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Reconstructing the postural sway using body segment inertial parameters

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SUMMARY

Until today a variety of studies have been conducted to improve the Body Segment Inertial Parameters (BSIP) estimations but real validation methods have never been completely successful. This research proposes an original method (OM) based on kinematic features of the movement using an optical motion capture system and kinetic parameters gathered from a force plate (FP) to estimate BSIPs. To validate the results, we used the measured contact force (FP) as the ground truth, and reconstructed the displacements of the Center of Pressure (CoP) using the inverse dynamics and the BSIP estimated by the proposed approach and compared classical postural parameters between OM and FP. The results of the OM are in accordance with the actual CoP movement (FP) and this method could be used as a tool to validate other estimation techniques.

INTRODUCTION

The body segment inertial parameter (BSIP) estimation without taking extra anthropometric measurements should be preferred over classical anthropometric models [1-3] and would be a useful tool if it delivers reliable and validated calculations. The BSIP have a major impact when evaluating the kinetics of joints as in the computation of inverse dynamics. Calculating BSIP has been also shown to be significant for clinical and biomechanical research [4-6]. The measurement of inertial parameters and the position of the center of mass (COM) of each body segment allow e.g. monitoring the variations in muscle-mass in patients during hospitalization, rehabilitation or neurological examination. Usually the obtained results are compared to data from the literature, which may not match the sample group or are based on regression methods or cadaver studies [7-8]. The objective of this research was twofold, first we introduce an original method (OM) to improve the BSIP estimation for each subject and secondly we compare the results with measured contact forces of the force plate (FP).

METHODS

10 subjects (22 ± 3 years) voluntarily participated in the experiment after signing a statement of informed consent as required by the Helsinki declaration. Subjects performed a 120 seconds predefined identification sequence which involves a variety of movements trying to use each DOF of the body and to perform it with different velocities and accelerations. As discussed in our previous work [9-11], the modeling depends on the purpose of identification and the real constraints such as the measurement facility. We consider a model of the human body consisting of 40 DOF and fifteen rigid as proposed by the recommendations of [5]. The geometric parameters of the human body were automatically measured using the positions of the passive optical reflective marker. The motions were recorded at a frequency of 100Hz by an optical motion capture system consisting in 8 cameras (T160 series, Vicon motion systems Inc., Oxford, UK). 35 passive reflective markers were attached to the body of the subjects. These markers are located at the defined anatomical points to insure accuracy of inverse kinematics computations. The contact forces are measured by 1 force-plate (Bertec) at 1000Hz. The inverse kinematics, to obtain the joint angles and their derivatives, is computed by an in-house software [9-10] using the human model. To quantify the results the data was analyzed individually, i.e. the measured ground reaction forces and CoP measurement (FP) separately from the computed sway using the estimated BSIPs of the OM (see Figure 1). This is important to see the coherence between the two signals. To characterize the measurement-estimation differences, the inter-signal comparison was computed using the mean velocity, the 95% Confidence Ellipse and Root-Mean Square error of the anterior-posterior and medio-lateral CoP movement.

RESULTS AND DISCUSSION

To analyze the calculated BSIP, we used the framework of a motion capture based estimation technique and computed the external forces obtained from the force plate and the assessed contact forces from the model.

Across all subject the proposed estimation technique shows its benefits and an individual BSIP estimation was possible including the validation with the external ground reaction forces. Furthermore the measured center of pressure movement and the efforts were recalculated by the inertial parameters of each body were compared using classical parameters to evaluate postural sway, as the length of the postural sway, the root mean square and average speed (see Table 1). An ANOVA combining the two calculation methods and the four variables, with an alpha set to 0.05 showed no differences between the parameters measured and recalculated by the proposed BSIP estimation technique

F(1, 9)=.052, p>.05, which is a good indicator for the success of the proposed estimation technique.

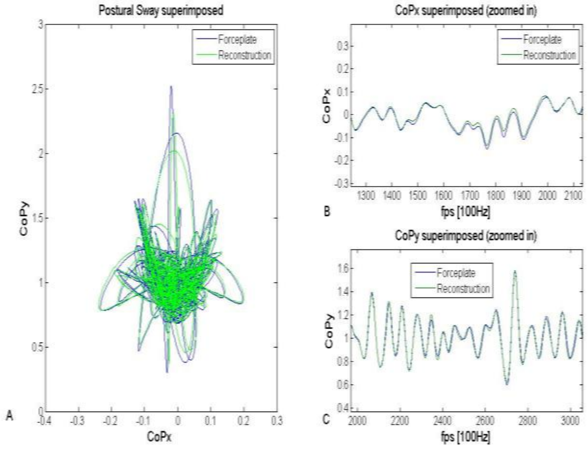

Figure 1: Shows the differences of the Force plate data and the reconstructed CoP movement. A) shows the CoPx and CoPy against each other, B) & C) show each CoP time series respectively.

CONCLUSIONS

The purpose of this research was to describe a novel method (OM) to validate the BSIP estimation using a force plate. The method was presented in the context of a dynamic movement. An advantage of this method is that the BSIP estimation approaches can be validated against a ground truth which does not exist when comparing the results with other data bases.

A characteristic feature of the method is that each research can be compared within subjects but also within studies.

For this reason, we do propose that method so researches can apply to their estimations without exception. This will allow adjusting previous considerations and choices concerning the estimation method. The validation method of the BSIP estimation was outlined in this paper. The method was applied to a dynamic movement obtained during a movement analysis study. The validation is straightforward and easy to implement when the BSIP parameters have already been estimated. Future studies will examine the efficacy during movements with different length and different movement speeds. This method could facilitate the comparison but especially the validation of new and previous estimation techniques and it will prove to be helpful in clinical and biomechanical research.

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T**able 1:** The classical postural sway parameters for each subject, calculated using the OM and the FP data

Classical Parameter Comparison								
Parameter	**mean Velocity FP**	**95% Ellipse FP Surface**	**RMS M/L FP**	**RMS A/P FP**	**mean Velocity OM**	**95% Ellipse OM Surface**	**RMS M/L OM**	**RMS A/P OM**
S1	3.85	0.06	0.04	1.00	3.73	0.06	0.05	1.00
S2	3.81	0.05	0.04	1.01	3.95	0.05	0.04	1.01
S3	5.30	0.08	0.06	1.01	5.44	0.09	0.06	1.01
S4	4.72	0.06	0.04	1.00	4.73	0.06	0.04	1.00
S5	6.47	0.07	0.04	1.01	6.75	0.07	0.04	1.01
S6	4.71	0.04	0.03	1.01	4.74	0.04	0.03	1.01
S7	5.01	0.05	0.03	1.01	5.16	0.05	0.03	1.01
S8	5.05	0.07	0.06	1.00	4.95	0.07	0.05	1.00
S9	13.70	0.25	0.06	1.04	13.16	0.24	0.06	1.04
S10	9.54	0.16	0.06	1.02	9.72	0.16	0.06	1.02
Average	**6.22 ± 2.21**	**0.09 ± 0.05**	**0.05 ± 0.01**	**1.01 ± 0.01**	**6.23 ± 2.19**	**0.09 ± 0.04**	**0.05 ± 0.01**	**1.01 ± 0.01**