

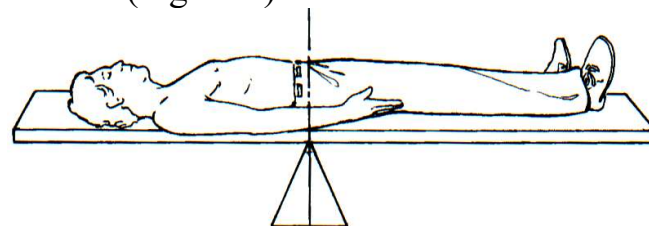


Locating the Human Center of Gravity

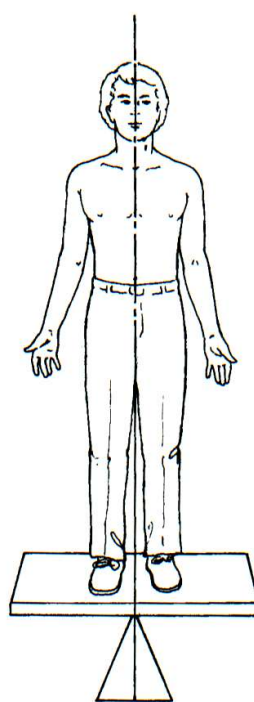
Introduction:

Locating the CG for a body containing two or more movable, interconnected segments is more difficult than for a non-segmented body because every time the body changes configuration, its weight distribution and CG location are changed. Every time an arm, leg, or finger moves, the CC location as a whole is shifted at least slightly in the direction in which the weight is moved.

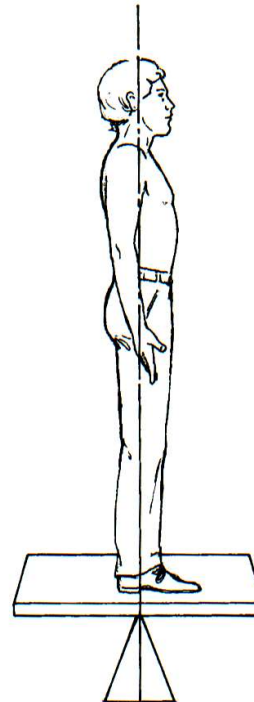
(Method 1) Some relatively simple procedures exist for determining the location of the CG of the human body. In the seventeenth century, the Italian mathematician Borelli used a simple balancing procedure for CG location that involved positioning a person on a wooden board (Figure 1).



Top and bottom portions balance



Right and left
portions balance



Front and back
portions balance

Figure.1 The relatively crude procedure devised by seventeenth century mathematician Borelli for approximating the CG location of the human body

(Method 2) A more sophisticated version of this procedure enables calculation of the location of the plane passing through the CG of a person positioned on a reaction board. This procedure requires the use of a scale, a platform of the same height as the weighing surface of the scale, and a rigid board with sharp supports on either end (Figure 2).

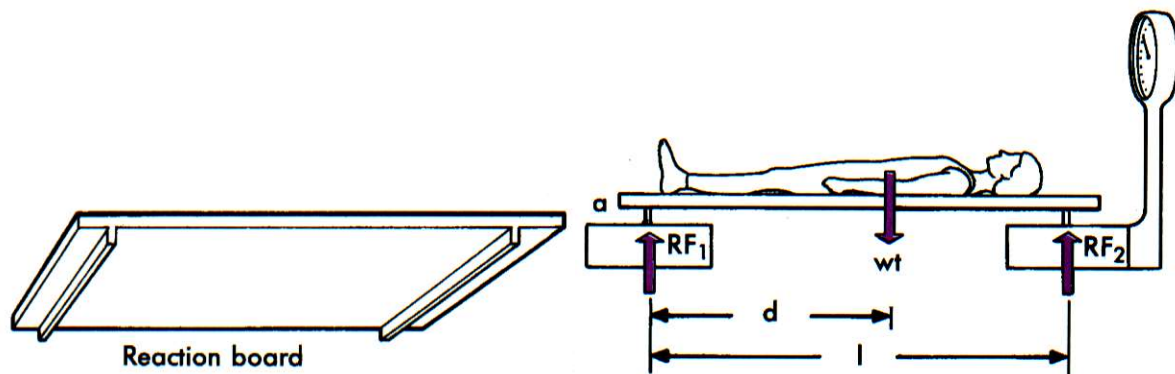


Fig.2 By summing moments at point a, d (the distance from a to the subject's CG) may be calculated

The calculation of the location of the plane containing the CG involves the summation of moments acting about the platform support. The subject's body weight, which acts at the CG, creates a moment at the platform support in one direction, and the reaction force of the scale on the platform, which the reading on the scale indicates, creates a moment at the platform support in the opposite direction. Although the platform also exerts a reaction force on the board, it creates no moment because the distance of that force from the platform support is 0. Since the reaction board and subject are in static equilibrium, the sum of the two moments acting at the platform support must be 0, and the distance of the subject's CG plane to the platform may be calculated (Figure 3).

$$\begin{aligned}\sum T_a &= 0 \\ \sum T_a &= (RF_2 \times l) - (wt \times d) \\ 0 &= (RF_2 \times l) - (wt \times d) \\ d &= \frac{RF_2 \times l}{wt}\end{aligned}$$

(Method 3) A commonly used procedure for estimating the location of the total body CG from projected film images of the human body is known as the segmental method. This procedure is based on the concept that since the body is composed of individual segments (each with an individual CG), the location of the total body CG is a function of the locations of the respective segmental CGs. Some body segments, however, are much more massive than others and have a larger influence on the location of the total body CG. When the products of each body segment's CG location and its mass are summed and subsequently divided by the sum of all segmental masses (total body mass), the result is the location of the total body CG.

The segmental method uses data for average locations of individual body segment CCs as related to a percentage of segment length

$$X_{cg} = \sum (x_s)(m_s) / \sum m_s$$

$$Y_{cg} = \sum (y_s)(m_s) / \sum m_s$$

In this formula, X_{cg} and Y_{cg} are the coordinates of the total body CG, x_s , and y_s are the coordinates of the individual segment CGs, and m_s is individual segment mass. Thus the x coordinate of each segment's CG location is identified and multiplied by the mass of that respective segment. The $(x_s)(m_s)$ products for all of the body segments are then summed and subsequently divided by total body mass to yield the x coordinate of the total body CG location. The same procedure is followed to calculate the y coordinate for total body CG location.

Anthropometric Parameters for the Human Body

Segment lengths

SEGMENT	MALES	FEMALES
Head and neck	10.75	10.75
Trunk	30.00	29.00
Upper arm	17.20	17.30
Forearm	15.70	16.00
Hand	5.75	5.75
Thigh	23.20	24.90
Lower leg	24.70	25.70
Foot	4.25	4.25

Segment lengths expressed in percentages of total body height

Segment weights

SEGMENT	MALES	FEMALES
Head	8.26	8.20
Trunk	46.84	45.00
Upper arm	3.25	2.90
Forearm	1.87	1.57
Hand	0.65	0.50
Thigh	10.50	11.75
Lower leg	4.75	5.35
Foot	1.43	1.33

Segment weights expressed in percentages of total body weights

Segmental center of gravity locations

SEGMENT	MALES	FEMALES
Head and neck	55.0	55.0
Trunk	63.0	56.9
Upper arm	43.6	45.8
Forearm	43.0	43.4
Hand	46.8	46.8
Thigh	43.3	42.8
Lower leg	43.4	41.9
Foot	50.0	50.0

Segment center of gravity locations expressed in percentages of segment length; measured from the proximal ends of segments.