

Experiment #10 Bio-Physics Pre-lab Comments, Thoughts and Suggestions

The purpose of this paper is to provide you with some information which may be useful for solving the pre-lab questions and performing the lab. I will attempt to help you understand the physics behind the system we will be using to measure the bio-mechanical forces/torques – and give you a few equations which may assist in solving problems.

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1) Let's say you had to move the Earth with a lever. You could use the Moon as a pivot point. Calculate how long of a lever you would need. It will be gigantic!

This is the classic see-saw problem. Here is our general setup of the see-saw: We have the Earth on one side of the see-saw, the Moon is our pivot point, and some random nerdy guy on the other side of the see-saw (since this is a physics problem, we need the nerdy guy).

**** Note that we are assuming the weight of the beam to be negligible. ****

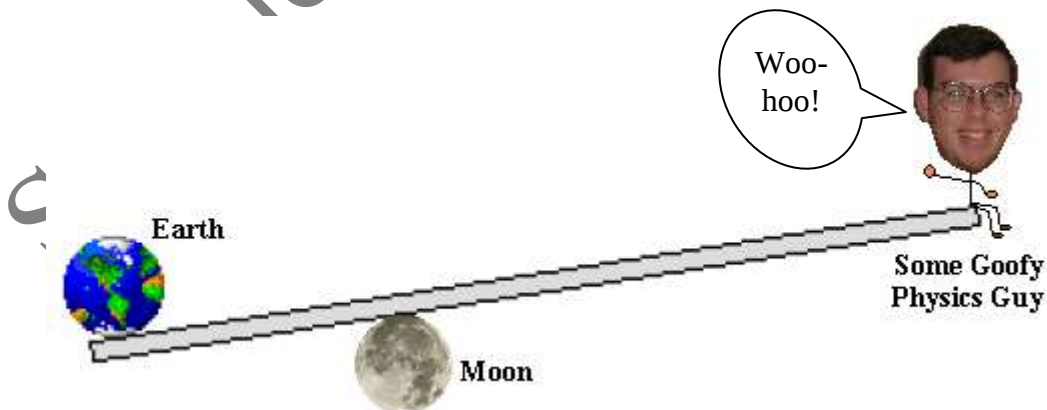


Figure 1: Setup of the Problem – Move the Earth with a Lever

**** Note that the Earth, Moon, Sun and Head of the Goofy Physics Guy are not to scale. That is, the moon may actually be smaller than shown. ****

For the sake of argument, let's say that this experiment is being performed on the sun. (I mean come on ... we're already "moving the Earth" – why not?!?! We have to do this since we need some reference frame with a mass to provide acceleration due to gravity. Typically we have the Earth where the acceleration due to gravity is $g = 9.81 \text{ m/s}^2$; however, since we're moving the Earth, it doesn't make much sense to have the Earth ON the Earth. That would require two Earths ... that's really deep philosophy. ☺)

We'll call the acceleration due to gravity on the sun, g_{sun} . If we draw in the various forces and distances, we get the following setup:

