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THE INFLUENCE OF JOINT CONSTRAINTS IN JOINT MOMENTS ESTIMATION DURING LEVEL WALKING IN THE ELDERLY

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SUMMARY

The purpose of this study was to verify the influence of model joint constraints in lower limb joint moments during level walking in the elderly. Nine healthy elderly subjects volunteered for this study. Three models were built and optimized differently (SO: segment optimization, each segment had 6 degrees of freedom; GO: global optimization, allowing only rotations in the joints; GOR: global optimization, allowing 3 rotations on the hip, one (flexion/extension) on the knee and 2 (flexion/extension; pronation/supination) on the ankle) and compared for the 9 participants. Differences between methods were especially critical between the GOR and both GO and SO for the ankle and knee moments in the frontal and transverse planes of motion, showing that GOR may not be suitable to be applied in every study.

INTRODUCTION

Motion capture is a widely used technique in human movement analysis for both clinical and sports applications. This technique allows the assessment of skeletal movement by estimating the pose (position and orientation) of body segments, from the measurement of instantaneous positions of markers located on the skin surface. However, the mentioned pose estimation process is affected by several sources of error, such as instrumental inaccuracies, anatomical landmark misplacement, and soft tissue artifact (STA) [1]. The last is considered the most critical source of error, being a special concern when dealing with subjects with high body mass index, such as the elderly population. Therefore, different methods have been proposed in order to compensate for STA [2], such as optimization methods, which make use of the redundancy of markers. In segmental optimization methods (SOM) [3] each segment is tracked independently and its pose is computed finding the optimal fit, in a least-squares sense, between the model determined and the experimentally measured markers coordinates. This method treats each segment independently, i.e. doesn't apply any joint constraints, making possible the occurrence of non anatomical joint displacements. Contrarily, in global optimization methods (GOM) [4] joint constraints are applied and the best fit is determined considering the entire limb or body at each frame instead of each segment independently.

Despite the controversy about the reliability of GOM methods in minimizing STA [5], the use of a kinematic model with joint constraints is becoming more usual in biomechanical analysis. Since computed joint kinematics and kinetics are dependent on the estimated pose of segments, and GOM also highly depends on joint constraints [6] (i.e. the model's degrees of freedom), further studies are needed for a better understanding of the phenomenon and its influence on kinematic and kinetic data. Thus, the purpose of this study is to verify the influence of these constraints in lower limb joint moments during level walking in the elderly.

METHODS

Nine participants over 65 years (72.2±4.0y) volunteered to this study. None of them had any neurologic or orthopedic condition that would affect their gait pattern. Immediately prior to data collection, all participants were informed about the study, accepted to participate and signed the informed consent. The Ethics Committee of Faculty of Human Kinetics approved the study protocol.

Gait kinematics and kinetics was collected with a Qualisys Track Manager system (Qualisys AB, Gothenburg, Sweden) with 8 infrared, high speed cameras (Qualisys Oqus 300, Qualisys AB, Gothenburg, Sweden) working at a frequency of 200 Hz and synchronized with two Kistler force plates (9281B e 9283U014 Kistler Instruments Ltd, Winterthur, Switzerland). Subjects were asked to walk naturally, at a self selected speed. Prior to data collection training trials were done so that the subjects would become comfortable with the task. Three gait cycles from each subject (in which the right foot would strike on the force plate) were selected to be analyzed.

In order to investigate the influence of different optimization methods on joint moment's data, three lower limb models were built for each subject and applied to the correspondent subjects' dynamical trials. These models had seven segments (feet, shanks, thighs and pelvis) and each of them was optimized differently. In the first model, each segment was considered independent, i.e. with six degree-of-freedom (segment optimization, SO) [3]. In the other two models global optimization [4] was used with different joint constraints. One of the models allowed all the rotations (X - flexion/extension, Y – abduction/adduction and Z -

internal/external rotation) in every joint (GO) and the other was more restricted (GOR), allowing three rotations in the hip, one at the knee (flexion-extension) and two at the ankle (flexion/extension and internal/external rotation) (GOR). A fourth order Butterworth low pass filter at 10Hz was used for both kinematic and kinetic data. Joint moments were computed for each model through inverse dynamics. All the data processing was performed through a continuous pipeline developed under Visual 3D software (Professional Version v4.80.00, C-Motion, Inc, Rockville, USA). Root mean square (RMS) differences between the three methods were computed for each of the joint moment curves for all the subjects. These differences were also normalized (RMSN) to the signal amplitude and averaged for the nine subjects. Furthermore, RMS differences were also determined within and between subjects in order to obtain intra and inter subject variability for each method.

