COMPARISON OF MARKER AND MARKERLESS MOTION CAPTURE SYSTEM FOR GAIT KINEMATICS

Wuyue Hong, Hanjun Li, Yufeng Yang, Yulin Zhou, Jialin Ding

Beijing Sports University, Beijing, China

The purpose of this study was to compare gait kinematics measured with a markerless motion capture system (FastMove AI 3D Analysis System) against data measured with a marker-based motion capture system. A sample of 14 over-ground walking trials were captured simultaneously with two camcorders (60Hz) and an 8-camera marker system. The markerless data was further processed to landmarks using markerless human movement automatic capture system. Body landmarks data of X and Z coordinates were highly consistent between the two systems, while data of Y coordinate showed low consistency. The Bland-Altman plots' results showed low agreement (average of differences ranged from -182.5% to 109%) between individual measurements of the maximum and minimum of knee and ankle flexion angles from both systems against the average of the measurements.

KEYWORDS: markerless motion capture, gait kinematics, joint angles

INTRODUCTION: Kinematic data is one of the most important features of biomechanics research, where motion capture systems are commonly used to evaluate human motor function (Astephen et al., 2008). The mainstream of motion capture is the passive optical method, in which the markers attached to the subject's body surface are tracked and the position of each part of the subject's body can be estimated from the three-dimensional coordinates of such markers to provide comprehensive 3D representations and quantification of individuals' movement patterns, particularly gait. However, it has several inherent issues that affect its ability to collect accurate and reliable measures of gait (Narayanan, 2007). This technology requires markers to be placed on patients' palpable anatomical landmarks, a process that makes the resulting data susceptible to inaccurate and inconsistent marker placement (Della Croce et al., 2005). The changing collection conditions lead to inconsistent error levels across gait studies, demonstrating that clinically acceptable errors are possible but not always achieved in gait analysis (McGinley et al., 2009). In addition, marker-based motion capture is susceptible to errors caused by the movement of the soft tissue to which the markers are affixed relative to the underlying bones (Dumas et al., 2014; Leardini et al., 2005).
Markerless motion capture has the potential to alleviate some of the technical and practical issues of marker-based motion analysis without sacrificing data quality by replacing physical palpation of bony landmarks with probabilistic estimation of segment pose by highly trained neural networks (Mathis et al., 2018). Beijing Sport University in collaboration with FastMove Technology Inc, and Chinese Athletics Association recently developed an artificial intelligence system for markerless human movement automatic capture, that uses 2D video data from an array of standard video cameras to perform 3D pose estimation on human subjects. In this system, landmark detection is performed by a highly trained deep neural network that applies rules consistently across individuals, thereby dissociating the tracking of human motion from the operator. It is a tool to carry out 3D motion analysis, provide the world-leading data analysis content for competitive sports athletes and coaches, and supporting digital solutions for sports science researchers. The software can not only support real-time motion video capture by using ordinary high-speed cameras or industrial cameras and Direct Linear Transformation (DLT) calibration, but also synthesize 3D coordinates of human body landmarks by aligning synchronized images captured by two or more cameras.
Thus, the aim of this study was to compare gait kinematics measured with a markerless motion capture system against data measured with a marker-based motion capture system.

METHODS: Seven recreationally active participants (male, 20±2 yrs, 1.74 ± 0.09m 71.5 ± 11.2kg) performed a test of gait. Exclusion criteria included having any neuromuscular or musculoskeletal impairments that could prevent their performance of walking. Participants performed 2 over-ground walking trials at their comfortable walking speed on a force plate (Kistler 9281CA, Switzerland, 1000Hz), while each walk was simultaneously captured by both an 8-camera marker-based motion capture system (Motion Analysis Raptor-4, USA, 200 Hz) and two camcorders (60Hz). A right-handed coordinate system was defined for both systems by placing a Motion L-Frame in the centre of the capture volume.

