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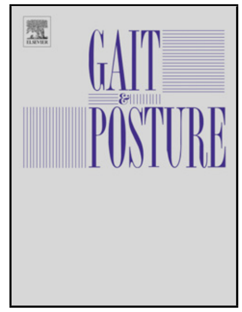

Title: Comparison of lower limb and trunk kinematics between markerless and marker-based motion capture systems

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Comparison of lower limb and trunk kinematics between markerless and marker-based motion capture systems.

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Highlights

- no significant difference between motion capture systems in isolated knee flexion
- change in angle in the pelvis & lower limb in single leg squat are similar
- specific joint angles should not be compared between systems in dynamic tests
- a markerless system adequately describes a squat motion enabling larger studies

Abstract

Three dimensional (3-D) motion capture systems are used by researchers and clinicians to analyze the kinematics of human movement. Traditional marker based systems are time consuming and limit the size of studies. Markerless 3-D systems are quicker to use but the differences between data captured in each system is unclear.

Aim

To examine the relationship of kinematic data captured by marker based and markerless motion capture systems.

Methods

Movement was assessed in two tests: a simple knee flexion test and single leg squat with a marker based protocol (Vicon) and a markerless protocol (Organic Motion).

Results

There was no significant difference between protocols in knee flexion angle (p=0.33). In single leg squat there was no significant difference in 9 of 13 clinically relevant joint angles in the change in angle from the start to the peak of squat. There were significant differences in the angle at the peak of the squat for 9 of 13 joint angles.

Discussion

This study provides evidence that a marker-based and a markerless protocol report similar ranges of change in angle from the start of a squat to peak squat in the pelvis and lower limb in single leg squat. Specific joint angles should not be compared between protocols.

Keywords

motion capture, marker, markerless, kinematics, single leg squat

Introduction

Three-dimensional kinematic measures are considered as the non-invasive gold standard of motion analysis [1]. These systems are used to examine gait [2] and sporting motion [3-5]. Marker based systems provide valid kinematic data but are time consuming to setup and process data [6], limiting their use in large studies. In contrast, markerless systems require less participant preparation and data processing time. The aim of this project was to understand the lower limb and trunk kinematic data collected using a markerless motion system with respect to a marker-based data collection protocol.

Methods

Healthy adult recreational athletes were recruited: 10 male and 10 female (median age 28.1, range 22-40) and informed consent obtained. The project was approved by the university ethics committee (FHEC12/183).

Marker-based motion capture

A ten camera Vicon system (Vicon Motion Systems, Oxford, UK) and Vicon Nexus software (Version 1.3.109.33342) collected motion data (100Hz). A modified Helen Hayes marker set [7, 8] was used, height, weight and anthropometric measures recorded and reflective markers applied to the skin (Supplement 1). Location of the knee joint centre was determined with standard Knee Alignment Devices [9]. Trunk angles were calculated between the shoulder and pelvis, with the shoulder segment defined by shoulder markers and a seventh cervical vertebra marker and the pelvis defined by anterior and posterior superior iliac spine markers [10]. Data were exported to Polygon (Version 3.1 Build 207, Apache Software Foundation, Maryland, USA) and Excel® spreadsheets for analysis of local joint angles for the trunk and lower limb.

Markerless Motion Capture

Fourteen grayscale cameras collected markerless motion data (120Hz) (Organic Motion, New York, USA). Height and weight was recorded. Participants stood with feet apart and arms outstretched to the side within a white capture space wearing tightly fitting dark clothing. A 3-D silhouette of the participant's form was captured. From the resultant 3-D visual hull a unique biometric skeleton was acquired [11]. Joint centre locations are based on weight and percentage values of height and wingspan of the arms. These percentage values locate joints at a point relative to the vertical and are further located at the centre of the visual hull at that point. Algorithms defining joint centres have been refined from comparisons of marker based and markerless systems [12]. Data files were uploaded to DARI Vault (version 3.2 - Denali) where the biomechanical analytics software produced full body kinematic results. Data were exported to Excel® for analysis of local joint angles of the trunk and lower limb.

