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ACCURACY OF BODY MASS PREDICTION USING SEGMENTAL INERTIA PARAMETERS MODELLED FROM PHOTOGRAPHIC IMAGES

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The aim of this study was to evaluate the accuracy between the measured and predicted body mass, using the methods of Gittoes et al. (2009), and investigate the relationship between mass and stature and this accuracy. Fifteen male, recreational athletes from a university's sporting population took part in the study. Measured whole-body masses were compared with predicted whole-body masses calculated using photographic dimensional data and an inertia model. Mean absolute error between measured and predicted whole-body mass was 5.42 ± 2.92 %. A strong, negative correlation between measured whole-body mass and relative % error (r = -0.80) and a normalising value and relative % error was found. It is suggested that for similar participants errors could be up to ± 10% for participants with body masses much greater or less than 71 kg or normalising values equating to 1230 Nm.

KEY WORDS: body segment inertia parameters, inertia modelling

INTRODUCTION: Accuracy of biomechanical analysis can depend upon the extent to which an approximation of the body represents the true anatomical structure. An important set of mechanical properties are the body segment inertia parameters (BSIP; Pearsall and Reid, 1994). Mathematical inertia models (e.g. Hatze, 1980; Yeadon, 1990) combining anthropometric measurement of an individual with cadaver data (e.g. Dempster, 1955; Chandler et al., 1975) are commonly used in Sports Biomechanics to estimate individual-specific BSIP (Gittoes et al., 2009). In order to individually customise geometric shapes which represent the performer, a series of anthropometric measures are taken. Inertia models have shown a good level of accuracy in the estimation of the body mass of the participant (Table 1). In a practical setting however, when there is a large sample size or athletic performers for whom time-consuming data collections are undesirable, appropriate methods for determining BSIP requires consideration of key accuracy and practicality factors for commonly used Mathematical inertia modelling techniques (Table 1).

Table 1. Accuracy and practicality for selected Mathematical inertia modelling techniques.

Mathematical Inertia Model	Method	No. of measurements required	Subjects time required (mins)	Researcher time required (mins)	% accuracy of predicted body mass
Jensen (1978)	Photo	408	10	120	< 2
Hatze (1980)	Direct	242	80	80	< 0.05
Yeadon (1990)	Direct	95	30	30	< 2.1
Gittoes et al. (2009)	Photo	95	5	30	< 2.9

The mathematical model of Yeadon (1990) in conjunction with the digital imaging technique of Gittoes et al. (2009) appears to provide a practical compromise for use with athletes. The aim of this study was to evaluate the accuracy between the measured and predicted body mass using the methods of Gittoes et al. (2009), and investigate the relationship between mass and stature and this accuracy when applied to a different and larger sample of males.

METHOD: Fifteen male participants gave voluntary informed consent to take part (M ± SD age: 20 ± 3 years, mass: 74.7 ± 8.0 kg and stature: 1.76 ± 0.06 m). All participants were recreational athletes from a university's sporting population.

Clothing was restricted to tight fitting shorts. Whole-body mass and height were measured using laboratory weighing scales (Avery Berkel Ltd, model ED01) and a stadiometer (Holtain, Ltd.), respectively. The average of three measures was used.

In order to obtain individual specific BSIP, anthropometric data were obtained using the digital image technique reported by Gittoes et al. (2009) for use within Yeadon's (1990) geometric inertia model. A Canon EOS 400D (Tokyo, Japan) digital camera was used to obtain frontal and left and right whole-body plane images of each subject in a stationary, upright position. Six calibration points of known location were positioned on an upright, rectangular frame to define the plane within which the performer stood, and from which body landmarks were obtained. Images were cropped to a maximum resolution of 720 x 576 pixels using Zoom Browser EX (Canon Inc.,version 5.7), converted to .avi format using DVgate Plus (Sony Corporation, version 2.2.01), and then imported into Peak Motus (Vicon Motion Systems, version 9.0.0.27-GM) for digitizing. Each image was digitized for 10 fields to obtain 2-D coordinate data of the calibration object and the body segment contours at 45 defined landmarks, as detailed by Yeadon (1990). The same digitiser worked on all trials. Coordinates were reconstructed using the 2-D direct linear transformation (Walton, 1981) using TARGET video analysis system (Kerwin, 1995), and were then used to obtain lengths, perimeters, widths, and depths corresponding to the measurements required (Gittoes at al., 2009). The derived body measurements were independently input into Yeadon's (1990) inertia model. Density values from Dempster (1955) were combined with Yeadon's (1990) inertia model to provide three sets of customized BSIP for each subject. The inertia model's accuracy in replicating each subject's measured whole-body mass was derived for the three sets of model input data as the quantified difference (error) between the predicted and measured whole-body mass such that;

$$\%Error = \left(\frac{\mathrm{M_p} - \mathrm{M_m}}{\mathrm{M_m}}\right)100$$

where Mp = whole-body mass predicted by the model and Mm = measured whole-body mass (Gittoes et al., 2009).

