Journal of Biomechanics 47 (2014) 1909–1913

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Determining the location of the body's center of mass for different groups of physically active people

Mikko Virmavirta*, Juha Isolehto

Neuromuscular Research Center, Department of Biology of Physical Activity, University of Jyväskylä, Finland

ARTICLE INFO

Article history:
Accepted 1 April 2014

Keywords:
Body center of mass
Segment inertia parameters
Reaction board
Motion analysis

ABSTRACT

The purpose of the present study was to compare the location of the body center of mass (CoM) determined by using a high accuracy reaction board (RB) and two different segment parameter models for motion analysis (Dempster, 1955, DEM and de Leva, 1996 adjusted from Zatsiorsky and Seluyanov, ZAT). The body CoM (expressed as percentage of the total body height) was determined from several subjects including athletes as well as physically active students and sedentary people. Some significant differences were found in the location of the body CoM between the used segment models and the reaction board method for all male subjects ($n=58$, 57.03 ± 0.79%, 56.20 ± 0.76% and 57.60 ± 0.76% for RB, ZAT and DEM, respectively) and separately for male ($n=12$, RB 57.02 ± 0.41%, ZAT 56.74 ± 0.62%, DEM 58.19 ± 0.60%) and female ($n=12$, RB 55.91 ± 0.88%, ZAT 57.24 ± 0.77%) students of physical activity. The ZAT model was a good match with RB for high jumpers (56.26 ± 0.94% and 56.63 ± 0.56%) whereas the DEM model was better for gymnasts (57.38 ± 0.46% and 57.89 ± 0.49%) and throwers (58.19 ± 0.69% and 57.79 ± 0.45%). For ice hockey players (IH) and ski jumpers (SJ) both segment models, ZAT and DEM, differed significantly from the reaction board results. The results of the present study showed that careful attention should be paid while selecting the proper model for motion analysis of different type of athletes.

1. Introduction

Determining the human body segment inertial parameters (BSIP) has a long history including many scientific studies, starting from simple reaction board methods and resulting in more advanced scanning technologies. In most of these studies, the location of the human body center of mass (CoM) has been one of the estimated parameters. The historical backgrounds of the old studies (e.g. Weber and Weber, 1836; Harless, 1860; Braune and Fischer, 1889; Meeh, 1894; Bernstein et al., 1931; Bernstein, 1967; Dempster, 1955) are well presented and cited in a comprehensive study by Clauser et al. (1969). Other high-quality reviews of this old era have been written by Drillis et al. (1964) and Chandler et al. (1975). Another frequently cited source of BSIPs was published by Plagenhoef et al. (1983). The history of the techniques used to assess body segment parameters for biomechanical analysis has been reviewed by Pearsall and Reid (1994). Much more recent review on human body segment parameters (BSP) was written by Durkin (2008) covering the time period from the end of 19th century to the beginning of 21st century. Durkin (2008) discusses the accuracy and limitations of the BSP studies including direct measurement techniques, cadaver methods, and mathematical/geometrical models (e.g. Hanavan, 1964; Jensen, 1978; Hatze, 1980). According to Durkin (2008), medical imaging techniques like the gamma-scanner method (Zatsiorsky and Seluyanov, 1983; Zatsiorsky et al., 1990a, 1990b), magnetic resonance imaging (MRI) (Martin et al., 1989), computed tomography (CT) (Pearsall et al., 1996) and dual energy x-ray absorptiometry (DEXA) (Durkin et al., 2002; Durkin and Dowling, 2003; Wicke and Dumas, 2008) provide more accurate and reliable methods for BSP measurements. A critical comparison between DEXA and gamma scanning methods was presented by Zatsiorsky (2003) in his letter to the editor. The 3D photonic scanner techniques have also been used to estimate BSIPs from the regional and whole body volumes for elite athletes (e.g. Okada et al., 2013; Hakamada et al., 2013). These systems collect up to 2,048,000 data points over a scan field (2 m × 1 m × 0.6 m) in 10 s (Wang et al., 2006).

