



BIOLOGICAL RELIABILITY OF A MOVEMENT ANALYSIS ASSESSMENT USING A MARKERLESS MOTION CAPTURE SYSTEM

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Introduction

Advances in motion capture technology include markerless systems to facilitate valid data collection. Recently, the technological reliability of this technology has been reported for human movement assessments. To further understand sources of potential error, biological reliability must also be determined.

Purpose

The aim of this study was to determine the day-to-day reliability for a three-dimensional markerless motion capture system to quantify 4 movement analysis composite scores, and 81 kinematic variables. From this, the biological variability can be determined.

Methods and Materials

Twenty-two healthy men (n=11; $\bar{x}\pm SD$; age=23.0 \pm 2.6 yrs, height=180.0 \pm 4.8 cm, weight=80.4 \pm 7.3 kg) and women (n=11; age=20.8 \pm 1.1 yrs, height=172.2 \pm 7.4 cm, weight=68.0 \pm 7.3 kg) participated in this study. All subjects performed four standardized test batteries consisting of 19 different movements on four separate days, from which 81 kinematic metrics, and 4 composite scores for overall movement assessments were obtained. These variables (with the number of variables in parentheses) included range of motion in degrees for both the right and left shoulders (12), hips (20), knees (16), ankles (16), torso rotation, flexion and extension (3), and knee valgus (4). Distances for lunge stride length (2) and center of mass displacement (8) were also measured. A three-dimensional markerless motion capture system (DARI Motion, Lenexa, KS) using 8 cameras surrounding the testing area was used to quantify movement characteristics. 1x4 RMANOVAs determined sig. differences across days for the composite movement analysis scores, and RM-MANOVAs were used to determine test day differences for the kinematic data (p<0.05). ICCs were reported for all variables to determine test reliability. To determine biological variability, mean absolute differences from previously reported technological variability data (Philipp et al. 2023) were subtracted from the present study.

Results

Table 1 (left) - Mean (±SD) values for segmental angles and ranges of motion for four different test sessions performed on separate days. No significant differences were observed for any variable as determined from MANOVA analyses (p>.05). *ICC = good - excellent (Cicchetti 1994).