Procedure

Since the two motion capture systems utilize different technology that prevents simultaneous data collection, all participants were tested in each system on different days. Participants completed two tasks of the lower limb; a simple knee flexion task (KFT) and a single limb squat (SLS). For KFT, participants stood on one leg balancing with a stick, bending the other knee ten times to touch a hurdle set at the height of their tibial tuberosity with their heel (Figure 1). One trial of five consecutive squats were performed: squatting down while keeping the heel on the floor and trunk upright (Figure 1).

Analysis

Normality was assessed using Shapiro-Wilk. Comparisons were made using paired samples t-test or Wilcoxon signed rank test if not normally distributed. Where significant differences were found, correlation between the two data sets was examined with a Pearson's product moment correlation (r) test or a Spearman's rho test if not normally distributed. The correlation results were interpreted as very weak (.00-.19), weak (.20-.39), moderate (.40-.59), strong (.60-.79), very strong (.80-1.0) [13]. Alpha level was ≤ 0.05.

Mean maximum knee flexion was determined for KFT. In SLS two movement measures were recorded: change in angle from the start to the peak of the squat and the joint angle at the peak of the squat (defined by peak knee flexion). The angle at the peak of the squat provided an identifiable point that could determine if specific joint angles could be compared between systems while the change in joint angle during the squat would determine if the systems were describing the same range of motion even if specific angles at peak squat were different.

Only the middle three squats were used to avoid potential variations at onset and completion of movement. Thirteen clinically relevant angles were examined: trunk flexion, sideflexion, rotation, pelvic tilt, obliquity and rotation, hip flexion adduction and rotation, knee flexion, varus/valgus and rotation and ankle dorsiflexion.

Results

Knee flexion test

There was no significant difference between systems for knee flexion angle (n=20): 78.7° (SD 5.7°, 95% CI 73.9-80.0) for the marker-based protocol and 76.9° (SD 6.6°, 95% CI 76.0-81.3) for the markerless protocol ($p = 0.33$, 95% CI mean difference -1.9 – 5.3).

Single leg squat

There were no significant differences between systems in change in angle from the start to the peak of the squat (n=17) in 9 of the 13 joint angles (Table 1). Significant differences were detected in change in angle of trunk flexion and rotation and pelvic and knee rotation with very weak correlations between these measures.

Peak knee flexion angle and therefore the definition of the peak of the squat was not significantly different between protocols (marker 61.6°, markerless 61.3°, p=0.87). There were also no differences between the protocols in terms of the peak trunk rotation, peak pelvic rotation, and peak hip adduction (Table 2). Significant differences were found in all other movements with strong correlation for hip flexion, moderate correlation for pelvic tilt, weak correlation for ankle dorsiflexion, and very weak correlation for all other measures. Trunk flexion, pelvic tilt, hip flexion and ankle dorsiflexion had higher measures in the marker-based protocol than the markerless protocol.

Discussion

No significant difference was found between systems in KFT demonstrating that they produce comparable kinematic data. The controlled nature of the KFT partially overcomes the inherent difficulties of comparing results from non-concurrent tests.

The SLS results indicate that the range through which participants moved was not significantly different in most angles of interest to clinicians. This provides evidence that a markerless system can adequately describe motion during a squat. Joint angles at peak squat cannot be directly compared between Organic Motion and Vicon, however the differences were either systematic differences or relatively small differences in the order of 3-6°, predominantly within the margin of error of Plug In Gait [14], except in trunk flexion and knee rotation.

Although there were large mean differences (18°) in peak pelvic tilt and hip flexion the measures were well correlated, indicating that the systems are reporting similar movement. This suggests a systematic difference most likely due to how the pelvis is modelled by the two systems. The Helen Hayes model identifies the pelvis using anterior and posterior superior iliac spine (ASIS/PSIS) markers and is typically in an anteriorly tilted position. Organic Motion system identifies the pelvis as the bottom 25% of the trunk and does not account for this forward tilt. Since the hip segment below and trunk segment above are reported in relation to the pelvis, this likely influences these angles.

