

Inertial and geometrical segment parameters for female elite gymnasts

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Abstract— Knowledge of body segment parameters is essential in sport movement biomechanical analysis. These parameters, such as segment length, mass, moments of inertia as well as centre of mass location, are usually derived from anthropometric models. A sample of 30 national level female gymnasts was investigated in order to create a database for body segment parameters. Statistical analysis of the data from this group allowed for the designed of a new anthropometric model devoted to elite female gymnasts. Data acquisition was performed using an optical measurement system and some of the parameters were also assessed with direct measurements. Data analysis demonstrated that some segment linear regression modelling was accurate but some other were not pertinent. This study demonstrated homogeneity of a group of female gymnasts. The design of this study could be easily extended to other sport performers.

Keywords – Biomechanics, anthropometrics, body segment parameters, elite female gymnasts, movement analysis

I. INTRODUCTION

Kinematic and kinetic sport movement analysis requires the knowledge of body segment parameters (BSP) [1]. These parameters can either be obtained through direct measurements on the subject using electromechanical, optical, or medical imaging systems [2], or be deduced from more or less sophisticated anthropometric tables or models [1,3-5].

Anthropometric models provide BSP through a quick, convenient, and cost effective way. They indeed only require basic anthropometry equipment such as tape measures and callipers, some of them only needing the knowledge of subject's height and weight. However, creating an anthropometric model demands a BSP database preferably from a given population. So far, most of the samples used to design such tables consisted of old men, military or cadavers. Indeed, race-based models are rare and sport-discipline-based ones are scarce [6]. Consequently great disparities are observed among models, selection of a model relying more often on availability of data or measurement material than

objectivity [7]. Unfortunately such variability in BSPs can adversely affect biomechanical movement analysis, particularly for movement involving important segment accelerations [8-9]. Therefore, selective sampling is of the greatest importance in order to obtain the most accurate dataset for BSPs. Female gymnast movement analyses are concerned by this issue and consequently require a dedicated model [10].

This paper presents a new anthropometric model dedicated to a specific sport population. It was designed using a sample of 30 national level female gymnasts. Geometric and inertia data were obtained with an optical measurement system similar to Jensen's [11] and a semi-automated digitizing and BSP computing software. Data gathered in this study allowed for the creation of a statistical model [12].

II. MATERIAL AND METHODS

A. Population

Thirty Caucasian female gymnasts, having at least a national level experience in artistic gymnastic, took part in this experiment; their demographics are showed in Table 1. They had trained, on average, eighteen hours per week for more than six years. All experimental procedures were conducted with the approval of the University of Valenciennes and written informed consents were obtained from the gymnasts and their parents prior to testing.

TABLE I. DEMOGRAPHICS

Variable (n=30)		Mean	SD	Max	Min
Age	(Years)	14.4	3.4	25.0	11.0
Standing height	(m)	1.55	0.09	1.69	1.36
Weight	(kg)	48.29	11.38	73.00	29.90
BMI ^A	(kg/m ²)	19.95	2.88	25.56	16.13

^A This index was calculated by dividing total body weight (kg) to the squared standing height (m²).

B. Procedure

Gymnasts were measured in a single session during a rest period within their training, in gymnasium area. All gymnasts were measured during their competitive season. Before measurements were taken, each gymnast read and signed the informed consent document, completed demographic and gymnastics career information, and was then photographed. The subject wore her training leotards, all were tight fit. Reflective markers were placed on anatomical landmarks of the subject in order to allow segmentation reproducibility. Simultaneous frontal and lateral photographs of the subjects were taken with Olympus (μ 410, resolution 2272 \times 1704 pixels) digital cameras, using an experimental set up similar to the one described by Jensen [11] and Jensen and Fletcher [13]. Subjects were photographed in a calibrated volume, in an upright position, similar to the anatomical orientation, with the arm pronated and abducted.

After each subject was photographed, she was directed to one of the different stations for the measurement of stature, segment lengths, body mass and hand and forearm volumetry. Measurements were all performed by the same researcher. For body mass measurement, the subject was standing, steady and still, on a weighing scale, with the body weight evenly distributed between her feet. Measurements were taken to the closest 0.1 kg and two consecutive measurements had to coincide within 0.1 kg. For stature measurement, the subject was standing, with her back to the stadiometer, in front of the examiner, heels together, feet slightly externally rotated, arms at the sides and looking straight forward. Segment lengths were measured between two consecutive anatomical landmarks on the right side of the body and bilateral symmetry was assumed. Single measures were recorded for length variables. Measurements were recorded to the nearest 0.1 cm.

