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Repeatability and comparison of 6 degrees-of-freedom and modified Helen Hayes marker sets in the lower body kinematics of young healthy adults

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SUMMARY

Three dimensional lower body gait kinematics of 12 young healthy adults was acquired and compared using the 6DOF and MHH models.
In this study, joint angles of the hip, knee and ankle were simultaneously recorded with different marker setups and compared refer to Collins [1].
The differences between the angles are highest for variables in the transverse plane (tibia rotation) and lowest for parameters in the sagittal plane (knee angle). Furthermore, the repeatability of marker placement fluctuates depending upon their anatomical location.
Both marker setups deliver acceptable results but it is recommended to not mix up the marker setup within a study.

INTRODUCTION

Clinical gait analysis is very useful in the diagnosis and treatment plan of individuals with pathological gait. Instrumented gait analysis is a special form of three-dimensional motion analysis and provides an objective documentation of the kinematics and kinetics of orthopedic pathologies. It provides a detailed analysis of most spastic gait disorders, which cannot be diagnosed in its complexity with the naked eye [2]. The choice of measurement method is crucial to the investigators so that patients can be provided with optimal support.
Variations of the Helen Hayes marker set using 3 rotational DOF appear to be most popular in clinical gait analysis although the model has many assumptions [3] and difficulties in marker placement [4]. An alternative is the 6DOF marker setup using marker clusters attached to soft tissue rather than bony landmarks (CAST). These clusters have between 3 and 5 fixed markers since at least 3 markers are needed to define a plane [5]. Positioning of the clusters is far less crucial compared to the wands used by the MHH setup.

METHODS

Participants in this study were 12 (male=9, female=3) sport students aged 23 to 26 years with no musculoskeletal injuries or disorders to the lower limbs in the past 12 months that could affect gait. Informed consent was attained prior to testing. Both marker sets were attached concurrently using passive retro-reflective 12.5 mm markers, 3-marker clusters and marker wands. Subjects were instructed to walk barefoot, at a self-selected speed over a 9-m long walkway. Individuals were allowed a couple of trial walks to familiarize with the environment. 3D kinematics was recorded at 100Hz using 13 infrared OQUS cameras (Qualisys AB, Sweden). At least 14 walks per subject were recorded. All data were collected by the same assessor. The study was approved by the University of Tübingen Ethics Committee.

To measure the accuracy of the marker positioning, a test-retest was performed on one subject. For this purpose, only the markers that were identical to both setups were incorporated. To control the marker positions photos were taken from all sides after application of the markers. Then a 3D static measurement lasting a few seconds was made with Qualisys®. Thereafter all the markers were removed except for the tibial markers which were kept constant as reference markers. The other markers were then re-attached, photos taken and another static measurement made. This procedure was repeated consecutively four more times during the same session. The entire session was repeated after a gap of four weeks.

The data were acquired in the Qualisys ® Track Manager (Version 2.7) software. Six trials were labeled and cropped to one complete gait cycle per walk. Gaps in the trajectories less than 100 ms were filled using polynomial interpolation. Using the Visual 3D software (C-Motion, USA, Version 4.96.11), the data were filtered at 6 Hz using a low pass Butterworth filter. Pelvic, hip, knee and ankle angles were computed, normalized to 101 points per gait cycle and a grand mean generated for visual comparison. For each subject, the mean, standard deviation of the the joint angles of the six selected trials at specific instances of the gait cycle were also calculated.
The difference in mean values and standard deviation of the CAST and MHH models were determined. To represent the two marker setups the Bland-Altman plot was used [6]. In addition, the Pearson correlation coefficient was calculated to represent the relationship of the data collected.
For the repeatability study, the positions of the markers relative to the reference tibial marker for all 5 trials in both sessions were calculated. Standard deviations of the marker

positions within each session were calculated and the correlation coefficient between both sessions found. This process was also implemented in Microsoft Excel (Version 14.0.6029.1000).

RESULTS AND DISCUSSION

Only data from the left limb has been analyzed and presented. Table 1 shows the correlations between the MHH and 6DOF left joint angles at specific gait phases in all three planes of movement. The differences between both marker setups in terms of mean (standard deviation) are also specified. No significant differences in any of the results were found.