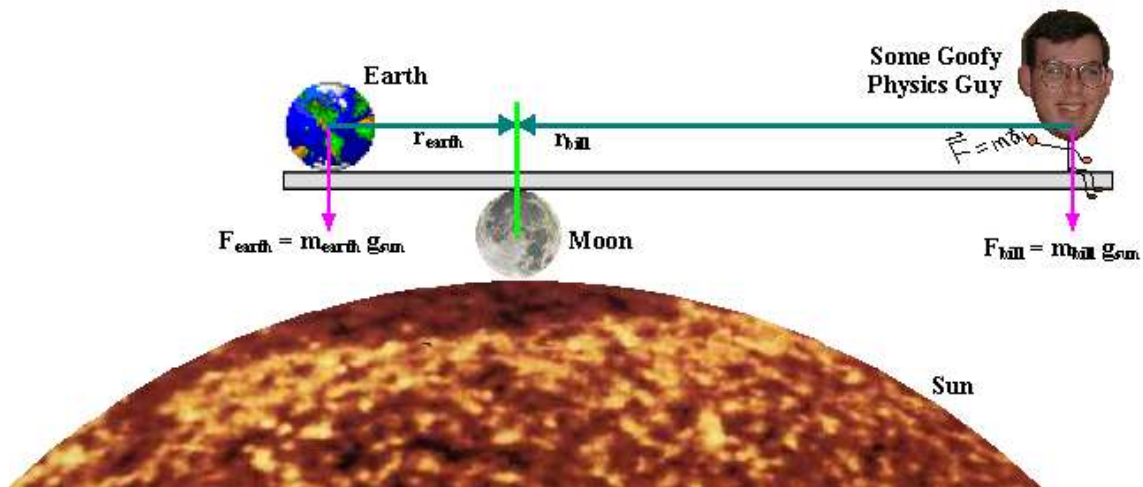


Figure 2: Experimental Setup on Solar Reference Frame

Some parameters which may be useful for solving this problem were given:

Force due to Mass of the Earth and Acceleration due to Gravity on the Sun (N)	Distance to the Moon (km)	Force due to Mass of Some Goofy Physics Guy and Acceleration due to Gravity on the Sun (N)
5.86×10^{25}	384000	1000

What we are first trying to find is what is the minimum length that Bill must be from the Moon in order to start to move the Earth. That is, we want the torque created by Bill to be greater than the torque created by the Earth.

$$\tau_{\text{Earth}} < \tau_{\text{Bill}}$$

We know the definition of magnitude of the torque is given by:

$$\tau = rF \sin(\theta)$$

We're going to assume that the angles between the forces and the lever arms are all nearly 90 degrees, because that makes the math A LOT EASIER. (They may in actuality be like 89.99999999999999 degrees, but that's close enough to 90 degrees.)

$$\tau = rF \sin(90^\circ) = rF$$

Thus:

$$\tau_{Earth} = r_{Earth} F_{Earth} \quad \text{and} \quad \tau_{Bill} = r_{Bill} F_{Bill}$$

Examining the original inequality:

$$r_{Earth} F_{Earth} < r_{Bill} F_{Bill}$$

Thus, the minimum distance Bill must be away from the moon is:

$$r_{Bill} > \frac{r_{Earth} F_{Earth}}{F_{Bill}}$$

Plugging in the values to see what you come up with.

The conversion factor for kilometers to light-years is:

$$1 \text{ ly} = 9.46 \times 10^{12} \text{ km}$$

Now, don't forget to answer the actual question: **How long of a lever you would need?**

The total length of the lever will be the length of the Earth's radial arm and Bill's radial arm summed together.

$$Lever_{Length} = r_{Earth} + r_{Bill}$$

2) Use the following parameters and the experimental setup to calculate values for F_{bicep} given that:

r_{bicep} (cm)	r_{arm} (cm)	r_{load} (cm)	m_{arm} (g)	m_{load} (g)
10	25	60	45	20

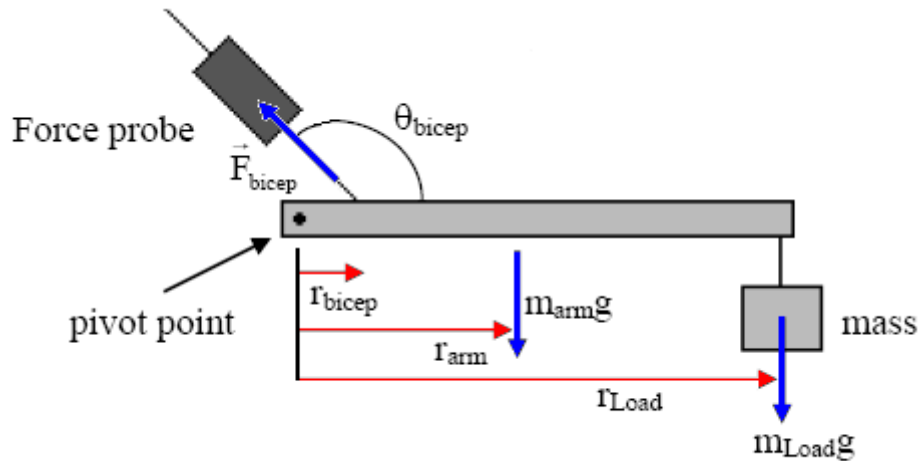


Figure 3: Experimental Setup of a Bicep Supporting a Massive Load

In the setup above, there are three torques (recall that a torque is force acting at a radial arm):