Pearson's correlation coefficient were calculated between the % error (relative and absolute) and the measured whole-body mass, height and a normalising value of mass*acceleration due to gravity*height, as denoted by Hof (1996).

RESULTS: The subject's time required was less than 5 minutes, and the researchers time required was 25 ± 5 minutes. The absolute % error between the measured predicted whole-body mass was 5.42 ± 2.92 %. The relative % error was -2.06 ± 5.98 %.

A strong, negative (r = -0.80) correlation coefficient between participant mass and relative % error, and the normalising value and relative % error (r = -0.83) was identified (Table 2, Figure 1).

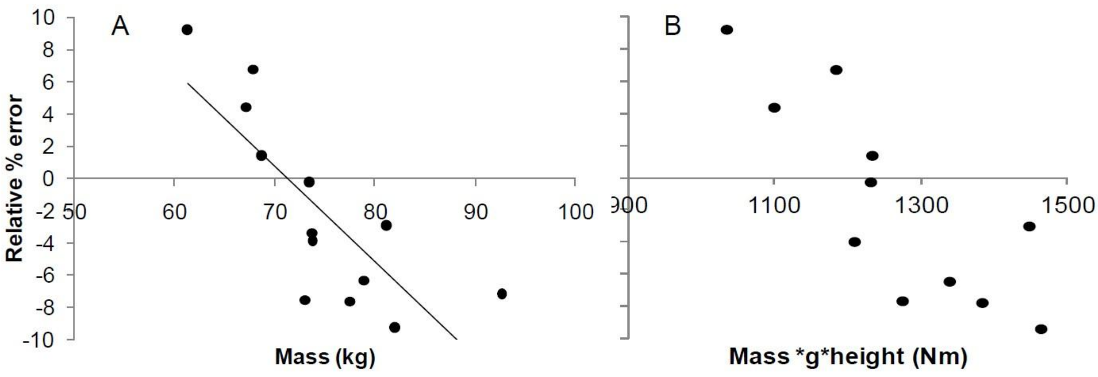

Figure 1. A - participant mass (kg) and B – participant normalised value (mass * g * height) against relative percentage (%) error between whole and predicted body mass, A - r = -0.80, B – r = -0.83.

Table 2. Pearson's correlation coefficients between percentage (%) errors in measured verses predicted whole body mass and anthropometric data for participants.

Correlation Cooefficient					
Relative % error			Absolute % error		
Mass (kg)	Height (m)	Mass*g* Height (Nm)	Mass (kg)	Height (m)	Mass*g* Height (Nm)
-0.80	-0.34	-0.83	0.12	0.12	0.06

DISCUSSION: A quantitative comparison of the predicted and measured whole-body mass was performed to indicate the level of confidence associated with an inertia modelling approach. Relative mean % difference between the predicted and measured whole body mass of participants was -2.06 ± 5.98 % indicating that, in line with Gittoes et al. (2009), for the whole group there was little systematic under or over estimation of body mass of the participants. In the current study, mean absolute error of 5.4 ± 2.9 % between the predicted and measure whole body mass were calculated. This is nearly double that found by Gittoes et al. (2009) of 2.87 %, however more comparable to a 4.1 % mean accuracy reported by Atack et al. (2009) for between digitiser comparison.

In order to increase understanding of the confidence associated with the inertia modelling approach, relative and absolute error were correlated with mass and height and a normalising value of the participants. A strong, negative correlation (r = -0.80) between mass of the participant and relative % error, and the normalising value and relative % error (r = -0.83) was identified. Based on the current data, which were representative of a male, university age sporting population, predicted mass of participants with a measured mass greater than 71 kg or to have a normalising value of 1230 Nm, were likely to be overestimated, while those measured as less that 71 kg or to have a normalising value of 1230 Nm were likely to be underestimated. Interestingly, participants reported in previous analyses were close to this critical mass. Gittoes et al. (2009) used five participants, of mean mass 70.9 ± 6.8 kg, while Atack et al. (2009) used one participant, mass 74.4 kg. Therefore, higher mean absolute error found in the current study was likely the result of a wider range of anthropometric characteristics of the participants. It should be noted however, that whether there would be a linear relationship through extremes in mass and height characteristics is questionable.

The ability of an inertia model to replicate the inertia characteristics of a participant is limited by assumptions within the model, for example the BSIP characteristics supplied by Dempster, 1955), and the homogenous segment density assumption of Yeadon's (1990) model.

CONCLUSION: The method of Gittoes et al. (2009) for estimating BSIP provided a practical solution when participant's time is limited. Although the absolute errors in predicted mass found in the current study were higher than those previously reported. It is suggested that for similar participants, errors could be up to ± 10 % for participants with masses greater or less than 71 kg or those to have a normalising value of 1230 Nm.

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