Anatomical Motion or Analysis Score	ICC	Day 1	Day 2	Day 3	Day 4
Movement Analysis Scores					
Athleticism (F=0.010; df=3,84; p=.999)	0.92*	1611.1±307.8	1611.8±271.4	1600.2±270.9	1601.5±270.5
Explosiveness (F=0.013; df=3,84; p=.998)	0.93*	836.5±216.9	836.4±196.5	825.7±197.9	833.5±207.6
Quality (F=0.319; df=3,84; p=.812)	0.83*	907.3±114.9	900.8±106.8	885.6±117.9	879.8±100.5
Readiness (F=0.296; df=3,84; p=.828)	0.89*	18.7±3.9	18.8±3.6	18.6±3.6	18.7±3.4
Shoulder_Left (Wilks' Lambda=.821; df=18.0,223.9; p=.578)					
Shoulder abduction mobility, maximum left (°)	0.87*	178.1±11.0	179.1±8.0	181.3±10.1	180.9±9.0
Shoulder horiz abduction mobility, max left (°)	0.85*	88.3±8.2	87.7±8.8	83.0±16.9	86.6±16.5
Shoulder external rotation, maximum left (°)	0.85*	-88.7±11.6	-92.5±22.7	-88.2±10.5	-89.1±10.9
Shoulder internal rotation, maximum left (°)	0.80*	62.7±13.5	75.5±27.7	71.4±13.5	72.3±13.6
Shoulder flexion, maximum left (°)	0.82*	172.1±15.9	170.2±13.8	172.8±11.5	170.1±13.0
Shoulder extension, maximum left (°)	0.84*	-33.9±12.3	-35.4±12.8	-34.5±13.9	-35.1±12.0
Shoulder_Right (Wilks' Lambda=.805; df=18.0,223.9; p=.473)					
Shoulder abduction mobility, maximum right (°)	0.66*	173.8±8.0	177.7±6.2	178.5±9.0	179.9±8.8
Shoulder horiz abduction mobility, max right (°)	0.85*	84.0±10.3	85.4±10.0	80.1±14.7	85.9±17.3
Shoulder external rotation, maximum right (°)	0.90*	-92.7±12.8	-95.0±10.6	-93.3±11.6	-94.0±11.9
Shoulder internal rotation, maximum right (°)	0.85*	61.6±12.8	72.9±25.9	71.3±11.3	70.8±13.0
Shoulder flexion, maximum right (°)	0.85*	171.7±17.7	169.8±13.4	170.9±11.6	169.5±13.9
Shoulder extension, maximum right (°)	0.85*	-34.7±12.9	-36.8±10.6	-35.7±14.5	-35.4±12.7
Trunk_Rotation (Wilks' Lambda=.886; df=6.0,166.0; p=.119)					
Maximum left (°)	0.80*	80.3±22.0	76.0±17.4	77.0±21.5	71.3±16.0
Maximum right (°)	0.87*	79.5±17.8	76.2±14.6	73.5±18.0	65.0±16.0
Overhead_Squat (Wilks' Lambda=.760; df=30.0,220.8; p=.856)					
Overhead squat COM depth (cm)	0.97*	23.0±3.7	23.9±3.8	22.5±3.5	22.0±3.6
Overhead squat hip flexion, maximum left (°)	0.89*	128.5±9.0	125.6±10.3	126.7±11.9	123.0±10.3
Overhead squat hip flexion, maximum right (°)	0.89*	126.5±9.1	125.5±9.3	126.3±11.2	123.4±8.7
Overhead squat knee flexion, maximum left (°)	0.95*	133.6±12.6	132.5±15.1	131.8±11.3	131.9±11.9
Overhead squat knee flexion, maximum right (°)	0.96*	134.4±13.7	133.5±15.0	132.5±10.4	132.3±11.6
Overhead squat ankle flexion, maximum left (°)	0.84*	45.6±7.0	44.8±9.0	46.5±8.0	47.3±7.0
Overhead squat ankle flexion, maximum right (°)	0.81*	48.5±6.8	47.7±8.2	48.4±8.1	49.8±8.0
Overhead squat, trunk flexion (°)	0.87*	31.9±11.1	29.6±7.7	28.4±11.3	31.4±11.7
Overhead squat hip abduction, left (°)	0.91*	17.2±7.0	18.0±7.7	17.8±9.7	17.1±8.1
Overhead squat hip abduction, right (°)	0.92*	20.1±7.8	20.1±6.6	19.8±8.5	17.1±6.8
Unilateral_Squat_Left (Wilks' Lambda=.899; df=15.0,221.2; p=.889)					
