AN IMAGE-BASED APPROACH TO OBTAINING ANTHROPOMETRIC MEASUREMENTS FOR ATHLETE-SPECIFIC INERTIA MODELLING

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This study aimed to develop and evaluate an image-based method of obtaining anthropometric measurements for athlete-specific inertia modelling. Anthropometric measurements were obtained directly from five athletic performers and indirectly from digitization of whole-body still images. The direct and image-based measurements were used in Yeadon's (1990) inertia model. The mean absolute accuracy in predicted whole-body mass achieved using the direct and image-based approach was 2.10% and 2.87%, respectively. The presented approach provided a successful alternative to direct measurement for obtaining anthropometric measurements for inertia modelling of athletic performers. The method offers a valuable solution for obtaining measurements from elite athletic performers for whom time-consuming data collections may be undesirable.

KEY WORDS: human body, two-dimensional, digitization, customised.

INTRODUCTION:

One important set of mechanical properties is body segmental inertia parameters (Pearsall & Reid, 1994), and in many applications including sports performance analysis a parameter set for the individual under study is desirable (Yeadon, Challis & Ng, 1993). Cadaver data has been used to estimate the inertia parameters of individuals if their body mass and stature are known (Forwood, Neal & Wilson, 1985). De Leva (1993) showed that the generalization of cadaver data, which in the main have been from elderly male Caucasians, leads to large errors in segmental centre of masses when applied to other populations. As the biomechanical representation of the human becomes more complex the requirement of specific inertia parameters becomes essential to avoid inaccurate kinetic analyses (Pearsall & Reid, 1994).

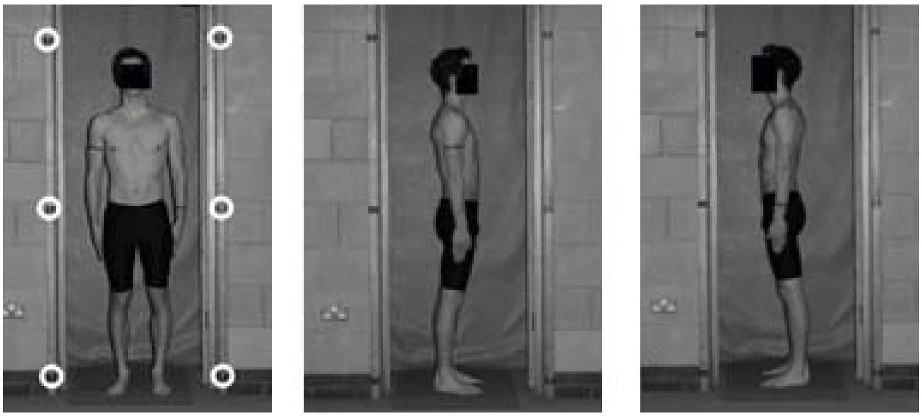
Mathematical models, which represent the body segments using a number of geometric solids are capable of estimating values of all segmental inertia parameters (Yeadon, 1990), which are derived using an individual's anthropometric measurements. The number of measurements taken depends on the number of solids that comprise the model. Yeadon's (1990) model, which estimates total body mass with a maximum error of 2.3%, comprises 40 solids, specified by 95 anthropometric measurements. The measurement time can be less than 30 minutes for an experienced operator, although when time with the subject is limited, as is frequently experienced when dealing with large sample sizes or elite athletic performers, this technique may not be feasible.

Jensen (1978) developed a geometric modelling approach, which used dimensions obtained by digitizing photographic images of the subject. Whilst data collection time using Jensen's (1978) method may have been less time consuming than direct measurement techniques, additional time for allocating reference points on the subject prior to obtaining the images was required. More recently, Baca (1996) developed a method for determining 220 anthropometric measurements from video images to be used as input to Hatze's (1980) model and found the results to be comparable to those obtained by direct measurement. Baca (1996) concluded this method was especially useful in situations where ease of application and rapid availability are of importance. The aim of this study was to develop and evaluate a method of obtaining anthropometric measurements, which may be used to derive athlete-specific inertia parameters using Yeadon's (1990) inertia model and a reduced collection time.

METHOD:

Anthropometric measurements were obtained from five athletic male performers (age: 22.8 ±2.6 years; whole-body mass: 70.9 ±6.8 kg; height: 1.729 ±0.114 m). Approval for the study

was provided by the University's Research Ethics Committee and each subject gave written informed consent. Subjects wore only tight-fitting shorts, allowing identification of body segment landmarks.
Ninety five anthropometric (direct) measurements, detailed for Yeadon's (1990) inertia model, were taken from each subject using a tape measure and anthropometric callipers. The whole-body mass (Table 1) and height of each subject were measured directly using laboratory weighing scales (Avery Berkel Ltd, model ED01) and a stadiometer (Holtain Ltd), respectively. Direct measurements for each subject were obtained within 30 minutes.
A Canon EOS 400D digital camera was used to obtain frontal and left and right sagittal plane whole-body images of each subject in a stationary, upright position (Figure 1). Six calibration points of known location were positioned on an upright, rectangular frame (1.800 m x 0.916 m) in the field of view of each whole-body image.



(a) (b) (c)

Figure 1: Whole-Body Images of the Frontal Plane (A) and Right (B) and Left (C) Sagittal Plane View of One Subject. Image A. Illustrates the Six Calibrations Points.

