SP3005/PH3025 ADVANCED BIOMECHANICS
Laboratory 2
Determination of the Body's Centre of Gravity and the weight of Distal Segments

Sven Richter

September 21, 2004

Contents

1 Introduction

A body's mass is the matter of which it is composed. A unique point is associated with every body, at which the body's mass appears to be concentrated. This point is known as the center of mass of the body. When the body is subject to a gravitational field, the centre of mass may also be referred to as the center of gravity (CG), provided that the gravitational field is uniform or that its variation is negligible over the dimension of the body. The CG is the point about which the bodies weight is equally balanced is all directions, or the point about which the sum of torques produces by the weight of the body segments is equal to zero.

The CG of a perfectly symmetric centre of the object. For example the CG of a perfect sphere made out of homogeneous material will be at the geometric centre of that sphere. However for bodies of complex shape and/or composed of non-homogeneous material(s), the CG is not so readily located, and often an experimental approach based upon the balancing of torques is more efficient than a theoretical approach based upon geometry and density distribution.

The location of a body's CG is of interest because, in a mechanical analysis linear motion, a body behaves as though all of its mass were concentrated at the CG. The CG of the human body is often of interest in the analysis of sporting activities, particularly those in which the entire body is airborne for a period.

2 Theory

One method of locating the CG of the human body is the so call "board and scale" method. In this method a person stands or lies on a board that is supported at each end by a fulcrum. At one end the fulcrum is places on a set of scales, while at the end the fulcrum acts as a hinge. Since the system is in static equilibrium, both the sum of forces and the sum of torques is zero. The net force down is the sum of the body weight and the weight of the board. This is equal tot the sum of the reachtion forces at ea h end. It is convienient to measure distances from the hinge support.

Let:

d the distance between the two suports

x the distance from the hinge to CG of the board

x_1 the distance from the hinge to the CG of the body

W the weight of the person

w the weight of the board

R_1 reaction force at the scales

Taking moments (torques) about the hinge we have:

$$Wx_1 + wx = R_1 d \tag{1}$$

From this equation the distnace x_1 can be determined if R_1 is measured. Note that equation (1) assumes the board is horizontal

3 Aims

1. To measure the CG of a male and female subject in all three cardinal planes.
2. For one of the subjects, to measure the weight of distal segments.

4 Equipment

- Weighing frame
- Load cell (250kg)
- Fulcrums
- Support
- Spirit level

5 Procedure

Part A - Determination of total body Centre of Gravity

1. Set up the equipment ready to determine the CG of a subject. List what you do. Be sure the board is horizontal.
2. How can you use equation (1) of the theory to determine the CG in all three dimensions?
3. In using equation (1) is it necessary to determine w & x separately ? or is there a better way? Explain.
4. Carry out you measurements for a female and a male subject. Report your results, compare and explain.
5. Will the procedure still work if the hinge is placed such that d is less than the height of the subject? try it for one suject (for the y direction) and compare with your first result. Explain the result.

Part B - Determination of the weight of distal segments

The concept behind equation (1) can be extended to determine the mass of a distal body segment if the CG of that segment is positioned directly above its proximal joint.

1. Show how this can be done. (see A)
2. Select one subject and calculate the weight of two distal segments using the anthropometric tables supplied. Record your results.
3. Use the reaction board to determine the weight of the same segments and compare with the results of 2 above

6 Results and Discussion

Part A

1. To setup the board to be ready to determine the center of gravity following steps where done:

   - The weighing frame was placed .
   - We have taken a stool to but one end of the board and put the other one one the weighing frame.
   - We placed hinges under each end of the board.
   - We used the spirit level to determine if the board was horizontal.
   - Because it was not horizontal we placed additional blanks under the hinges till it was horizontal.
   - We measured the length between the hinges and marked the position of the fulcrum on the upper board side. We also insured that the hinges are placed in a right angle to the board.
   - We did calibrate the load cell.

2. To use equation (1) of the theory to determine the CG in all three dimensions, it is needed to place the subject in a different way. Because it is only possible to measure the CG of a subject in one axis at a time. Therefore the subject must lie down to measure the CG of the y-axis, stand up facing the front to measure the x-axis and faced sideway to measure in the z-direction.