Trunk flexion angles at peak and the change in angle were not well correlated. The custom-made model used in the marker-based system identifies the trunk angle as the angle between the shoulder segment and pelvis [10]. Organic Motion identifies the trunk as the upper chest angle minus the lower torso (pelvis), which may underestimate the angle of the trunk relative to the marker-based motion system. It is possible that the trunk modeling method may account for the 12° difference in angle at peak squat but a possible performance difference should also be considered.

Trunk flexion/extension change in angle was described by the marker-based system as extension whereas Organic Motion recorded the movement as flexion. It is possible that markers on the ASIS in Vicon may encourage the participants to remain upright to avoid contact on these points where this is not a hindrance to movement in Organic Motion. Although a definite conclusion cannot be reached it is important to consider whether the method of measurement may cause an individual to move differently in the presence of reflective markers.

Other significant differences were reported for change in angle data for trunk rotation and pelvic rotation with the values very weakly correlated. With these differences of 6.5 and 6.9 degrees outside the acceptable margin of error of motion capture systems they may indicate a real difference in the angle measured. The large differences in knee rotation cannot be readily accounted for, however rotation measures of trunk, pelvis and knee have been shown to be less reliable [14].

This comparison study is limited by the need to perform non-concurrent tests so it cannot be assumed that the participants performed the test in identical fashion on different days. It is likely that some differences in measures may be explained by variability in test performance. The inherent nature of the technology of each system made it impossible to use the systems simultaneously. The study is limited to a comparison of kinematic data and does not compare kinetic data. This needs investigation.

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Figure 1 Knee flexion test and single leg squat