1. $[\tau_{load}]$ = The load mass hanging (force) at the end of the length (radial arm).
2. $[\tau_{bicep}]$ = The bicep holding (force) the length straight (radial arm).
3. $[\tau_{arm}]$ = The mass of the length itself hanging (force) at the center of mass (radial arm).

For static equilibrium (where nothing is rotating/moving) the net sum of the torques acting on the system must add up to zero. (Remember we use the greek letter “tau” for torque.)

$$\sum_{i=1}^n \vec{\tau}_i = 0$$

So, for our system, we have three torques; so, for static equilibrium, we must have:

$$\sum_{i=1}^3 \vec{\tau}_i = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 = \vec{\tau}_{load} + \vec{\tau}_{bicep} + \vec{\tau}_{arm} = 0$$

For this experiment, we will always force (no pun intended) the “arm” to be level (again no pun intended). That is, we want the arm to be perfectly parallel horizontally with the table. This will greatly simplify the calculation for the torques due to the load and the arm. If we explicitly write out each of the three torques:

Torque 1 (due to load):

First, recall the definition of torque:

$$\vec{\tau}_{load} = \vec{r}_{load} \times \vec{F}_{load}$$

To find the direction of the torque, we need to use the right-hand rule. First point your fingers in the direction of $\vec{r}_{load}$ then curl them to the direction of $\vec{F}_{load}$. The direction your thumb points is the direction of the torque for the cross product. For this case, $\vec{r}_{load}$ is pointing to the right (so point your pointer-to-pinky fingers in the right direction), and $\vec{F}_{load}$ is pointing down (keeping your fingers in the right direction, twist your hand (palm down) so when you bend your fingers they are pointing down. Your thumb should be pointing away from you. This means that the direction of the rotation is clockwise (nod your hand up and down while keeping your thumb pointing away from you and you'll see that the direction from your knuckles to your finger tips is in the clockwise direction) and the sign of the torque is negative).

**** Aside ****

I can never remember the “righty-tighty, lefty-loosey” thing my Dad taught me for screws, especially when I’m on my back. When I want to know which way I want the screw to go, I simply use the direction of torque (because that’s exactly what I’m doing). If I want the screw to go away from me, I point my thumb in that direction and see that the rotation direction from my knuckles to my finger tips is in the clockwise direction. If I want the screw to go toward me, I point my thumb in that direction and see that the rotation direction from my knuckles to my finger tips is in the counter-clockwise direction.

**** End Aside ****

By the right-hand rule:

$$\tau_{load} = -r_{load} F_{load} \sin(\theta_{load})$$

And since the angle (by design) between the force and the lever arm is 90 degrees:

$$\tau_{load} = -r_{load} F_{load}$$

Torque 2 (due to bicep):

To find the direction of this torque, $\vec{r}_{bicep}$ is pointing to the right (so point your pointer-to-pinky fingers in the right direction), and $\vec{F}_{bicep}$ is pointing leftish-up (keeping your fingers in the right direction, twist your hand (palm up) so when you bend your fingers they are pointing backwards. Your thumb should be pointing toward you. This means that the direction of the rotation is counter-clockwise (nod your hand up and down while keeping your thumb pointing toward you and you'll see that the direction from your knuckles to your finger tips is in the counter-clockwise direction) and the sign of the torque is positive).

By the right-hand rule:

$$\tau_{bicep} = r_{bicep} F_{bicep} \sin(\theta_{bicep})$$

Torque 3 (due to arm):

To find the direction of this torque, $\mathbf{r}_{arm}$ is pointing to the right (so point your pointer-to-pinky fingers in the right direction), and $\mathbf{F}_{arm}$ is pointing down (keeping your fingers in the right direction, twist your hand (palm down) so when you bend your fingers they are pointing down. Your thumb should be pointing away from you. This means that the direction of the rotation is clockwise and the sign of the torque is negative).