Subject's volumetric measurements were performed with a forearm volumeter (Volumeters Unlimited, Phoenix, AZ) measuring displaced water volume of the forearm and hand. Subjects were instructed to lower the arm slowly into the volumeter and to stop when the top of the volumeter came in contact with the stylium or the radiale. Hand water volume was a direct measurement of the water displaced, forearm volume being a derived measurement determined by subtracting the hand water displacement value.

C. Data analysis

The anthropometrical model used in this study consisted of 16 segments (two feet, two shanks, two thighs, two hands, two forearms, two arms, upper trunk, lower trunk, neck and head). Their definition was based on Dempster's [14]. Limb segments were separated from each other using horizontal planes going through the joint centres (ankle, knee, wrist and elbow). The thigh segment was separated from the lower trunk along the inguinal fold in the frontal plane. The upper trunk was separated from the lower trunk by a horizontal plane at the xyphoid process level and from the neck rostral to the collarbones. Arm was separated from the trunk with a vertical plane at the distal end of the collarbone.

TABLE II. REGRESSION ÉQUATION FOR SEGMENT MASSES (IN G) WITH TOTAL BODY MASS (TBM IN KG) AS A PREDICTOR^B

Segment (n)	b ₀ (95% CI)	b ₁ (95% CI)	r ²
Arm (28)	66.8 (-168;301)	21.7 (16.9;26.6)	0.765
Forearm (24)	196 (72.9;319)	12.1 (9.43;14.7)	0.805
Hand (30)	152 (106;198)	3.37 (2.44;4.29)	0.664
Thigh (29)	-592 (-1276;91.2)	148 (134;162)	0.946
Shank (30)	58,8 (-272;389)	45.4 (38.7;52,1)	0.874
Upper Trunk (28)	-1167 (-2633;300)	163 (132;193)	0.823
Lower Trunk (30)	-1325 (-4455;1805)	290 (227;354)	0.760
Head (25)	1922 (1275;2570)	33.0 (19.6;46.4)	0.531

^BPrediction equations are in the form: $mass(g) = b_0 + b_1 \times TBM(kg)$

The software horizontally sliced the segments in one-pixel-thick slices. Slices were then modelled as elliptical cylinders; ellipses' axes being slices' length in both views, front and side. According to Jensen's method and using semi-automated software designed at the Université de Valenciennes (France), segments' masses and centre of mass were computed from sagittal and frontal planes photographs. Body segment parameters computation method relying on the assumption of known segment densities, Drillis and Contini's [15] were used for this study except for the trunk, head and neck segments for which Dempster's [14] were preferred.

D. Statistical analysis

Regression equations were computed using the parameter presenting the greatest correlation coefficient as a predicting variable for the parameter of interest. Consequently segment masses regression had total body mass as explanatory variable; segment lengths regressions were computed using subject's height, and segment's centre of mass position was predicted using corresponding measured segment length. 95% confidence intervals for population estimate were also computed both for the slope (b₁) and the intercept (b₀) of each regression equations. Data were graphically verified and outliers were removed from the sample when data were obviously biased prior to regression equation computations. All statistical analyses were performed with SPSS software version 12.0 (SPSS, Chicago, IL).

TABLE III. REGRESSION EQUATIONS FOR SEGMENT LENGTH (IN CM) WITH HEIGHT (M) AS A PREDICTOR^C

Segment (n)	b ₀ (95% CI)	b ₁ (95% CI)	r ²
Arm (30)	-4.75 (-12.1;2.55)	21.2 (16.4;25.9)	0.751
Forearm (30)	-2.64 (-10.4;5.09)	16.0 (11.0;21.0)	0.607
Hand (30)	-3.11 (-9.15;2.94)	14.0 (10.1;17.9)	0.657
Thigh (30)	2.53 (-13.5;18.6)	18.8 (8.46;29.2)	0.330
Shank (30)	2.68 (-7.77;13.1)	22.4 (15.6;29.1)	0.623
Foot (30)	1.33 (-3.36;6.02)	32.0 (1.62;6.23)	0.143
Upper Trunk (30)	-3.45 (-15.2;8.35)	17.0 (9.41;24.7)	0.428
Lower Trunk (30)	-6.14 (-22.4;10.1)	28.4 (1.79;3.89)	0.524
Head+Neck (30)	10.5 (3.07;17.9)	6.82 (2.04;11.6)	0.234

^CPrediction equations are in the form: $dist(cm) = b_0 + b_1 \times height(m)$

III. RESULTS

Measured segment lengths and computed data (mass and centre of mass location) means and 95% confidence interval for the population means are shown in Figure 1 for mass and centre of mass location, respectively.

Table 2 shows the coefficients for segment mass regressions as well as their confidence intervals and r^2 for each of the segments of interest. Foot mass regression equation was not computed because of biased data, neither was neck mass because of obviously overestimated segment volumes.

Segment lengths data are displayed in Table 3, head and neck length are shown as only one because they were measured as such.