3. In using equation (1) it is not necessarily needed to determine w & x separately. Because the weight of the board is constant over the whole meassurement and does not change with the subject or the position of the subject. So it can simply be removed by calibrating the load cell with the board. The load cell should be calibrated that it shows zero of there is no additional load on the board. Than this part of the equation (1) is zero, too.

$$x_1 = \frac{R_1 d}{W} \tag{2}$$

4. The following results where measured and x_1 was derived with equation (2)

   The distance from the first hinge to the CG of the female subject in the z and y axis is smaller than from the male subject. This was expected because he was taller and therefore must the distance to the CG greater.

axis	male F (kg)	$W = 85.4\ kg$ x_1 (m)	female F (kg)	$W = 60.85\ kg$ x_1 (m)
x	6.5	0.166	5.0	0.179
y	42.5	1.080	25.8	0.923
z	4.5	0.115	3.0	0.107

$$d = 2.178m$$

Table 1: Determination of total-body centre of gravity

The result for the x-axis was reverse compared to the expected value. This can be explained as a deviation. Because for the measurement for the x and z-axis the subject has to stand straight and because the CG is on a great vertical distance from the board and therefore a small movement of the subject will result in a great difference of the measured Force. Only the result for the y-axis can be taken really serious because the derivation is to great for the other two axis.

5. The measurement will be also possible if the hinge is placed such that d is less than the height of the subject. But the result will be less precise than otherwise because the difference of force will be lesser because the lever is shorter.

axis	F (kg)	x_1 (m)
y	57.9	1.040

$W = 85.4\ kg$ $\qquad$ $d = 1.53\ m$

Table 2: Determination of total-body centre of gravity, d less than subject height

Part B - Determination of the weight of distal segments

To determine the weight of a distal body segment the complete CG must be measured two times. Once with the body segment plain on the board and once with the CG of the segment above a joint. Therefore is only possible to measure segments which can be bend in the appropriate manner. For example the upper body, the arms or the lower body.

The thru measurement determined values and the ones derived thru the table are not so different for the legs but do differ for the arms. This was expected

segment	E_1	E_2	$l_{segment}$ (m)	$y' - y$ (m)	w_1 (kg) calculated	w_1 (kg) table
legs	41.5	47.0	1.00	0.433	27.67	27.50
arms	41.5	42.5	0.67	0.355	6.14	8.54

Table 3: Determination of the weight of distal segments

because the both legs have a greater mass compared to the whole body and therefore the deviation will be smaller.

7 Conclusion

The "board and scale" method is an easy way to determine the CG of a subject but it is only usable for measurement in y-direction because otherwise the derivation will become to large. Even to measure the weight of a body segment it returns useful data if the segment is big enough compared to the rest of the body. But because you have to use tables to determine the distance from the CG of this segment it would be more precise to use the tables to calculate the segment weight, too.

A Determination of segment mass

Segment wieght can be optained by the following procedure, where we consider the wieght of th two thighs and lower legs.

The symbols in the figures have the following meaning:

$w$weight of plank

W_1weight of both thighs and lower legs (lower body)

W_2weight of rest of body (upper body)

$y$distance from hinge to centre of mass of lower body in position A_1

y_1'distance from hinge to centre of mass of upper body

y_2 distance from hinge to centre of mass of upper body

d distance from hinge to scale support

E_1 scale reading in position A_1

E_2 scale reading in position A_2

In position A_1 the sum of the torques about the hinge = 0. This implies

$$W_1 y_1 + W_2 y_2 + wy = E_1 d \quad (3)$$

In position A_2 the sum of the torques about the hinge =0. This implies

$$W_1 y_1' + W_2 y_2 + wy = E_2 d \quad (4)$$

Eqn(4)-Eqn(3) gives

$$W_1 y_1' - W_1 y_1 = E_2 d - E_1 d \quad (5)$$

$$W_1 = frac(E_2 - E_1) d y_1' - y_1 \quad (6)$$

Now E_1, E_2 and d are readily measured. What about y_1 and y_1'?

$y_1' - y_1$ the dinstance the centre of mass of the lower body has moved in changing position

It is possible to get this from anthropometric tables. It's major source of error in the above measurement.