Marker-based system: 21 retro-reflective markers were placed on the participant’s bony landmarks according to Helen Hayes model (HH). The trajectories of the retroreflective markers placed on relevant anatomical landmarks of the subjects’ body were tracked using an 8-camera marker-based system (Motion Analysis Raptor-4, USA). Markers were exported for further analysis in Cotex (USA). Markers were filterd using a lowpass Butterworthtfilter of 13.3Hz.

Markerless system: The 2D video data was collected using two camcorders (60Hz, one was placed directly in front of the walking direction, the other was placed on the right of the walking direction, and the angle between them was 90°), which were calibrated using Direct Linear Transformation（DLT）method. The video records of each test were digitized by human movement automatic capture system. Markerless human movement automatic capture system (FastMove) was used to automatically parse all 14 sets of test videos. Three‑dimensional coordinates of 10 body landmarks were obtained. Markers were filterd using a lowpass Butterworthtfilter of 7.4Hz.

Comparison: Both systems acquired data for one complete gait cycle of the participants. The data of the two systems is synchronized by the keyframe sync method. The correlation coefficient of 10 body landmarks between the marker-less system data and the marker-based system data were calculated. Bland-Altman plots were used to compare maximum and minimum knee flexion angles and maximum and minimum ankle flexion angles during one complete gait cycle, from both systems.

RESULTS: The correlation coefficient of 10 body landmarks (3 coordinates, X, Y, Z) ranged between 0.16 to 1 (Table 1&2). Most CMCs of the X and Z coordinates were greater than 0.90, which means data were highly consistent between the two systems. However, CMCs of the Y coordinate were low, especially the Y coordinate right hip, which means data from the two systems have differences in Y coordinate.

Bland-Altman plot, showing the difference between individual measurements of the maximum and minimum of knee and ankle flexion angles from both systems against the average of the measurements. Solid lines and printed values represent the bias (mean difference) obtained from each comparison, and dashed lines represent 95% limits of agreement (95% LoA) of the measurements，the error bars are confidence intervals (Figure 1&2). Bland-Altman plot of knee flexion angle shows low agreement between the two systems: average of differences (Marker-Markerless) ranged from -182.5% to 7.8%, and the maximum of the differences (Marker-Markerless) ranged from -125.3%~109.0%. Bland-Altman plot of ankle flexion angle shows higher agreement than knee flexion angle between the two systems: average of differences (Marker-Markerless) ranged from -3.1%~5.5% to 7.8%, and the maximum of the differences (Marker-Markerless) ranged from -10.9%~22.4%. For both of knee and ankle flexion angles, most of the points are within 95% LoA.

Table 1: The Multiple Correlation Coefficients of the Human Body Joint Point (Right) Coordinate‑time Curve Obtained by Using Both Systems（*：can’t be calculated）