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), then imported into Peak Motus (Vicon Motion Systems, version 9.0.0.27-GM) for digitizing. Each image was digitized to obtain two-dimensional (2D) coordinate data of the calibration object (ten fields digitized) and the body segment contours (ten fields digitized) at 45 defined landmarks as detailed by Yeadon (1990). Coordinates were reconstructed using the 2D Direct Linear Transformation (Walton, 1981) and used to obtain lengths, perimeters, widths and depths corresponding to the measurements required by Yeadon's (1990) inertia model. Perimeter measurements were not obtainable directly from the images, so 2D width and depth images were used to derive perimeter measurements for input into the inertia model. All image-based measurements were taken as the mean value over the ten digitized fields.
The measurements derived directly and using whole-body images were independently input into Yeadon's (1990) inertia model. The inertia model's accuracy in replicating each subject's measured whole-body mass was derived for each set of model inputs such that:

$$\text{Accuracy} = \left(\frac{M_p - M_m}{M_m}\right)100$$

where M_p = whole-body mass predicted by the model, M_m = measured whole-body mass.
The mean absolute accuracy of the image-based approach for obtaining anthropometric measurements for inertia modelling was compared with the mean absolute accuracy achieved using direct measurements across the five subjects investigated. A comparison of the absolute accuracy of the two approaches was made to prevent potential distortion of the total error of each approach due to subject-specific over or under estimations.
The model accuracies achieved using whole-body image data derived from repeated digitizations (each of 10 fields) of one subject were examined to determine within- and

between-operator reliability. Within-operator reliability was assessed by comparing model accuracies achieved for the same subject using measurements from repeated digitizations performed by one operator. Model accuracies achieved using measurements from a digitization performed by each of two operators and for one subject were used to define between-operator reliability. Reliability was subsequently established as the percentage difference between the model accuracies achieved with each corresponding digitization.

RESULTS:
The levels of agreement between the measured and predicted whole-body mass derived using the inertia model and the two sets of anthropometric input data are illustrated in Table 1. On average, the direct measurement produced a more successful replication of the measured whole-body mass compared to the image-based approach. The mean ±SD of the absolute accuracies were 2.10 ±1.61% and 2.87 ±1.57% using the direct and digitized whole-body image measurements, respectively. However, for two subjects (C & D), the image data produced more accurate whole-body mass replications than the direct measurements. The image-based approach produced a slightly larger maximum percentage difference (5.42%) in whole body mass replication across the five subjects than the direct approach (4.86%).
The direct and image-based approaches were not found to systematically over or under estimate whole body mass across the five subjects. Within- and between-operator repeatability of accuracy achieved for Subject A (Table 1) was 0.20% (within-operator) and 0.35% (between-operator), respectively for whole-body image data.

Table 1 Subject-Specific Measured Whole-Body Mass and Model Accuracy (%) Produced Using Direct and Digitized Whole-Body Image Anthropometric Measurements

Subject	Measured whole-body mass (kg)	Accuracy (%) Direct	Whole-body image
A	74.40	1.37	3.12 [a]
B	80.90	-1.84	-2.52
C	67.70	1.77	-1.33
D	67.90	4.86	1.96
E	63.70	0.66	-5.42

[a] model accuracy for a repeated within-operator digitization: 3.32%; model accuracy for a repeated digitization performed by a second operator: 3.47%

DISCUSSION:
An image-based approach for obtaining indirect athlete-specific anthropometric measurements for inertia modelling of body segments was presented. The success of the approach was determined by the level of accuracy achieved in replicating whole-body mass using Yeadon's (1990) inertia model compared to that achieved using traditional direct measurements. The direct measurement approach successfully replicated whole-body mass of athletic male performers to a mean absolute accuracy of 2.1%, which was comparable to that achieved by Yeadon (1990) (2.0%) using direct measurements from three subjects.
A higher mean absolute (2.9%) accuracy and maximum percentage difference was achieved using the presented whole-body image-based approach compared to that achieved using direct measurements, which suggested that accurate inertia modelling of whole-body mass ideally requires the use of measurements taken directly from the subject. Although the image-based method required additional time for digitization (approximately 40 minutes for each subject), the slightly improved mean absolute accuracy achieved using the direct measurements was counterbalanced by the substantially longer subject contact time required (direct: 30 minutes; image: 5 minutes). Furthermore, the image-based approach produced a better replication of the whole-body mass of two subjects compared to the direct approach.
The findings of this investigation supported the suggestion of Baca (1996) that image-based measurements can be used to produce similar levels of accuracy as direct when estimating

inertia parameters using a geometric model. In comparison to the 220 measurements derived by Baca (1996) for Hatze's (1980) inertia model, the presented approach required only 95 measurements. A high level of accuracy in replicating inertia parameters of athletic individuals was maintained using the presented approach when using a low number of image-based measurements. The benefits of a reduced measurement set are a shorter processing time integrated with a potentially reduced measurement error across the whole-body profile.
The success of the image-based approach in replicating whole-body mass only was addressed in this investigation. Unlike other body segment inertia parameters e.g. segment masses, the predicted whole-body mass could be quantitatively compared to a direct subject-specific measurement. As suggested by Yeadon (1990), simulation studies using the predicted inertia parameters, and assessing the level of agreement between simulations and actual performances, may provide future insight into the appropriateness of other predicted inertia parameters.

CONCLUSION:
The presented image-based approach provided a successful alternative to direct measurement for obtaining anthropometric measurements required for customised inertia modelling of athletic performers. The image-based approach is potentially beneficial for indirectly deriving comprehensive anthropometric measurements from large samples of subjects or elite athletic performers for whom time-consuming data collections may be undesirable.

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