Table 1: Summary of comparison between 6DOF and MHH based on discrete parameters extracted from left joint angle curves (n = 12). All values are relative to standing angles.

	Code	Parameters	Correlation	Correlation Collins	Difference (deg) Mean	Mean Collins	*S.D.*	*S.D.* Collins
Hip								
Sagittal	H1	Flexion at initial contact (IC)	0,954	0,924	-7	3	2,6	2,1
	H2	Max. extension in stance	0,975	0,953	1	-2	1,6	1,1
Coronal	H3	Max. adduction in stance	0,811	0,668	1	4	1,7	1,9
	H4	Max. abduction in swing	0,767	0,446	0	-1	1,9	1,9
Knee								
Sagittal	K1	Flexion at IC	0,875	0,814	-8	3	2,2	3,0
	K2	Max. flexion in stance	0,821	0,935	4	1	2,9	2,4
	K3	Max. extension in stance	0,825	0,928	-3	-2	2,5	1,5
	K4	Max. flexion in swing	0,699	0,868	1	-6	2,6	2,9
Transverse	K5	Max. int. rotation in terminal stance	0,523	0,765	-26	-5	10,0	3,6
Ankle								
Sagittal	A1	Flexion at IC	0,383	0,688	-3	1	2,5	2,5
	A2	Max. dorsiflexion in stance	0,838	0,919	-1	-2	1,7	1,9
	A3	Max. plantarflexion in pre-swing	0,742	0,983	1	5	3,7	2,6
	A4	Max. dorsiflexion in swing	0,472	0,711	-1	4	2,2	2,2
Coronal	A5	Max. adduction in swing	-0,898	0,869	7	-14	8,9	4,5

The grand mean graphs of the knee angles in the transverse plane show a very low correlation. This confirms the statement of the high variability in the transverse plane [7]. Despite the complex anatomical condition of the ankle, the grand mean curves shows very high (sagittal plane) and high (frontal plane) correlations. The vertical shift in the frontal plane can be attributed to the positioning of the wands with a high probability, as these are placed approximately at the m peroneus longus. Generally a level dependency is recognizable. The highest correlation and lowest variability of both measurement methods can be found in the sagittal plane.

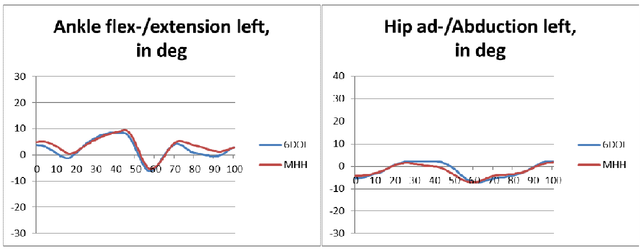

Figure 1: grand mean graphs of the ankle angle in the sagittal (left) and of the hip angle in the frontal plane (right) x-axis in % gait cycle, y-axis = in °, n=12 of 6 trials.

In terms the repeatability study, the correlation coefficient of the marker placements between both sessions was 0.33, 0.48 and 0.49 for the x, y and z coordinates. These values confirm a good repeatability in palpation and marker placement. Regarding the intra-rater reliability, the standard deviations of the marker positions between both sessions ranged from 12.2mm to -4.1mm. The markers with differences of SD over -1.0mm were especially located at the medial knee, the calcaneus, the toes (metatarsale 1 and 5) and the SIPS and SIAS.

CONCLUSIONS

There seems to exist a similarity in measured data between the MHH and CAST models. Therefore, the statement can be made that both models result in approximately the same discrete kinematic parameters, yet the markers setups are not compatible. It is our recommendation that marker setup should not be blended. Nevertheless, it should be noted that no information about the validity of the marker setup can be made because there are no true values available. Within the MHH and CAST marker setups, a level dependency is found. The differences in the results for the parameter in the transverse plane are the largest, since the identification of the rotation due to their complexity still contains major problems. In the determination of rotations, positioning of the marker in the sagittal plane has primarily to be optimized [8].

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