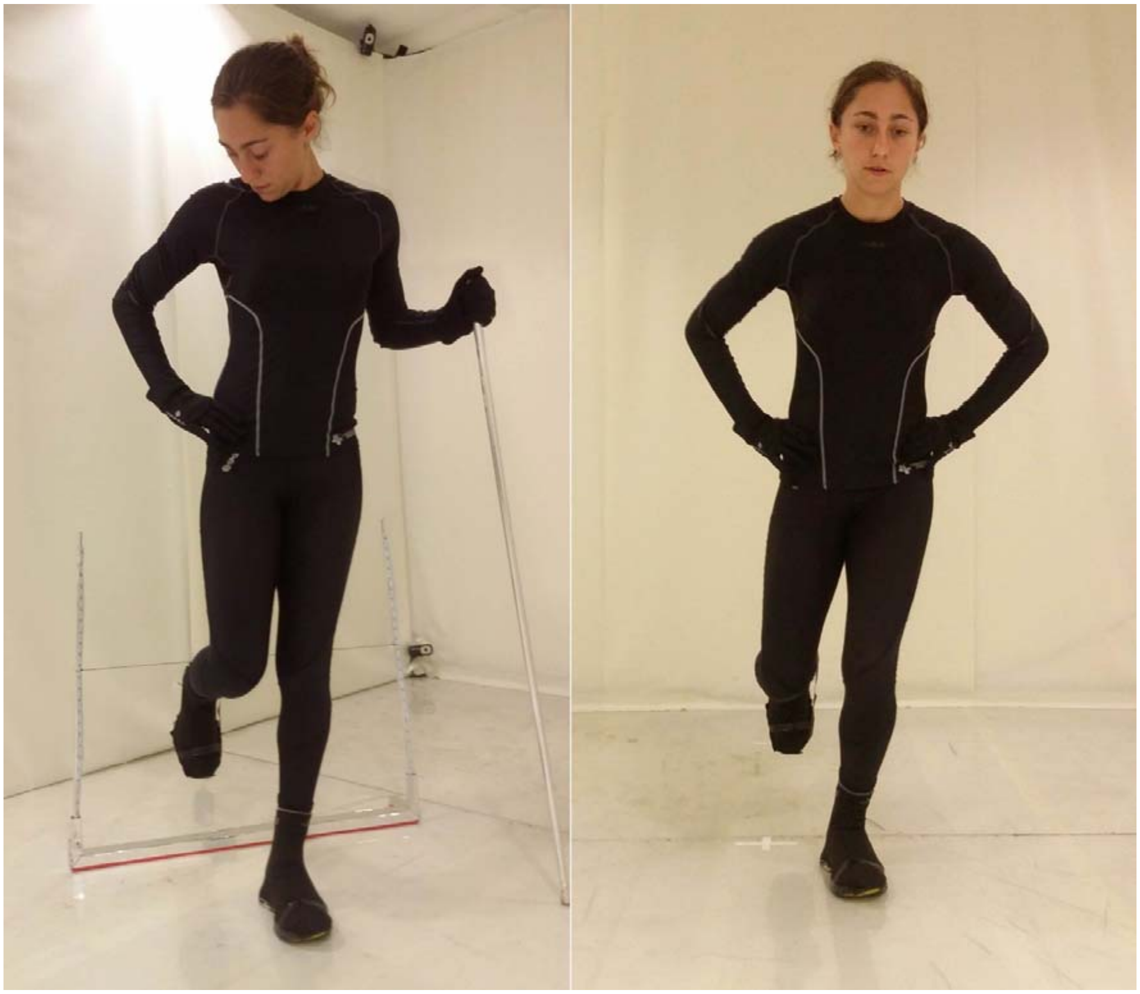

Table 1 Change in angle from the start of the squat to the peak of the squat

	Movement	Vicon Organic Motion	95% CI Lower	95% CI Upper	p	Correlation	Mean Difference (SD)	Paired Difference 95% CI Lower	Paired Difference 95% CI Upper
Trunk	Flexion V*	-2.0 (5.2)	-4.7	0.6	0.003	0.116	-6.5 (7.8)	-10.5	-2.5
	Flexion OM*	4.4 (6.4)	1.1	7.7					
	Sideflexion V LSF*	6.2 (3.7) LSF§	4.3	8.1	0.191		-1.6 (4.9)	-4.1	0.9
	Sideflexion OM LSF	7.8 (4.2) LSF	5.6	10.0					
	Rotation V RR*	-1.5 (2.3) RR§	-2.7	-0.4	0.011	-0.062	7.7 (11.0)	2.0	13.3
	Rotation OM RR	-9.2 (10.6) RR	-14.6	-3.7					
Pelvis	Tilt V	7.6 (4.1)	5.5	9.7	0.398		1.2 (5.5)	-1.7	4.0
	Tit OM	6.4 (6.6)	3.0	9.8					
	Obliquity V RSL*	-5.6 (2.6)§	-6.9	-4.2	0.100		2.0 (4.7)	-0.4	4.4
	Obliquity Om RSL	-7.6 (5.9)	-10.6	-4.5					
	Rotation V LR†*	2.7 (3.8)‡§	2.1	5.6	0.044	-0.16			
	Rotation OM RR†	-4.2 (9.2)‡	-7.5	6.9					
Hip	Flexion V	40.2 (11.1)	34.5	45.9	0.118		3.5 (8.6)	-1.0	7.9
	Flexion OM	36.7 (10.5)	31.4	42.1					
	Adduction V	10.4 (6.1)	7.3	13.5	0.478		-1.2 (6.9)	-4.8	2.3
	Adduction OM	11.6 (8.4)	7.3	15.9					
	Rotation V IR*	2.1 (6.4)	-1.2	5.3	0.381		-3.2 (14.7)	-10.8	4.4
	Rotation OM IR	5.3 (12.6)	-1.2	11.8					
Knee	Flexion V	59.7 (13.1)	52.9	66.4	0.559		1.1 (7.8)	-2.9	5.1
	Flexion OM	58.5 (9.2)	53.8	63.3					
	Valgus V	4.3 (7.6)§	0.4	8.2	0.543		-1.4 (9.3)	-6.2	3.4
	Valgus OM	5.7 (6.5)	2.4	9.0					
Knee	Rotation V IR	9.6 (8.5)	5.3	14.0	0.000	0.027	15.9 (11.6)	9.9	21.8