Unilateral squat COM depth, left (cm)	0.85*	14.9±4.6	14.7±2.6	14.2±3.1	14.4±2.6
Unilateral squat hip flexion, maximum left (°)	0.88*	106.7±18.6	106.1±13.0	105.4±18.6	102.3±16.8
Unilateral squat knee flexion, maximum left (°)	0.84*	101.9±24.8	104.3±7.9	104.7±11.7	105.3±10.0
Unilateral squat ankle flexion, maximum left (°)	0.85*	52.3±5.6	51.6±6.7	53.1±6.2	53.6±5.8
Unilateral squat dynamic valgus, left (°)	0.61*	5.4±1.8	5.5±1.8	5.0±3.2	5.0±3.2
Unilateral_Squat_Right (Wilks' Lambda=.928; df=15.0,221.2; p=.976)					
Unilateral squat COM depth, right (cm)	0.89*	15.0±3.4	15.0±2.7	14.4±3.4	14.0±2.9
Unilateral squat hip flexion, maximum right (°)	0.84*	108.0±14.7	108.3±12.8	105.5±16.0	104.7±16.5
Unilateral squat knee flexion, maximum right (°)	0.88*	108.7±12.4	107.3±12.6	104.7±13.2	105.0±8.8
Unilateral squat ankle flexion, maximum right (°)	0.84*	49.1±8.6	48.5±8.6	49.3±7.1	50.8±7.8
Unilateral squat dynamic valgus, right (°)	0.75*	4.2±2.8	5.3±2.9	4.7±2.9	5.6±3.6
Forward_Lunge_Left (Wilks' Lambda=.870; df=15.0,221.3; p=.718)					
Forward lunge stride length, left (cm)	0.82*	38.6±5.3	37.1±8.3	39.2±5.9	39.2±5.3
Forward lunge trail hip extension, left (°)	0.91*	-31.2±16.4	-29.8±13.2	-27.4±13.2	-31.5±14.5
Forward lunge hip flexion, maximum left (°)	0.71*	106.2±13.4	102.2±22.0	106.3±16.8	106.7±9.8
Forward lunge knee flexion, maximum left (°)	0.70*	123.3±9.1	120.2±12.5	119.3±5.1	120.1±6.5
Forward lunge ankle flexion, maximum left (°)	0.62*	25.1±9.9	19.0±13.0	20.8±10.8	22.8±9.0
Forward_Lunge_Right (Wilks' Lambda=.946; df=15.0,218.5; p=.995)					
Forward lunge stride length, right (cm)	0.96*	38.6±6.1	38.3±4.8	39.1±5.9	38.8±5.4
Forward lunge trail hip extension, right (°)	0.90*	-29.6±17.6	-31.7±15.5	-32.9±15.0	-32.9±15.0
Forward lunge hip flexion, maximum right (°)	0.88*	105.3±12.1	104.8±9.5	103.0±15.0	105.6±10.6
Forward lunge knee flexion, maximum right (°)	0.69*	119.1±8.7	121.0±7.3	119.0±6.7	119.4±6.4
Forward lunge ankle flexion, maximum right (°)	0.65*	23.1±12.9	25.5±12.7	23.3±12.7	24.4±10.6
Vertical_Jump (Wilks' Lambda=.876; df=21.0,224.5; p=.967)					
Vertical jump center of mass height (cm)	0.95*	19.3±5.2	19.2±5.9	18.7±4.7	19.5±5.7
Vert jump eccentric phase hip flex, max left (°)	0.92*	111.5±14.9	116.5±18.8	116.4±17.9	115.0±18.1
Vert jump eccentric phase hip flex, max right (°)	0.91*	111.3±15.5	116.1±19.3	116.5±16.9	114.7±17.6
Vert jump eccentric phase knee flex, max left (°)	0.92*	111.1±24.5	118.2±13.9	117.0±13.6	118.5±13.6
Vert jump eccentric phase knee flex, max right (°)	0.92*	113.0±12.6	115.2±14.4	114.7±13.9	116.3±13.2
Vert jump eccentric phase ankle flex, max left (°)	0.83*	42.5±7.4	39.2±9.0	39.0±7.6	41.5±8.3
Vert jump eccentric phase ankle flex, max right (°)	0.85*	40.6±8.7	36.3±11.9	37.9±7.4	38.8±10.1
Drop_Vertical_Jump (Wilks' Lambda=.889; df=21.0,224.5; p=.984)					
Drop jump height (cm)	0.99*	20.7±5.2	20.4±4.8	20.3±4.5	20.1±4.8