RESULTS AND DISCUSSION

Considering all planes of motion (table 1), hip joint moments showed to be the least affected by the models' constraints. The largest differences were found between GOR and SO methods, being approximately 12% for the internal/external moments. Further, the obtained differences were lower than intersubject variability for all the axes; the curve shapes had a very good agreement both between subjects and methods and were in accordance with the literature [7, 8].

Comparing with the hip, the RMS differences between methods obtained for the knee were higher, especially concerning knee abduction moments. In this plane of motion, the standard deviation of the differences was also high, indicating that the effect of the method varies according with subject. Even so, differences between GO and SO remained small and, although the more restricted model showed higher differences when compared to GO and SO, the curve patterns had a good shape agreement between all methods and subjects and had a good agreement with the literature [7, 8].

Ankle joint moments in the sagittal plane were the least affected by joint constraints. The RMS differences were found to be smaller than intrasubject variability and the curve shapes had a perfect agreement and were in accordance with the literature [7, 8]. In the other planes of motion, however, the differences were higher and especially critical when comparing GOR with the other two less restrictive models, being larger than intersubject variability for the Y axis. Moreover, the curve shape agreement between GOR and the other two models was also poorer in this axis.

CONCLUSIONS

The purpose of this study was to verify the influence of model joint constraints in lower limb joint moments during level walking in the elderly. It was verified that: (1) hip joint moments were the least affected by the joint constraints, considering all planes of motion; (2) differences between methods were higher for knee and ankle joint moments in the frontal and transverse planes, especially between GOR and both SO and GO; (3) differences between SO and GO maintained lower for all joints and planes of motion, being the highest absolute difference obtained for knee abduction moments. Therefore, care should be taken when choosing the kinematic model, especially if the goal is to analyze knee and ankle joint moments in the frontal and transverse planes. These variables are particularly affected by the chosen joint constraints and the more restrictive model may not be suitable to perform such analysis.

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Table 1: RMS joint moments differences (absolute and normalized to signal amplitude) between methods

JOINT MOMENTS		GO-SO		GOR-SO		GO-GOR	
		RMS X±sd Nm/Kg	RMSN X±sd % SO SA	RMS X±sd Nm/Kg	RMSN X±sd % SO SA	RMS X±sd Nm/Kg	RMSN X±sd % GO SA
HIP	X	0.10±0.02	7.6±2.5	0.12±0.02	9.2±2.4	0.07±0.02	5.1±1.8
	Y	0.05±0.02	5.9±2.7	0.07±0.02	7.7±3.2	0.05±0.02	6.0±2.0
	Z	0.03±0.01	7.9±1.3	0.05±0.01	12.4±3.1	0.03±0.01	8.7±2.6
KNEE	X	0.04±0.01	4.2±1.2	0.16±0.07	16.5±7.2	0.16±0.06	17.1±5.7
	Y	0.03±0.01	11.8±11.2	0.09±0.05	29.7±30.3	0.07±0.04	20.0±13.0
	Z	0.01±0.00	5.8±3.0	0.03±0.01	15.3±5.6	0.02±0.01	11.4±3.1
ANKLE	X	0.01±0.01	0.9±0.6	0.02±0.01	1.2±0.7	0.02±0.01	1.2±0.7
	Y	0.02±0.02	7.8±6.2	0.11±0.04	30.8±6.8	0.12±0.04	33.5±8.1
	Z	0.01±0.00	6.8±2.0	0.02±0.01	21.8±16.1	0.02±0.01	19.0±15.5

SA – Signal amplitude; SO – Segment optimization; GO – global optimization unrestricted; GOR – global optimization restricted; RMS – absolute root mean squares differences; RMSN – normalized root mean squares difference