Probably the most frequently referenced papers in motion analysis studies have been the cadaver studies of Dempster (1955) and Clauser et al. (1969), later adjusted by Hinrichs (1990), which have served as the BSIP basis of motion analysis for years. However, it has been shown by de Leva (1993) that generalization of cadaver data to younger population is likely to cause errors in the calculated position of their CoM. The data of Zatsiorsky et al. (1990a) were derived from young, athletic subjects

* Correspondence to: Department of Biology of Physical Activity, University of Jyväskylä, P.O. Box 35, 40014 Finland. Tel: +358 14 602070; fax: +358 14 602071.
E-mail address: mikko.virmavirta@jyu.fi (M. Virmavirta).

http://dx.doi.org/10.1016/j.jbiomech.2014.04.001
0021-9290/

(instead of cadavers) and they are considered to be more representative of the BSP's of young people. Although the validity of the data of Zatsiorsky's group is clear, especially for athletes, many sport biomechanists are still using cadaver data. In order to find the best segmental model for young male and female athletes, de Leva (1993) photographed subjects in four different positions on a high-precision reaction board and measured the error in the position of subjects' CoM calculated with the different segmental methods. When the mathematical model for flexible trunk was applied, the average errors were dramatically reduced. The adjusted data of de Leva (1996) has been successfully used in the analysis of sport events (e.g. in the Olympic Games, Virmavirta et al., 2005, 2009) in which the athletes usually cannot be measured for personalized mathematical models.

The purpose of the present study was to determine the location of the body CoM by using a high accuracy reaction board and two different segment parameter models (Dempster, 1955 and Zatsiorsky et al., 1990a adjusted by de Leva, 1996). Suitability of the selected body segment models for motion analysis of the different groups of physically active people was examined.

2. Methods

The true location of subjects' body center of mass was determined by using a high accuracy balance board with knife edge pivot in the mid region, and a very sensitive force transducer at one end (Figs. 1 and 2). Calibration of the reaction board was done by moving a homogenous steel bar with a known CoM location along the board covering the range of force values used in measurements with subjects. The difference between the true position of CoM and the position estimated by the reaction board was 1.2 ± 1.3 mm, thus providing a reliable method for determining the reference values for motion analysis (Fig. 3).

Subjects (Tables 1 and 2) were in a supine position on the balance board with their heels placed at a fixed distance from the pivot axis and they were filmed with one overhead camera (Fig. 1). For the 2D analysis, corners of the reaction board were used for the image space calibration. Subjects were informed about the measurement procedure and provided written consent for the measurements. Mass (% TBM) and CoM position (% segment length) of the different body segments used in the present study can be seen in Table 3. MIDG was used as an endpoint of the head segment and therefore Dempster's original CoM for the head segment (43.3%, VERT-C7/T1) was modified according to de Leva's (1996, Fig. 1) adjusted parameters.

Dempster's study is probably the most often cited reference in motion analysis studies. Almost as often as this study is referred there are discrepancies in the citations made from the original Dempster data. Dempster himself wrote (Dempster, 1955, p. 185) that the result of summing the segments' masses (97.2%) does not match the total body mass (TBM) measured before the cuts and discrepancies are often found. “In general, the errors appeared to be proportional to the size of the mass treated. These percentage ratios are of most interest in applications to living subjects”. According to the above mentioned proportionately of the errors, Clauser et al. (1969, Table 24, p. 59) obtained the adjusted values which are those often referred to as Dempster's data.

In the statistical analysis differences between locations of CoM determined by the reaction board (RB) and two different segment models (ZAT, DEM) were tested by using paired two-tailed t-test or non-parametric Wilcoxon test for subgroups of small sample size.

Fig. 1. Overhead camera view of the reaction board set-up.