Drop jump landing hip flexion, left (°)	0.93*	87.7±39.1	97.1±36.4	104.9±29.3	104.8±34.5
Drop jump landing hip flexion, right (°)	0.93*	89.4±38.0	94.5±35.4	104.9±29.3	103.9±34.9
Drop jump landing knee flexion, left (°)	0.87*	106.0±27.5	108.8±18.8	113.8±15.7	112.6±26.6
Drop jump landing knee flexion, right (°)	0.83*	102.3±34.2	106.5±22.3	112.4±13.3	111.5±29.7
Drop jump landing ankle flexion, left (°)	0.84*	22.3±8.5	21.0±5.9	33.7±24.6	36.1±22.1
Drop jump landing ankle flexion, right (°)	0.49	25.3±35.6	18.5±35.1	29.5±33.1	33.9±22.4
Static_Vertical_Jump (concentric only) (Wilks' Lambda=.866; df=21.0,224.5; p=.946)					
Static VJ center of mass height (cm)	0.99*	18.8±5.1	17.9±4.5	17.9±4.3	17.7±4.4
Static VJ hip flexion, maximum left (°)	0.87*	113.5±11.2	117.7±9.8	114.2±25.5	110.9±23.3
Static VJ hip flexion, maximum right (°)	0.90*	114.5±11.9	116.7±10.7	118.7±12.5	115.7±11.6
Static VJ knee flexion, maximum left (°)	0.87*	114.8±11.4	116.8±12.6	117.4±9.1	118.0±11.3
Static VJ knee flexion, maximum right (°)	0.90*	113.7±12.3	115.2±13.8	115.3±10.0	116.5±11.8
Static VJ ankle flexion, maximum left (°)	0.70*	38.1±7.0	34.8±7.1	34.2±7.1	37.0±8.1
Static VJ ankle flexion, maximum right (°)	0.76*	36.9±7.1	33.8±9.5	33.2±7.2	35.6±8.0
Unilateral_Vertical_Jump_Left (Wilks' Lambda=.944; df=15.0,221.2; p=.994)					
Unilateral VJ center of mass height, left (cm)	0.91*	13.3±3.9	13.7±3.4	13.3±4.4	13.4±4.6
Unilateral VJ hip flexion, maximum left (°)	0.93*	87.0±19.7	84.0±19.7	85.8±21.4	84.8±20.0
Unilateral VJ knee flexion, maximum left (°)	0.90*	85.2±10.7	84.9±10.0	87.3±12.3	86.6±11.1
Unilateral VJ ankle flexion, maximum left (°)	0.84*	44.7±9.6	44.1±9.1	44.0±9.6	45.1±9.4
Unilateral VJ dynamic valgus, left (°)	0.88*	0.6±4.1	1.5±4.2	1.4±3.8	1.4±3.8
Unilateral_Vertical_Jump_Right (Wilks' Lambda=.917; df=15.0,221.2; p=.953)					
Unilateral VJ center of mass height, right (cm)	0.96*	12.8±3.7	12.5±3.4	12.5±3.1	12.7±3.5
Unilateral VJ hip flexion, maximum right (°)	0.93*	82.7±19.8	79.7±18.5	81.8±19.9	79.7±19.0
Unilateral VJ knee flexion, maximum right (°)	0.90*	85.9±11.5	85.4±13.9	86.7±12.1	87.8±11.6
Unilateral VJ ankle flexion, maximum right (°)	0.79*	44.1±8.8	41.4±9.2	44.0±7.4	44.1±10.1
Unilateral VJ dynamic valgus, right (°)	0.81*	0.6±3.0	0.0±3.6	1.4±3.8	1.2±3.6
Multi-Hop (Wilks' Lambda=.897; df=24.0,223.9; p=.998)					
Multi-hop eccentric phase hip flex, max left (°)	0.90*	66.9±22.3	68.8±22.4	61.0±26.2	64.5±26.2
Multi-hop eccentric phase hip flex, max right (°)	0.80*	69.0±20.5	64.7±21.1	53.6±36.3	62.5±27.5
Multi-hop eccentric phase knee flex, max left (°)	0.71*	72.4±18.9	74.0±10.1	72.0±14.6	71.5±15.7
Multi-hop eccentric phase knee flex, max right (°)	0.81*	77.2±11.9	74.8±11.9	71.9±15.1	73.7±15.9
Multi-hop eccentric phase ankle flex, max left (°)	0.72*	36.5±16.6	33.8±12.1	32.7±17.6	36.9±16.4
Multi-hop eccentric phase ankle flex, max right (°)	0.61*	41.1±15.8	36.6±15.5	35.4±16.5	38.5±12.5

