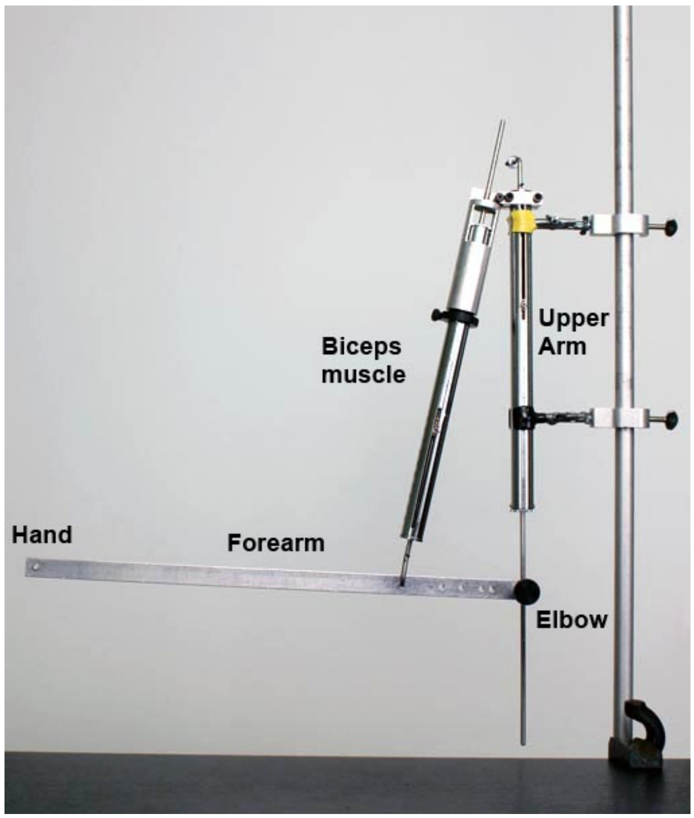
Comment from meeting:

- Have them fill in the same diagram with forces and distances, given a description of those forces/distances in words.

  They'll be given a rectangle with some holes, and diagonal lines to give the appropriate angle for the upper arm and biceps

  Have W on diagram already, mentioning center of mass

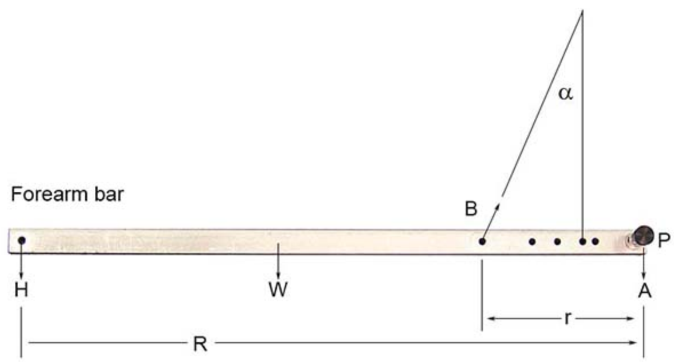
  Label θ already
- Fix pivot point in diagram (doesn't currently line up)



Potential question for students:

Comment from Shanna: Probably not worth the confusion this will cause. Just tell them how to deal with the scale as is.

The biceps force gauge is labeled in kilograms. Strictly speaking, does this make sense? In particular, would this be correct if we used the gauge on the moon? What units should the scale be labeled with instead? Can you think of any reasons why it might be useful to have the scale labeled in kilograms?


α
Forearm bar
B
P
H
W
A
r
R

Procedure

We wish to investigate some of the forces involved with weight lifting. 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.

TODO: Common sense warning about using reasonable values, making sure to keep everything but the thing you're measuring constant, etc.

TODO: Make sure to emphasize that we'll keep the forearm horizontal, to simplify things.

Start by measuring the biceps force B for some fixed weight H being held in the hand.

Comment from Shanna: Tell them to record the values.

Then devise and carry out a procedure for measuring the forces 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.

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.

Comment from Shanna: Remind them "You did this in the XX lab"

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* $y(t) = \left(10\,\mathrm{m}\right) + \left(4.9\,\mathrm{m/s^2}\right)t^2$ *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 the quantities. The idea is that they need to realize to make a graph to do this. Then they need to notice that the graph is linear, so the 'formula' is just the equation of a line.

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.

Comment from Shanna: "Before you make the measurement, have your TA approve your prediction and reasoning."

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

TODO: Expand this prompt

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 chart 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	Effect on slope of graph	Effect on vertical intercept of graph
$\uparrow R$			
$\uparrow r$			
$\uparrow W$			

Comment from meeting:

- Replace slope with "$\Delta B/\Delta H$" and intercept with "value of B when $H = 0$".
- Ask them whether these quantities correspond to anything on their graph

We're implicitly telling the students here that the data should be linear. This is perhaps not ideal, but it makes questions like this one much less awkward and much more straightforward.
Liz pointed out that nonlinear graphs still have slopes and intercepts, so technically we're not giving linearity away completely. At least not yet.

Consider having students come up with their own ideas of what parameters to vary. Maybe only provide 3 lines. Note that they might have trouble coming up with parameters other than r. (Hopefully r will be easy.)

The way our apparatus is set up, The easiest of the above parameters to vary is r. Devise 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. 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 α as well. This might be worth a footnote (or mills), but I won't lose any sleep over it, and it won't much affect the data. **If we really want to emphasize the importance of the angle at which the force is applied, we probably want to address this more than is already done.**

Understanding model parameters

Ideally we'd have enough time to guide the students in deriving this formula, but this isn't out main goal for the lab. Hopefully we'll still give them some intuition for the formula.

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:

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

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

- 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 $R, r, W, H = ...$]. 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 2 kilograms. Solve the equation above for B, and plug in the values of your experimental parameters. 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. Redo the calculation of the prediction correctly, and verify that it agrees with your experimental result.

  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**.

  Comment from meeting:
  - Don't even need to have them redo the caluclation. Just need them to realize they forgot the angle.
  - Let them know this analysis will help them on the test.

  Give explicit numerical values for R, r, W, H. including a large value of r, so $\cos\alpha$ is small.

- Why do we bother doing this experiment, when we have the theory of torques and forces to explain the experimental situation for us? Because the theory doesn't account for everything – it's just an approximation to the real-world situation. This is especially true for something as complicated as a human arm, but it also applies to all the previous experiments we've performed.

Consider changing this into a ‘Student A says ..., student B says ...; which one is more correct?’

Comment from Shanna: This type of question is beyond their level of understanding.

Comment from meeting: New problem: Difference between this model and the real world?