For centre of mass location, hand and foot data were not shown due to obviously biased volume computations, preventing us from computing an accurate location. Results for the other segments are shown in Table 4.

IV. DISCUSSION

These data acquired from a sample of elite female gymnasts permitted the creation of a partial model for estimation of

body segment parameters for this population. However, potential users should be aware of the present study's limitations. These data are population specific; it is consequently advised to use them on appropriate subjects only, i.e. elite female gymnasts. This sample included 30 subjects and was not tested for accuracy on other gymnasts. Finally, means should be preferred to regression equations presenting a coefficient of determination lower than 0.600 between parameter of interest and anthropometrics.

Segment centre of mass location using regression equations should only be used for thigh and shank segments. Segment length estimation using regression equations are reliable for half of the segments investigated, i.e. whole upper limb and shank segments.

Concerning segment masses presented here, only the head segment equation use is not recommended.

Neck and foot mass, as well as neck, foot and hand centre of mass locations were not investigated here due to lack of reliable data obtained with the semi-automated digitizing and BSP computing software.

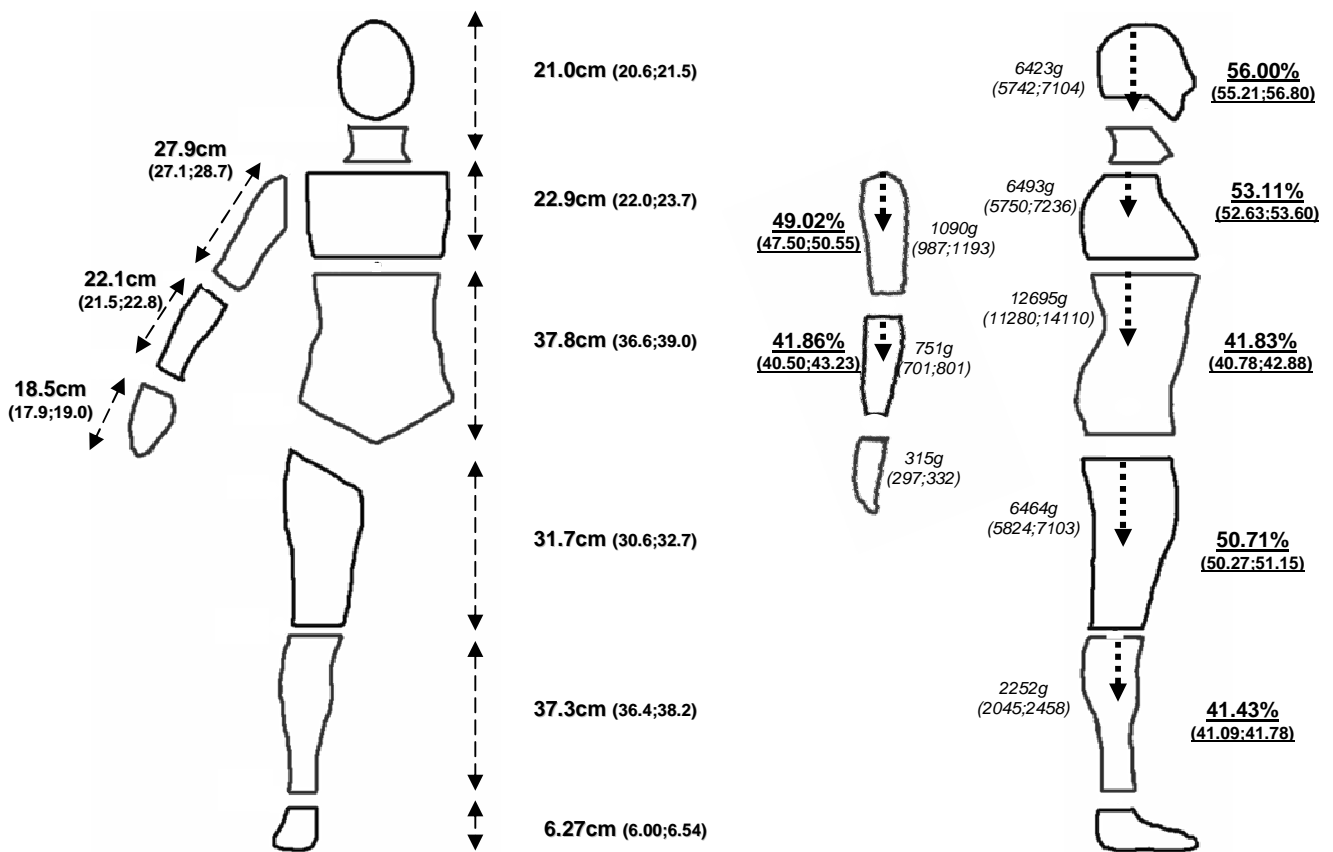


Figure 1. Mean segment length, mass, and centre of mass location (95% CI)