By the right-hand rule:

$$\tau_{arm} = -r_{arm} F_{arm} \sin(\theta_{arm})$$

And since the angle (by design) between the force and the lever arm is 90 degrees:

$$\tau_{arm} = -r_{arm} F_{arm}$$

Bringing it all together:

Now, if we add each of these up and set their sum equal to zero, we have the static equilibrium equation:

$$\sum_{i=1}^3 \vec{\tau}_i = \vec{\tau}_{load} + \vec{\tau}_{bicep} + \vec{\tau}_{arm} = 0$$

$$(-r_{load} F_{load}) + (+r_{bicep} F_{bicep} \sin(\theta_{bicep})) + (-r_{arm} F_{arm}) = 0$$

$$-r_{load} F_{load} + r_{bicep} F_{bicep} \sin(\theta_{bicep}) - r_{arm} F_{arm} = 0$$

Solve this for the force acting on the bicep.

$$F_{bicep} = \frac{r_{load} F_{load} + r_{arm} F_{arm}}{r_{bicep} \sin(\theta_{bicep})} = \frac{r_{load} m_{load} g + r_{arm} m_{arm} g}{r_{bicep} \sin(\theta_{bicep})}$$

$$F_{bicep} = \frac{r_{load} m_{load} g + r_{arm} m_{arm} g}{r_{bicep} \sin(\theta_{bicep})}$$

We are given the distances and the masses, and we know the acceleration due to gravity; so, for any give theta we can calculate the force on the bicep.

r_{bicep} (cm)	r_{arm} (cm)	r_{load} (cm)	m_{arm} (g)	m_{load} (g)
10	25	60	45	20

First though, don't forget to convert all the distances to meters and all the masses to kilograms!

The following is not in the pre-lab – but is a question posed in the lab!

Across your shoulder there is a muscle called the deltoid (you have two – one on each shoulder). It is called the “deltoid” due to its shape. It looks like the greek capital letter delta “Δ”. When you are standing with your arm “relaxed” (hanging vertically) your deltoid muscle does not get tired; but if you you're holding your arm out horizontally, your deltoid muscle is contracted and after a long time gets quite fatigued. (There is actually an exercise <http://www.bodybuildingforyou.com/training-fitness/shoulder-exercise-workout.htm> to exercise the deltoid with free weights.)

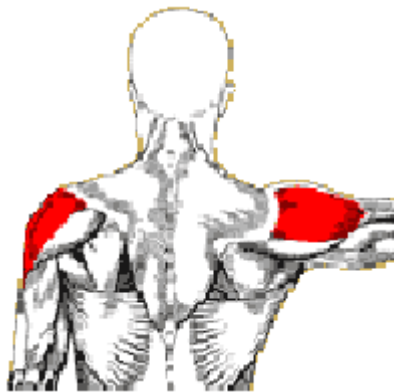


Figure 4: Location and Position of the Deltoid Muscles

Let's examine a force diagram of the upper arm - deltoid muscle system in both states, and see if we can describe the force exerted on the deltoid when it contracts. In both states we are considering a state of equilibrium. This means:

The sum of all the torques must be equal to zero.

$$\sum_{i=1}^n \vec{\tau}_i = 0$$

We will consider each of these rules and their application to determining the force acting on the deltoid.

State 1: Standing with your Arm Relaxed:

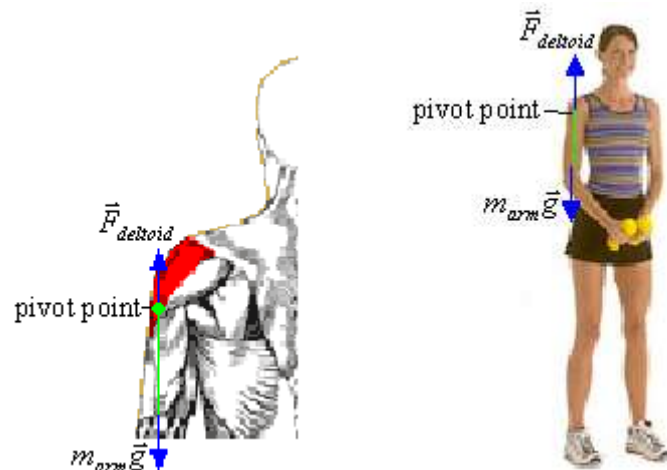


Figure 5: Operational Forces acting on the Deltoid in a Relaxed (Extension) State

