

VALIDITY OF MARKERLESS MOTION ANALYSIS USING A DYNAMIC TIME WARPING APPROACH

Eleonora Cabai¹, Jorge Chahla¹, Leonardo Metsavaht, Gustavo Leporace, *Jonathan A. Gustafson¹

¹Rush University Medical Center, Chicago, IL, USA

*Corresponding author's email: jonathan_a_gustafson@rush.edu

Introduction: Motion analysis offers valuable insights into human movement that have aided in the diagnosis and treatment of musculoskeletal conditions to improve patient outcomes. Traditional marker-based motion capture (MoCap) systems require specialized equipment and setup. In contrast, markerless systems offer a more accessible alternative, but their reliability is still a concern [1], with most validation studies to date only evaluating differences in discrete peak values of kinematic trajectories. The objective of this study was to assess the differences in dynamic time series trajectories of marker-based and markerless MoCap systems during a lateral step-down task, a key activity for evaluating several pathologic orthopedic conditions.

Methods: Three-dimensional kinematics data were measured from 22 individuals with femoroacetabular impingement (n=7), patellofemoral pain (n=11), and healthy, asymptomatic subjects (n=4) as part of an ongoing, IRB-approved prospective study to develop large-data biomechanical models of various orthopedic conditions. Individuals were outfitted with a marker set combining ISB recommendations [2] with the CAST method [3] and conducted repeated lateral step-down trials (n=3) from a 30 cm box while both a marker-based optoelectronic motion capture system (Qualisys) and markerless system (Theia) collected movements.

A Python script was developed to segment the data into comparable samples by identifying key events (START, MID, END) based on the center of gravity of the pelvis (z-axis) and extracting the relevant kinematics per segment. Data were scaled by min and max values for each variable and time normalized. Kinematics of the trunk, pelvis, hip, knee, and ankle were compared across both systems (Figure 1) using both Dynamic Time Warping (DTW)—a technique for quantifying the similarity between time series [4] (Figure 1)—and cross-correlation analysis (*dtw* function from *tslearn*, *corrcoef* function from *numpy*, Python 3.13.1).

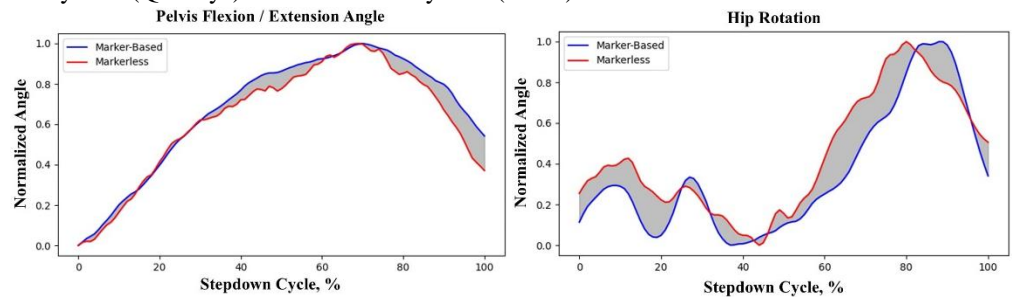


Figure 1. Example of Dynamic Time Warping Analysis for pelvis (left) and trunk (right) kinematics using both Dynamic Time Warping (DTW)—a technique for quantifying the similarity between time series [4] (Figure 1)—and cross-correlation analysis (*dtw* function from *tslearn*, *corrcoef* function from *numpy*, Python 3.13.1).

Results & Discussion: The cohort comprised 13 females (age: 36.1 ± 11.4 years, BMI: 22.6 ± 2.8 kg/m²) and 9 males (age: 36.8 ± 10.9 years, BMI: 26.7 ± 3.9 kg/m²). We found an average and median DTW distance of 0.88 and 0.81, respectively (Table 1). The lowest DTW distances—indicating a high degree of similarity between marker-based and markerless—were found for the sagittal knee angle (mean 0.13, median 0.08). In contrast, the highest DTW distances were found for the transverse knee angle (mean 1.92, median 1.74) and the frontal ankle angle (mean 2.22, median 2.29).

Cross-correlation was strong, with an overall mean of 0.67. High correlation was found for variables exhibiting low DTW distances, including both sagittal and frontal plane hip angles (mean 0.98 and 0.93, median 1.00 and 0.98). Interestingly, frontal plane ankle angle (mean -0.13, median -0.10) had negative correlations, suggesting potential measurement noise in the two systems at specific segments in the time series.

Future work will expand this cohort to 100 subjects and implement a regression model to adjust markerless data and reduce systematic biases, improving data alignment and enhancing the accuracy of markerless motion capture.

Significance: We compared marker-based and markerless kinematics using Dynamic Time Warping (DTW) to find similarity between the measurement systems, validating kinematic trajectories of the trunk, hip, knee, and ankle. Improved confidence in the use of markerless motion analysis technologies can enhance research via lower operational costs and enhanced efficiency. By understanding and improving these systems, physicians can achieve more accurate results without the need for physical markers.

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References: [1] Mündermann (2006), *J NeurolEng & Rehab*. [2] Wu et al., (2002), *J Biomech*. [3]. Thewlis et al., (2008), *J App Biomech*. [4] Lee (2019), *J Exercise Rehab*.

Table 1: DTW and cross-correlation of kinematic variables (mean±SD)

Variable	Plane	DTW	Cross-Correlation
Trunk Angle	Flexion/extension	1.42 ± 1.15	0.42 ± 0.61
	Lateral lean	1.39 ± 0.63	0.37 ± 0.40
	Transverse rotation	1.30 ± 0.71	0.50 ± 0.38
Pelvic Angle	Anterior/posterior tilt	0.63 ± 0.83	0.86 ± 0.41
	Pelvic drop	1.05 ± 0.78	0.61 ± 0.34
	Transverse rotation	1.97 ± 0.51	0.74 ± 0.25
Hip Angle	Flexion/extension	0.16 ± 0.15	0.98 ± 0.06
	Abduction/adduction	0.31 ± 0.33	0.93 ± 0.17
	Internal/external rotation	1.98 ± 0.80	0.28 ± 0.40
Knee Angle	Flexion/extension	0.13 ± 0.10	0.98 ± 0.03
	Varus/valgus	1.57 ± 0.82	0.38 ± 0.40
	Internal/external rotation	1.92 ± 0.69	0.02 ± 0.44
Ankle Angle	Dorsiflexion/plantarflexion	0.22 ± 0.13	0.96 ± 0.04
	Inversion/eversion	2.22 ± 0.73	-0.13 ± 0.37
Overall		0.88 ± 0.91	0.67 ± 0.46