Table 1 (left) - Mean (±SD) values for segmental angles and ranges of motion for four different test sessions performed on separate days. No significant differences were observed for any variable as determined from MANOVA analyses (p>.05). *ICC = good - excellent (Cicchetti 1994).

Table 2 (below) - Mean absolute differences between test sessions for all kinematic variables, and the relative contributions of biological variability and technical variability. *Technical variability data from Philipp et al. (2023); * difference between devices (p < .05). * Combined from thoracic and lumbar rotation. * Biological variability < technical variability.

Anatomical Motion	Mean Absolute Difference		Contributions to Variability (%)	
	Inter-Device*	Inter-Day	Technical*	Biological
Shoulder Abduction				
Shoulder abduction mobility, maximum left value (°)	0.6	6.3	9.5%	90.5%
Shoulder abduction mobility, maximum right value (°)	0.6	7.5	8.0%	92.0%
Shoulder Horizontal Abduction				
Shoulder horizontal abduction mobility, maximum left value (°)	3.3	12.6	29.2%	73.8%
Shoulder horizontal abduction mobility, maximum right value (°)	2.4	14.7	16.3%	83.2%
Shoulder Internal/External Rotation				
Shoulder external rotation, maximum left value (°)	1.1	9.0	12.2%	87.8%
Shoulder external rotation, maximum right value (°)	0.3	13.0	2.3%	97.7%
Shoulder internal rotation, maximum left value (°)	0.1	12.0	0.8%	99.2%
Shoulder internal rotation, maximum right value (°)	1.0	11.8	8.5%	91.5%
Shoulder Flexion/Extension				
Shoulder flexion, maximum left value (°)	1.6	13.4	11.9%	88.1%
Shoulder flexion, maximum right value (°)	3.6	11.5	31.3%	68.7%
Shoulder extension, maximum left value (°)	0.9	11.9	7.6%	92.4%
Shoulder extension, maximum right value (°)	0.3	12.5	2.4%	97.6%
Trunk Rotation				
Maximum left value (°)	1.3a	19.2	5.2%	94.8%
Maximum right value (°)	1.8a	15.6	11.5%	88.5%
Overhead Squat				
Overhead squat COM depth value (cm)	1.9	1.9	100.0%	0.0% b
Overhead squat hip flexion, maximum left value (°)	5.9*	6.1	96.7%	3.3% b
Overhead squat hip flexion, maximum right value (°)	6.0	6.5	92.3%	7.7% b
Overhead squat knee flexion, maximum left value (°)	0.2	6.1	3.3%	96.7%
Overhead squat knee flexion, maximum right value (°)	1.2	5.1	23.5%	76.5%
Overhead squat ankle flexion, maximum left value (°)	2.5	5.7	43.9%	56.1%
Overhead squat ankle flexion, maximum right value (°)	2.9	6.0	48.3%	51.7%
Overhead squat, trunk flexion value (°)	0.5	6.3	7.9%	92.1%
Overhead squat hip abduction, left value (°)	0.2	4.2	4.8%	95.2%
Overhead squat hip abduction, right value (°)	0.1	3.9	2.6%	97.4%
Unilateral Squat				
Unilateral squat COM depth, left value (cm)	0.3	2.0	15.0%	85.0%
Unilateral squat COM depth, right value (cm)	0.3	1.8	16.7%	83.3%
Unilateral squat hip flexion, maximum left value (°)	8.5	10.2	83.3%	16.7% b
Unilateral squat hip flexion, maximum right value (°)	8.5	10.2	83.3%	16.7% b
Unilateral squat knee flexion, maximum left value (°)	1.4	9.5	14.7%	85.3%
Unilateral squat knee flexion, maximum right value (°)	2.0	7.9	25.3%	74.7%
Unilateral squat ankle flexion, maximum left value (°)	1.0	4.0	25.0%	75.0%
Unilateral squat ankle flexion, maximum right value (°)	3.4	5.5	61.8%	38.2% b
Unilateral squat dynamic valgus, left value (°)	7.5	3.4	100.0%	0.0% b
Unilateral squat dynamic valgus, right value (°)	2.8	2.3	100.0%	0.0% b
Forward Lunge				
Forward lunge stride length, left value (cm)	2.3	2.8	82.1%	17.9% b
Forward lunge stride length, right value (cm)	1.8	2.4	75.0%	25.0% b
Forward lunge trail hip extension, left value (°)	1.5	8.0	18.8%	81.2%
Forward lunge trail hip extension, right value (°)	1.8	9.4	19.1%	80.9%
Forward lunge hip flexion, maximum left value (°)	0.3	10.8	2.8%	97.2%
Forward lunge hip flexion, maximum right value (°)	1.1	8.7	12.6%	87.4%
Forward lunge knee flexion, maximum left value (°)	1.5	6.2	24.2%	75.8%
Forward lunge knee flexion, maximum right value (°)	0.1	4.8	2.1%	97.9%
Forward lunge ankle flexion, maximum left value (°)	0.4	8.9	4.5%	95.5%
Forward lunge ankle flexion, maximum right value (°)	1.1	9.5	11.6%	88.4%
Vertical Jump				
Vertical jump center of mass height (cm)	0.4	1.8	22.2%	77.8%
Vertical jump eccentric phase hip flexion, maximum left value (°)	4.3	10.0	43.0%	57.0%
Vertical jump eccentric phase hip flexion, maximum right value (°)	6.1	9.8	62.2%	37.8% b
Vertical jump eccentric phase knee flexion, maximum left value (°)	1.8	9.8	18.4%	81.6%
Vertical jump eccentric phase knee flexion, maximum right value (°)	4.0	7.1	56.3%	43.7% b
Vertical jump eccentric phase ankle flexion, maximum left value (°)	2.1	6.2	33.9%	66.1%
Vertical jump eccentric phase ankle flexion, maximum right value (°)				