All rotational acceleration (α) must be equal to zero:

$$\sum_{i=1}^n \vec{\tau}_i = 0$$

In the diagram above, we can see that both the force on the deltoid and the force due to gravity acting on the arm lie along the same line through the pivot point. This means that the distance from the pivot point to the force for both cases is zero.

$$\tau_{\text{deltoid}} = F_{\text{deltoid}} r_{\text{deltoid}} = F_{\text{deltoid}} (0 \text{ m}) = 0 \text{ Nm}$$

$$\tau_{\text{arm}} = m_{\text{arm}} g r_{\text{arm}} = m_{\text{arm}} g (0 \text{ m}) = 0 \text{ Nm}$$

$$\tau_{\text{deltoid}} + \tau_{\text{arm}} = 0 \text{ Nm} + 0 \text{ Nm} = 0 \text{ Nm}$$

By inspection, we can see that the force on the deltoid and the force due to gravity acting on the arm should be equal and opposite. That is to say, that for the static case (see lab 7):

$$\sum_{i=1}^n \vec{F}_i = 0$$

$$F_{\text{deltoid}} - m_{\text{arm}} g = 0$$

$$\boxed{F_{\text{deltoid}} = m_{\text{arm}} g}$$

State 2: Holding your Arm Outstretched:

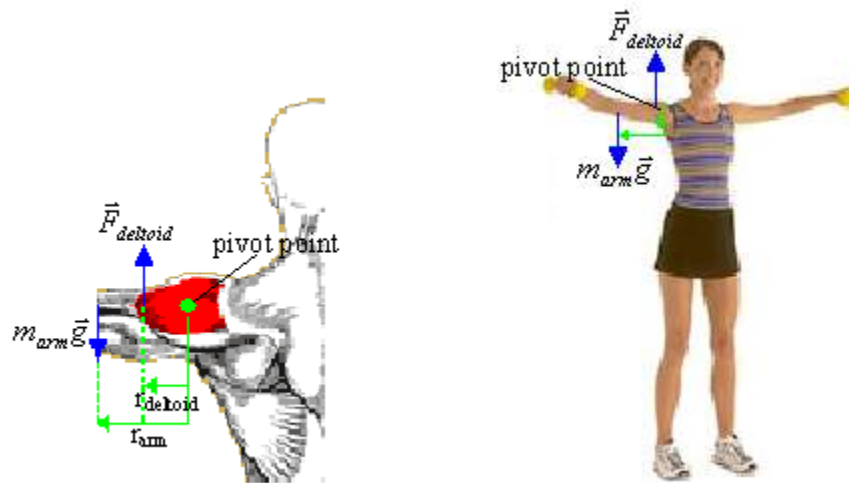


Figure 6: Operational Forces acting on the Deltoid in a Outstretched (Flexion) State

All rotational acceleration (α) must be equal to zero:

$$\sum_{i=1}^n \vec{\tau}_i = 0$$

In the diagram above, we can see that both the force on the deltoid and the force due to gravity acting on the arm lie at different lengths from the pivot point. This means that since there is a distance from the pivot point to the force, for both cases there will be a torque.

Torque 1 (due to deltoid):

To find the direction of this torque, $\vec{r}_{deltoid}$ is pointing to the left (so point your pointer-to-pinky fingers in the left direction), and $\vec{F}_{deltoid}$ is pointing up (keeping your fingers in the left direction, twist your hand (palm up) so when you bend your fingers they are pointing up. Your thumb should be pointing away from you. This means that the direction of the rotation is clockwise (nod your hand up and down while keeping your thumb pointing away from you and you'll see that the direction from your knuckles to your finger tips is in the clockwise direction) and the sign of the torque is negative).

