Biomechanics Lab: Center of Mass

**Purpose:** To understand the concept of COG and COM as well as learn methods of determining the location of the COG of an object and person.

**Center of Gravity:** The point at which all of the body’s mass seems to be concentrated; ...the point about which the sum of the torques equals zero.

**Center of Mass:** A balance point of a body; the point about which all of the mass particles of the body is evenly distributed.

⇒ Torque is defined as: the tendency of a force to cause rotation about a specific axis.
⇒ The equation to calculate Torque is $T=Fd_\perp$ where $F=$force applied at a distance $d_\perp$ is the moment arm. The units for torque are Nm (or ftlb).
⇒ Torque is a vector, and therefore has magnitude and direction. Direction is + if the torque tends to cause rotation in a counter-clockwise direction and - if in a clockwise direction.

Part 1: Center of mass of an object using the ‘hanging’ technique.
You do not need to answer these questions for the lab – just consider the answer for the purpose of preparing yourself for the next exam.

- When the object is hanging, how much mass is on one side of the string compared to the other side?
- Why hang the object from more than one location?

Part 2: Center of mass of a person using the reaction board technique.
You do not need to answer these questions for the lab – just consider the answer for the purpose of preparing yourself for the next exam.

- What would happen to the force at the scale if the person’s arms are placed above the head vs. to the sides?
- How would that influence the math of calculating the location of the COM?
- Why should the person place their feet just above the axis of rotation?
- Why do you not need to measure the force at the end that is considered the axis of rotation?
Part 1: Determine the center of mass of a cardboard cut out.

**Instruments:** cardboard, pencil, scissors, string with weight tied on end.

**Cut out a shape from a piece of cardboard.**

**Poke at least three holes around the outer edge of the shape.** The holes should be large enough so the pencil can easily fit.

**Tie the string to the pencil and hang the object from one of the holes.** Mark the line that the string makes across the object. Repeat with each hole.

The intersection of the lines is the location of the COM.

On the blank piece of the paper, trace your object and indicate the location of the COM. Or, sketch the object and the location of the COM below.
Part 2: Determine the center of mass of a person using the reaction board technique.

**Instruments:** Reaction board, scale

**Methods**

- To determine the location of the COM of a person using the reaction board technique requires completing two steps.
  - The purpose of Step 1 is to determine the torque due to the reaction board itself.
    - Measure the length of the reaction board between the two supports (this is the moment arm).
    - With nothing on the reaction board, read the scale (this is the magnitude of force).
    - Calculate the torque due to this force ($F_d \perp$). This torque is the same magnitude as the torque due to the board itself.
  - The purpose of Step 2 is to determine the location of the COM of the person.
    - Measure how much the person weighs. Make sure to use Newtons for units.
    - Have the person lie on their back with the bottom of their feet lined up with the axis of rotation (i.e., right above the support).
    - Measure the reading on the scale.
    - Knowing the torque due to the board (Step 1), the torque due to the scale (for Step 2), and the weight of the person, you can solve for the location of the COM from the axis of rotation.

### Step 1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_L$</td>
<td>Length of board (between supports)</td>
<td>m</td>
</tr>
<tr>
<td>$F_{scale}$</td>
<td>(convert to Newtons: 4.4 Newtons = 1 lb)</td>
<td>N</td>
</tr>
<tr>
<td>$T_{scale}$</td>
<td></td>
<td>Nm</td>
</tr>
</tbody>
</table>

### Step 2

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{person}$</td>
<td>Weight of subject</td>
<td>N</td>
</tr>
<tr>
<td>$T_{board}$</td>
<td></td>
<td>Nm</td>
</tr>
<tr>
<td>$F_{scale}$</td>
<td>(convert to Newtons: 4.4 Newtons = 1 lb)</td>
<td>N</td>
</tr>
<tr>
<td>$d_L$</td>
<td>Length of board (between supports)</td>
<td>m</td>
</tr>
<tr>
<td>$T_{scale}$</td>
<td></td>
<td>Nm</td>
</tr>
<tr>
<td>$d_{\perp person}$</td>
<td>$(T_{scale} - T_{board})/(F_{person})$</td>
<td>m</td>
</tr>
</tbody>
</table>
Free body diagram of reaction board only.

Solve for Torque due to the reaction board ($T_{board}$)

Free body diagram of a person lying on the reaction board.

**Step 1: Determine $T_{scale}$**

- $\Sigma T = I\alpha$
- $\alpha = 0 \text{ rad/s/s}$
- $\Sigma T = 0 \text{ Nm}$
- CCW+
- $T_{scale} + (-T_{board}) = 0 \text{ Nm}$
- $T_{board} = T_{scale}$

**Step 2: Solve for $d_{\perp person}$**

- $\Sigma T = I\alpha$
- $\alpha = 0 \text{ rad/s/s}$
- $\Sigma T = 0 \text{ Nm}$
- CCW+
- $T_{scale} + (-T_{board}) + (-T_{person}) = 0 \text{ Nm}$
- $T_{person} = T_{scale} - T_{board}$
- $T_{person} = (F_{person})(d_{\perp person})$
- $(F_{person})(d_{\perp person}) = T_{scale} - T_{board}$
- $d_{\perp person} = (T_{scale} - T_{board})/(F_{person})$