	Rotation OM ER*	-6.2 (8.1)	-10.3	-2.1				
Ankle	Dorsiflexion V	25.8 (6.2)	22.6	29.0	0.478	0.9 (4.9)	-1.7	3.7
	Dorsiflexion OM	25.0 (3.7)	23.1	26.9				

* V Vicon, OM Organic Motion, LSF left side flexion, RR right rotation. LR left rotation, RSL Right side lower, IR internal rotation, ER external rotation

†not normally distributed - Wilcoxon signed rank test

‡ Median (IQR)

§ Vicon sign changed for comparison

Table 2 Angles at the peak of the squat

	Movement	Vicon (SD)	95% CI		p	Correlation	Mean Difference (SD)	Paired Difference 95% CI	
		Organic Motion (SD)	Lower	Upper				Lower	Upper
Trunk	Flexion V*	2.1 (10.4)	-3.3	7.4	<0.01	0.05	-12.1 (11.6)	-18.1	-6.2
	Flexion OM*	14.3 (5.5)	11.4	17.1					
	Sideflexion V LSF*	1.7 (4.7)§	-0.7	4.1	0.04	0.17	3.7 (6.7)	0.3	7.2
	Sideflexion OM RSF*	-2.0 (5.7)	-4.9	1.0					
	Rotation V RR*	-1.4 (4.1)§	-3.4	0.7	0.42		2.3 (11.3)	-3.5	8.1
	Rotation OM RR	-3.6 (9.8)	-8.7	1.4					
Pelvis	Tilt V	25.7 (5.2)	23.0	28.4	<0.01	0.56	18.1 (7.6)	14.2	22.1
	Tit OM	7.6 (9.2)	2.8	12.3					
	Obliquity V RSH*	0.8 (4.3)§	-1.4	3.0	0.01	0.00	-5.1 (5.3)	-7.9	-2.4
	Obliquity OM RSH	6.0 (6.9)	2.4	9.5					
	Rotation V LR*	2.4 (3.6)§	0.5	4.2	0.92		0.3 (11.0)	-5.4	5.9
	Rotation OM LR	2.1 (10.7)	-3.4	7.6					
Hip	Flexion V	53.5 (11.9)	47.4	59.6	<0.01	0.65	17.7 (11.1)	12.0	23.5
	Flexion OM	35.8 (14.1)	28.5	43.0					
	Adduction V	6.9 (5.9)	3.8	9.9	0.22		2.8 (9.0)	-1.8	7.4
	Adduction OM	4.1 (9.3)	-0.7	8.9					
	Rotation V ER*	-3.1 (7.6)	-7.0	0.8	0.03	0.17	-5.8 (9.7)	-10.8	-0.8
	Rotation OM IR*	2.8 (7.4)	-1.1	6.6					
Knee	Flexion V	61.6 (10.5)	56.2	67.0	0.87		0.3 (8.0)	-3.8	4.4
	Flexion OM	61.3 (7.9)	57.2	65.4					
	Varus	-0.2 (7.3)§	-3.9	3.6	0.02	0.11	-6.0 (9.2)	-10.7	-1.2
	Valgus	5.8 (6.4)	2.5	9.1					
Knee	Rotation V IR	15.9 (7.4)	12.1	19.7	<0.01	-0.13	22.5 (11.0)	16.9	28.2

	Rotation OM ER	-6.6 (7.3)	-10.4	-2.9		
Ankle	Dorsiflexion V	32.7 (7.6)‡			0.01 †	0.37
	Dorsiflexion OM†	30.0 (0.6)‡				

* V Vicon, OM Organic Motion, LSF left side flexion, RSF right side flexion, RR right rotation. LR left rotation, RSH right side higher, ER external rotation, IR internal rotation

†not normally distributed - Wilcoxon signed rank test

‡ Median (IQR)

§ Vicon sign changed for comparison