By the right-hand rule:

$$\tau_{deltoid} = -F_{deltoid} r_{deltoid} \sin(\theta) = -F_{deltoid} r_{deltoid} (1) = -F_{deltoid} r_{deltoid}$$

**** Note that since the angle between the force and the lever arm is 90 degrees, the sine term went to 1. ****

Torque 2 (due to arm):

To find the direction of this torque, r_{arm} is pointing to the left (so point your pointer-to-pinky fingers in the left direction), and F_{arm} is pointing down (keeping your fingers in the left direction, twist your hand (palm down) so when you bend your fingers they are pointing down. Your thumb should be pointing toward you. This means that the direction of the rotation is counter-clockwise and the sign of the torque is positive).

By the right-hand rule:

$$\tau_{arm} = m_{arm} g r_{arm} \sin(\phi) = m_{arm} g r_{arm} (1) = m_{arm} g r_{arm}$$

** Note that since the angle between the force and the lever arm is 90 degrees, the sine term went to 1. **

Bringing it all together:

Now, if we add each of these up and set their sum equal to zero, we have the static equilibrium equation:

$$\sum_{i=1}^2 \vec{\tau}_i = \vec{\tau}_{deltoid} + \vec{\tau}_{arm} = 0$$

$$(-r_{deltoid} F_{deltoid}) + (r_{arm} F_{arm}) = 0$$

Solve this for the force acting on the deltoid.

$$F_{deltoid} = \frac{r_{arm} F_{arm}}{r_{deltoid}} = \frac{r_{arm} m_{arm} g}{r_{deltoid}}$$

Comparison of the forces on the deltoid when the arm is hanging vertically and outstretched horizontally:

Let's compare the two states and see which is the larger of the two.

$$F_{deltoid} = m_{arm} g \text{ (Vertical)} \quad F_{deltoid} = \frac{r_{arm} m_{arm} g}{r_{deltoid}} \text{ (Horizontal)}$$

For numerical purposes, let's assign some generic numbers:

$r_{deltoid}$ (m)	r_{arm} (m)	m_{arm} (kg)
0.10	0.25	0.045

For the arm hanging vertically:

$$F_{\text{deltoid}} = m_{\text{arm}}g = (0.045 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right) = 0.44145 \text{ N}$$

$$F_{\text{deltoid,Vert}} = 0.44145 \text{ N}$$

For the arm outstretched horizontally:

$$F_{\text{deltoid}} = \frac{r_{\text{arm}}m_{\text{arm}}g}{r_{\text{deltoid}}} = \frac{(0.25 \text{ m})(0.045 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)}{0.1 \text{ m}} = 1.103625 \text{ N}$$

$$F_{\text{deltoid,Horz}} = 1.103625 \text{ N}$$

Thus, you can see that the force acting on the deltoid in the horizontal position is much larger (2.5 times larger to be exact) than the force acting on the deltoid in the vertical position. This is obviously due to the torque acting about the pivot point.

Hold your arms straight out horizontally and see how long your deltoid can “handle the pressure”. For me it takes a few seconds then I can start to feel the force acting on my deltoid. ☺ If you’re more buff than I, then it may take a little longer, but you’ll eventually feel it. Notice that the woman in the figures was holding a free weight. We did not include that in our calculation, but it could easily be done. The free weight is in essence creating a hanging mass (load mass) similar to problem 2 above. Notice that in both the horizontal and vertical states of the arm that the deltoid force would be increased if the mass of the arm increased ... so even just holding a briefcase by your side is working your deltoid! That’s my kind of exercise! ☺

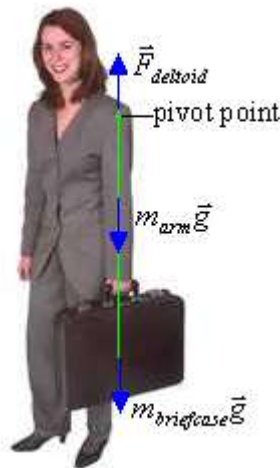


Figure 7: Exercise of the Deltoid due to Carrying a Briefcase