THE RELIABILITY OF TRUNK SEGMENT INERTIAL PARAMETER ESTIMATES MADE FROM GEOMETRIC MODELS

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The purpose of this study was to examine the reliability with which trunk segment inertial parameters could be estimated using a geometric modelling technique. Repeat width and depth measurements were obtained from eight male participants by two examiners. This enabled trunk inertial parameters to be estimated using a geometric model similar to that defined by Yeadon (1990). The majority of these parameters were estimated with acceptable inter-examiner and intra-examiner reliability, this was determined by an intra-class correlation value greater than 0.7. The lowest reliability was obtained for the shoulders segment which can be difficult to model due to its irregular shape. If shoulder segment inertial parameters are to be considered in a given analysis, the use of repeat measures is recommended as a way to improve reliability.

KEYWORDS: inter-examiner, intra-examiner, electromagnetic tracking system.

INTRODUCTION: In many applications including the analysis of sports performance, individual specific body segment inertial parameter (BSIP) estimates are desirable (Damavandi, Farahour, & Allard 2009). For example body segment masses and centre of mass locations are required to calculate intersegmental forces and net joint moments using inverse or forward dynamics equations. Several methods have been used to calculate BSIP including; regression based techniques, scanning techniques, and geometric modelling techniques.
Geometric models use a series of geometric shapes to represent body segments. The dimensions of these shapes are defined by anthropometric measurements taken directly on a participant. Using these measurements, it is possible to approximate the segment geometry and subsequently, by assuming uniform density, estimate the inertial parameters. Several geometric models have been proposed (e.g. Hatze, 1980; Yeadon, 1990), with varying complexity.
Irrespective of which model is chosen, the reliable estimation of BSIP is essential for analyses of human movement. Small changes in BSIP have previously been shown to influence kinetic measures especially when movements involve large accelerations (Damavandi et al., 2009). In comparison with accuracy, the reliability of BSIP estimates is relatively easy to assess. However, reliability has been the focus of few studies examining body segment inertial parameters estimates made from geometric models.
Challis (1999) reported that human limb segment inertial parameters can be determined with high precision when estimated using a geometric model. However the reliability of trunk segment inertial parameter estimates was not examined. In comparison to modelling the limb segments Wicke and Dumas (2010) suggested that modelling the trunk segments using simple shapes is difficult. The complexity of trunk segment inertial parameter estimates made from geometric models is further increased due to its tendency to change shape as a result of breathing. It is therefore likely that the inertial parameters of the trunk would be estimated with lower reliability.
The purpose of this study was to examine the reliability with which trunk segment inertial parameters could be estimated using a geometric modelling technique. Both inter- and intra-operator reliability was assessed.

METHODS: Eight males were recruited to participate in this study (27.38 ±3.58 y, 1.81 ±0.08 m and 79.49 ±12.73 kg). Before data collection, ethics approval was granted by the Faculty of Health and Wellbeing Research Ethics Committee.

The trunk was modelled using an approach similar to that defined by Yeadon (1990). Four trunk segments were defined using five stadium solids (Figure 1). The dimensions of the stadiums were obtained by taking anthropometric measurements on the participants.

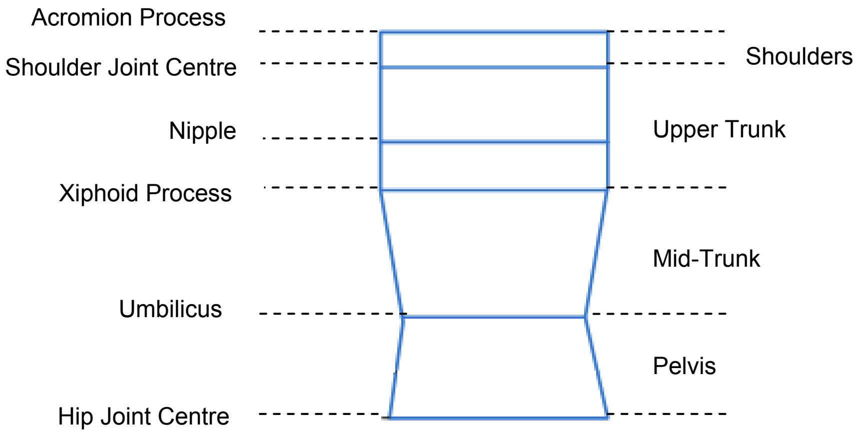

Figure 1: Trunk segmentation adapted from Yeadon (1990).

Two examiners made the anthropometric measurements required to estimate BSIPs. The examiners had received the same training in taking model measurements and were accustomed to the data collection protocol. The anthropometric measurements were made eight times for each participant: twice by examiner A and twice by examiner B: on two consecutive days. On each day the measurements were taken in the same session lasting approximately one hour and the order in which examiners performed data collection was randomly assigned. The examiners had no record of any previous measurements and to ensure that all of measures were independent at least 20 minutes elapsed between measurements.