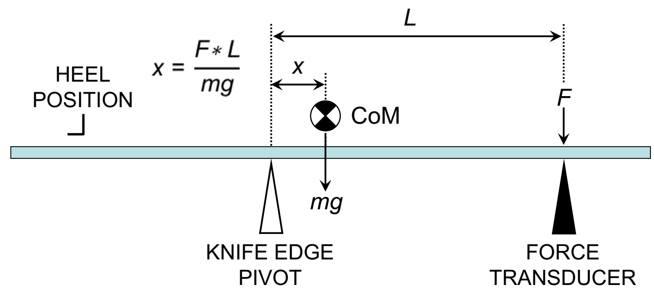

Fig. 2. Calculation of the location of the CoM (x) using moments about the pivot axis.

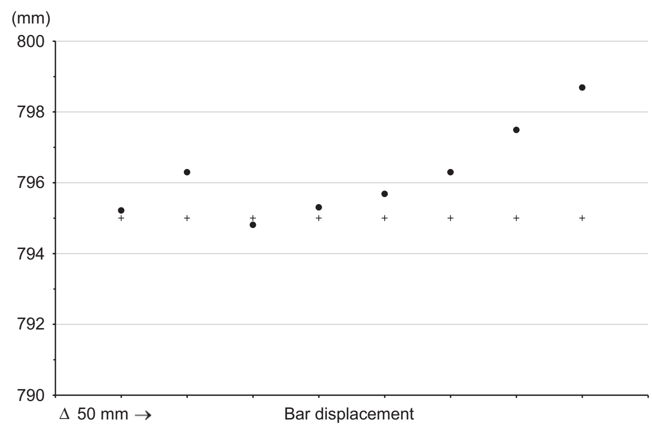

Fig. 3. Calibration readings of the reaction board at 50 mm intervals covering the range of force values in real measurements. + = true position.

Table 1
Physical characteristics of the subjects.

	Males	Students M	Students F
	(n=58)	(n=12)	(n=12)
Age (years)	26.3 ± 5.6	26.7 ± 3.9	23.8 ± 3.4
Body mass (kg)	81.8 ± 14.9	80.2 ± 8.3	62.1 ± 4.5
Height (cm)	181.3 ± 6.9	179.6 ± 3.9	169.4 ± 6.2
BMI	24.8 ± 3.6	24.8 ± 2.3	21.6 ± 1.2
F (%)	14.9 ± 5.6	15.4 ± 4.1	27.0 ± 3.0

3. Results

The location of the body's center of mass (CoM) determined by a reaction board (RB) and two different segment models of motion analysis (ZAT and DEM) for different groups of physically active people is presented in Figs. 4 and 5. Fig. 4 shows the comparison for male subjects (57.03 ± 0.79%, 56.20 ± 0.76% and 57.60 ± 0.76% for RB, ZAT and DEM, respectively) and separately for male (57.02 ± 0.41%, 56.74 ± 0.62%, 58.19 ± 0.60%) and female (55.91 ± 0.88%, 57.24 ± 0.77%, 58.70 ± 0.76%) students of physical activity.

Fig. 5 shows the corresponding differences for the different groups of male athletes. It can be seen that for the high jumpers (HJ) the ZAT model (56.26 ± 0.94%) does not differ significantly from reaction board results (56.63 ± 0.56%) but the DEM model differs (57.47 ± 0.96%, p=0.010). For the gymnasts (GYM) and throwers (THR) the results of the DEM model (57.38 ± 0.46% and 58.19 ± 0.69%, correspondingly) do not differ from the reaction board values (57.89 ± 0.49% and 57.79 ± 0.45%), whereas the results of the ZAT model (55.95 ± 0.49% and 56.73 ± 0.68%) differ significantly from the board values ($p < 0.001$ and $p < 0.05$). For ice hockey players (IH) and ski jumpers (SJ) both segment models, ZAT and DEM, differed significantly from the RB results.