**Torque**

**Exploration**

**GE 1.**
Obtain a meter stick with a sliding weight on it. Hold the meter stick on one end, out horizontally, with the weight close to your hand. Then have someone slide the weight out to the end.

1. Does the meter stick become harder to hold up? Why? You are holding up the same weight.

Now conduct a similar investigation using the bones of a skeleton with the following string locations:

First consider the string attached to the arm. This approximates the insertion point of the deltoid muscle. Use this string to lift the arm horizontally. Adjust the angle the string makes with respect to the arm, as shown in the figure below.
2. How does the force required to lift the arm depend on the angle?

3. Approximately what angle does your deltoid muscle actually make with your arm?

**Exploration**

Let's consider a simple system that is conceptually similar to an arm rotating about the shoulder. We will consider a door rotating about its hinges.

**GE 2.**

Let the biggest, baddest, strongest person in your group push on an open door a couple of centimeters from the hinge.

1. Can he or she close the door?

2. Is it possible for a small, relatively weak person to keep the door open while the first person pushes with all their strength?

**GE 3.**

Place a book lying down, with a string attached to its cover. You are going to hold the book cover halfway open by pulling on the string.
Keeping the applied force perpendicular to the book cover, investigate the force required as a function of distance, \( l \), to the hinge.

3. Record your data here.

4. Can you develop a rule that would allow you to predict the force required for a specific distance?
GE 4.

Using just one string, sense the force needed to hold the book cover halfway open, with the string at various angles (90°, 60°, 30°) relative to the book cover. Keep the position of application constant.

1. Record your data here.

2. How is the amount of force required to hold the cover open affected by the angle of the string?

Invention

We need a new physics concept to help us understand and make predictions about situations involving rotations about an axis. Physicists call the combination of force and position that determines rotational motion, torque. We use the Greek letter tau to represent torque and define torque specifically as:

\[ \tau = rF \sin \theta \]

where \( r \) is the distance the force is applied away from the axis of rotation (the hinges in the case of a door) and \( F \sin \theta \) is the component of the force that is perpendicular to the vector \( r \).
Sometimes torque is written as

\[ \tau = Fr_p \]

where \( F \) is the magnitude of the force and \( r_p \) (read as "\( r \) perpendicular") is the lever arm. The lever arm can be determined by drawing a line through the force vector, called the line of action, and finding the perpendicular distance from the line of action to the axis of rotation.

The structure that goes from the hinge to the point where the force acts is called a lever. In the above figure, the door is a lever.

There is a sign convention for the torque. If it causes a counterclockwise rotation we will consider it positive. If it causes a clockwise rotation we will consider it negative.

**Application**

Practice calculating torque for some situations involving the human body. For each example,

- Identify the rotation axis
- Identify the lever and lever arm
- Calculate the torque about the axis

**Example 1:**

Lever is the whole arm
Axis is the shoulder.
Given: the weight the arm is holding up - 10 lbs

the lever arm (distance) for each orientation of the arm.

For highest orientation of arm
torque = Force times lever arm

\[ \tau = F r_p \]

= 10 lbs x 12 in

= 120 lb. in.
GE 5.

Try the other orientations.

1. Horizontal

2. Low

Example 2:
Find the torque on the spinal column due to the weight of the head

Lever is spinal column (trunk)
Axis is fifth lumbar vertebrae

Force is weight of head - 7% of body weight
Distance from fifth lumbar vertebrae to center of mass of head (along spine) is given - 72cm
Angle weight of head makes with spinal column is 60

\[ \tau = Fr\sin(\theta) = 0.070w\times 0.72[m]\sin(60) \]

**GE 6.**

1. Now find the torque due to the arms about the 5th lumbar vertebrae.

2. Find the torque due to the trunk.

**Example #3**
GE 7.

Find the torque about the hip due to the weight of the leg

1. Leg held horizontally,

2. Bent leg.

Example 4
GE 8.

1. Find the torque about the knee joint due to the added ankle weight.

Example 5
GE 9.

1. Find the torques on the head due to the weight of the head and the neck muscle. The atlanto-occipital joint is the axis.

2. What is the total torque?