Three Polhemus electromagnetic sensors were attached to each participant using a specially designed jacket. The locations of 31 anatomical landmarks were then identified by palpation and recorded in relation to the relevant sensor using the Polhemus stylus, the Polhemus electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA) and custom written software. The identification of anatomical landmarks was performed with the participants in the anatomical position, standing upright with their arms by their sides and palms facing forwards. The position of the anatomical landmarks was used to calculate the width and depth measurements required to form the stadium solids used to represent the trunk. This enabled after assuming uniform density (Dempster, 1955) segment mass, centre of mass location and moments of inertia to be estimated using the equations defined by Yeadon (1990). Each segment's local coordinate system was defined such that the x, y and z axes were sagittal, longitudinal and frontal, respectively.

The reliability of trunk inertial parameter estimates was analysed using SPSS. Relative reliability was quantified by computing intraclass correlation coefficients (ICC). Inter-examiner reliability was measured using a two way random effects model with single measures reliability (ICC (2,1)) and intra-examiner reliability was assessed using a two way mixed effects model with single measure reliability (ICC (3, 1)) (Shrout & Fleiss 1979). The standard error of measurement (SEM) was also calculated to assess absolute reliability. Acceptable reliability was determined by an ICC value greater than 0.70. This ICC scale has previously been used in reliability studies (De Vet, Terwee, Knol & Bouter, 2006) and was deemed appropriate for reliability analyses in health care studies (Munro, 1986).

RESULTS: The majority of trunk segment inertial parameters were estimated with acceptable reliability (Table 1). Pelvis and upper trunk inertial parameters were estimated with the highest reliability. High ICC values were reported for these segments for inter-examiner and intra-examiner reliability. In general, there appeared to be little difference between inter-examiner and intra-examiner reliability. However examiner 1 produced slightly

less reliable inertial parameter estimates for the pelvis segment; demonstrated by greater SEM relative to the mean value.
Shoulder segment inertial parameters were estimated with the lowest reliability. Shoulder segment mass was estimated with moderate inter-examiner reliability (ICC=0.63). Finally the results also suggest that COM estimates for all trunk segments were made with low inter-examiner and intra-examiner reliability.

Table 1: Inter-examiner and intra-examiner reliability of trunk inertial parameter estimates.

		Inter-Examiner		Intra-Examiner 1		Intra-Examiner 2	
Segment	BSIP	ICC	SEM	ICC	SEM	ICC	SEM
Pelvis	Mass (kg)	0.95	0.58	0.81	1.09	0.94	0.60
	COM (cm)	0.65	0.56	0.57	0.71	0.70	0.44
	Ixx ($kg.cm^2$)	0.94	7.20	0.80	13.47	0.93	7.13
	Iyy ($kg.cm^2$)	0.97	6.94	0.90	13.45	0.97	7.72
	Izz ($kg.cm^2$)	0.95	8.79	0.83	16.20	0.94	9.55
Mid- trunk	Mass (kg)	0.76	1.24	0.83	0.92	0.88	0.92
	COM (cm)	0.49	1.07	0.57	0.76	0.77	0.72
	Ixx ($kg.cm^2$)	0.75	12.38	0.80	8.98	0.89	9.16
	Iyy ($kg.cm^2$)	0.88	12.84	0.90	10.90	0.93	10.91
	Izz ($kg.cm^2$)	0.79	15.24	0.83	11.23	0.89	12.04
Upper	Mass (kg)	0.95	0.39	0.90	0.62	0.87	0.60
trunk	COM (cm)	0.70	0.54	0.68	0.61	0.49	0.61
	Ixx ($kg.cm^2$)	0.93	8.08	0.86	12.80	0.85	10.10
	Iyy ($kg.cm^2$)	0.98	4.59	0.94	8.45	0.91	8.86
	Izz ($kg.cm^2$)	0.94	7.20	0.92	8.84	0.88	9.27
Shoulders	Mass (kg)	0.63	0.37	0.78	0.31	0.86	0.27
	COM (cm)	0.33	0.28	0.37	0.28	0.46	0.26
	Ixx ($kg.cm^2$)	0.82	1.02	0.85	1.06	0.84	0.76
	Iyy ($kg.cm^2$)	0.73	5.50	0.85	4.65	0.80	3.58
	Izz ($kg.cm^2$)	0.72	4.57	0.82	4.20	0.80	2.83

Moments of inertia are presented about the anterior posterior (Ixx), longitudinal (Iyy) and Izz (medial-lateral) axes.