TABLE IV. REGRESSION EQUATIONS FOR SEGMENT CENTRE OF MASS DISTANCE FROM PROXIMAL JOINT CENTER (IN CM) WITH SEGMENT LENGTH (M) AS A PREDICTOR^D

Segment (n)	b ₀ (95% CI)	b ₁ (95% CI)	r ²
Arm (28)	0.472 (-4.63;5.58)	44.3 (26.0;62.6)	0.488
Forearm (23)	0.733 (-3.38;4.85)	35.0 (16.3;53.7)	0.420
Thigh (29)	6.57 (1.74;11.4)	51.6 (36.2;67.0)	0.637
Shank (30)	1.41 (-1.56;4.38)	34.6 (0.266;42.5)	0.739
Upper Trunk (28)	1.69 (-3.33;6.71)	30.2 (8.32;52.1)	0.236
Lower Trunk (30)	2.99 (-2.18;8.16)	33.2 (19.6;46.9)	0.472
Head (25)	5.43 (1.03;9.82)	18.6 (-2.42;39.6)	0.127

^DPrediction equations are in the form: $dist(cm) = b_0 + b_1 \times segmentLength(m)$

V. CONCLUSION

A reliable model, for both kinematics and kinetics applications, was computed from the data obtained in this study. Even though our model is not predicting all parameters for all segments, i.e. for neck segment, it is the only one, to our knowledge, that has been designed for female elite gymnasts. Certain segments data did not allow for reliable modelling and the results were excluded from this paper and should consequently be investigated further. Feet volume assessment, for instance, should be performed in order to improve the dataset. For data showing a coefficient of determination lower than 0.600, means provided in this paper should be preferred to regression equations until stronger relationships are found.

Consequently, methods used for this study proved to be both quick and inexpensive and could therefore be extended to other specific populations, as other elite sportsmen or disabled persons, or even used for individuals.

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References

- [1] D. A. Winter, "Anthropometry", in Biomechanics and motor control of human movement, third edition, Wiley-Interscience, New York, 2005.
- [2] D. J. Pearsall, J. G. Reid, "The study of human body segment parameters in biomechanics – An historical review and current status report" Sport Med., vol. 18 (2), pp. 126-140, 1994.
- [3] H. A. Hatze, "A mathematical model for the computational determination of parameter values of anthropomorphic segments", Journal of Biomechanics, vol. 13, pp. 833-843, 1980.
- [4] V. Zatsiorsky, V. Seluyanov, L. Chugunova, "In vivo body segment inertial parameters determination using a gamma-scanner method", in Biomechanics of human movement: application in rehabilitation, sports and ergonomics, N. Berme and A. Cappozzo, Eds. Worthington: Bertec Corporation, 1990, pp. 186-202.
- [5] P. de Leva, "Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters", Journal of Biomechanics, vol. 29, pp. 1223-1230, 1996.
- [6] T. R. Ackland, A. B. Schreiner, D. A. Kerr, "Absolute size and proportionality characteristics of world championship female basketball player", Journal of sport science, vol. 15, pp. 485-490, 1997.
- [7] M. Begon, P. Lacouture, "Modélisation anthropométrique pour une analyse mécanique du geste sportif partie 1: modèles leurs caractéristiques et leur validation" Science & Motricité, vol. 54, pp. 11-33, 2005.
- [8] G. Rao, D. Amarantini, E. Berton, D. Favier, "Influence of body segment's parameters estimation models on inverse dynamics solutions during gait", Journal of Biomechanics, in press, 2006.
- [9] D. J. Pearsall, P. A. Costigan, "The effect of segment parameter in error on gait analysis results", Gait and Posture, vol. 9, pp. 173-183, 1999.
- [10] V. A. Bricout, "Effects of gymnastics on growth and pubertal maturation in young girls", Science et Sport, vol. 18, pp. 65-73, 2003.
- [11] R. K. Jensen, "Estimation of the biomechanical properties of three body types using photogrammetric method", Journal of Biomechanics, vol. 11, pp. 349-358, 1978.
- [12] H. You, T. Ryu, "Development of a hierarchical estimation method for anthropometric variables", International Journal of Industrial Ergonomics, vol. 35, pp. 331-343, 2005.
- [13] R. K. Jensen, P. Fletcher, "Body segment moments of inertia of the elderly", Journal of Applied Biomechanics, vol. 9, pp. 287-305, 1993.
- [14] W. T. Dempster, "Space requirements of the seated operator", WADC Technical Report (TR-55-159), Wright-Patterson Air Force Base, OH, 1955.
- [15] R. Drillis, R. Contini, "Body segment parameters", PB 174 945, technical report 1166.03, New-York, School of engineering and science, 1966