DISCUSSION: The reliability of trunk inertial parameter estimates from a geometric model was assessed. Whilst the results presented are specific to the selected geometric model, it is anticipated that they can be used as a general indication of the reliability of trunk inertial parameter estimates made using the geometric modelling technique. The results indicate that the majority of trunk BSIPs can be estimated with high reliability. They also suggest that there is little difference between inter-examiner and intra-examiner reliability.
The ICC values reported in this study were slightly lower than the ICC values reported by Challis (1999) for the estimation of human limb inertial parameters. This would appear reasonable as it has been suggested that due its tendency to change shape as a result of breathing and irregular shape trunk inertial parameters can be difficult to estimate reliably using geometric models (Challis, 1999; Wicke & Dumas, 2010).
Questionable inter-examiner and intra-examiner reliability was reported for the majority of COM estimates (Table 1). Weir (2005) suggested that lower ICC values can be reported when the difference between means and within participant variability are low. A previous study indicated that within participant variability in COM estimation is likely to be low as it is the most accurately estimated inertial parameter. This could explain the low ICC values reported for COM estimation especially for intra-examiner reliability.

In this study the locations of anatomical landmarks were recorded using the Polhemus system. The nature of this equipment dictated that width and depth values were used to define the stadium solids rather than perimeter and width values which were used by Yeadon (1990). The use of width and depth values to define a stadium solid is not entirely new. Gittoes, Bezodis and Wilson (2009) reported that perimeter values derived from width and depth measurements provided a successful alternative for obtaining BSIP estimates from geometric models.
Lower inter-examiner and intra-examiner reliability was reported for the mid-trunk segment. This segment contains a relatively high amount of fat compared to limb segments (Wicke & Dumas, 2010). This is likely to increase anatomical landmark identification variability compared to other body segments where landmarks are frequently located on bony prominences (Huijbregts, 2002). A larger proportion of fat also increases the likelihood and variability of soft tissue depression during anatomical landmark identification. These soft tissue depressions would alter the width and depth values used to define the stadium solid therefore increasing the variability of inertial parameter estimates.
Shoulder mass was also estimated with only moderate inter-examiner reliability. Using a single shape to model this segment has been reported to be extremely difficult as its transverse cross-sectional area is not symmetrical, especially about the medio-lateral axis (Wicke & Dumas, 2010). Challis (1999) suggested that the reliability of inertial parameter estimates, particularly for segments more difficult to measure reliably, can be improved, by summing repeated measures of inertial parameters. Improving the consistency of anatomical landmark identification could also improve the reliability of BSIP estimate.

CONCLUSION: The results presented in this study indicate that the majority of trunk segment inertial parameters can be estimated with high inter-examiner and intra-examiner reliability. These results therefore provide support for the use of body segment inertial parameter estimates made using this geometric modelling technique in kinetic and energetic analyses of human movement. Further studies are required to examine the generalizability of these results, in particular whether they are representative of other geometric models.

REFERENCES:

Challis, J. H. (1999). Precision of the estimation of human limb inertial parameters. *Journal of Applied Biomechanics,* 15, 418-428.

Damavandi,M., Farahpour, N. & Allard, P. (2009). Determination of body segment masses and centre of mass using a force plate method in individuals of different morphology. *Medical Engineering and Physics,* 31 (9), 1187-1194.

Dempster, W.T. (1955). Space requirements of the seated operator. WADC Technical Report (TR-55-159). Wright-Patterson Air Force Base.

De Vet, H.C.W., Terwee, C.T., Knol, D.L. & Bouter, L.MI. (2006). When to use agreement versus reliability measures. *Journal of Clinical Epidemiology*, 59 (10), 1033-1039.

Gittoes, M.J., Bezodis, I.N. & Wilson, C. (2009). An image-based approach to obtaining anthropometric measurements for inertia modelling. *Journal of Applied Biomechanics*, 25 (3), 265-270.

Hatze, H. (1980). A mathematical model for the computational determination of parameter values of anthropomorphic segments. *Journal of Biomechanics*, 13 (10), 833-843.

Huijbregts, P.A. (2002). Spinal motion palpation: A review of reliability studies. *The Journal of Manual and Manipulative Therapy,* 10 (1), 24-39.

Munro, B.H. (1986). Statistical methods for health care research. Lippincott Philadelphia (JB).

Shrout, P.E. & Fleiss, J.L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin*, 86 (2), 420-428.

Weir, J.O. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research,* 19 (1), 231-240.

Wicke, J. & Dumas, G. (2010). Influence of the volume and density functions within geometric models for estimating trunk inertial parameters. *Journal of Applied Biomechanics*, 26 (1), 26-31.

Yeadon, M.R. (1990). The simulation of aerial movement II. A mathematical inertia model of the human body. *Journal of Biomechanics*, 23 (1), 67-74.