	R.Hip-x	R.Hip-y	R.Hip-z	R.Knee-x	R.Knee-y	R.Knee -z	R.Ankle-x	R.Ankle-y	R.Ankle-z	R.Heel-x	R.Heel-y	R.Heel-z	R.Toe-x	R.Toe-y	R.Toe-z
Ave	0.9999	*	0.9434	0.9996	0.7871	0.9413	0.9994	0.8724	0.9948	0.9993	0.548	0.9701	0.9996	0.9404	0.9435
test1	0.9989	0.3997	0.9441	0.9595	0.3919	0.5006	0.9994	0.7173	0.9941	0.999	0.5044	0.9748	0.9997	0.7142	0.9069
test2	0.9974	*	0.8819	0.9999	0.8134	0.929	0.9996	0.4281	0.9962	0.9994	*	0.9747	0.9999	0.5821	0.9261
test3	0.9991	0.7096	0.8856	1	*	0.9718	0.9999	*	0.9958	0.9996	*	0.9752	0.9997	*	0.7387
test4	0.9994	*	0.8904	0.9998	0.6793	0.9636	0.9998	0.8386	0.994	0.9996	0.7947	0.9694	0.9995	0.8274	0.8401
test5	0.9996	*	0.8674	0.999	*	0.8712	0.9986	0.3867	0.9805	0.9983	0.558	0.9533	0.9975	*	0.9254
test6	0.9995	*	0.8707	0.9997	0.4036	0.9236	0.9998	0.3021	0.9887	0.9995	0.5073	0.9638	0.9999	*	0.9442
test7	0.9995	0.4774	0.9191	0.9996	*	0.9777	0.9991	*	0.9971	0.9988	*	0.979	0.9988	0.1822	0.8715
test8	0.9997	*	0.9007	0.9996	0.4867	0.9586	0.9992	0.6431	0.9928	0.9993	0.2965	0.9739	0.997	0.633	0.8482
test9	0.9985	0.3655	0.9358	0.9975	*	0.821	0.9886	0.6202	0.9461	0.9883	0.5898	0.9215	0.9867	0.7234	0.8977
test10	0.9998	*	0.8714	0.9998	0.8269	0.8218	0.9996	0.9157	0.9961	0.9991	0.8407	0.9828	0.9996	0.9122	0.9619
test11	0.9998	*	0.8685	0.9999	*	0.7943	0.9996	*	0.9917	0.9995	*	0.9681	0.9991	*	0.9089
test12	0.9996	*	0.8443	0.9999	0.1591	0.7724	0.9999	*	0.995	0.9998	*	0.9752	0.9993	0.2531	0.8836
test13	0.9962	0.2246	0.8248	0.995	*	0.9181	0.992	*	0.8905	0.992	*	0.8761	0.9912	*	0.972
test14	0.9913	*	0.856	0.9906	*	0.9144	0.9863	*	0.8807	0.9866	*	0.8782	0.9831	*	0.9518

Table 2: The Multiple Correlation Coefficients of the Human Body Joint Point (Left) Coordinate-time Curve Obtained by Using Both Systems（*：can't be calculated）

	L.Hip-x	L.Hip-y	L.Hip-z	L.Knee-x	L.Knee-y	L.Knee - z	L.Ankle-x	L.Ankle-y	L.Ankle-z	L.Heel-x	L.Heel-y	L.Heel-z	L.Toe-x	L.Toe-y	L.Toe-z
Ave	0.9998	0.4251	0.8696	0.9997	0.7737	0.9586	0.9992	0.6933	0.9893	0.999	0.379	0.9648	0.9992	0.8664	0.9272
test1	0.9997	0.5273	0.8552	0.9965	0.951	0.9443	0.9937	0.869	0.9658	0.9928	0.6749	0.9424	0.9946	0.9189	0.8759
test2	0.9999	*	0.6232	0.9987	0.9618	0.9335	0.9979	0.9091	0.9852	0.9975	0.7595	0.9568	0.9982	0.9257	0.8888
test3	0.9999	0.5325	0.8586	0.999	0.7262	0.957	0.9981	0.7639	0.9764	0.9983	0.7243	0.9527	0.9979	0.6685	0.8637
test4	0.9999	*	0.8798	0.9996	0.8713	0.9703	0.9995	0.7564	0.989	0.9993	0.6749	0.9709	0.9994	0.7503	0.8574
test5	0.9998	*	0.9255	0.9995	0.4391	0.9098	0.9997	0.6932	0.9878	0.9995	0.5043	0.9599	0.9995	0.8148	0.8767
test6	0.9996	*	0.8779	0.9973	0.517	0.7949	0.9967	0.6446	0.9853	0.9962	0.4278	0.959	0.9971	0.7865	0.8938
test7	0.9993	0.6816	0.94	0.9981	*	0.9674	0.9984	*	0.9857	0.9979	*	0.951	0.9983	0.8356	0.9429
test8	0.9998	*	0.9365	0.9997	0.1602	0.9195	0.9998	0.1474	0.9917	0.9995	*	0.9591	0.9994	0.7919	0.9517
test9	0.9985	0.7107	0.8387	0.9991	0.6936	0.9122	0.9971	0.6546	0.9945	0.9971	0.5183	0.9785	0.9969	0.7471	0.901
test10	0.9997	*	0.8517	0.9996	0.87	0.864	0.9996	0.8492	0.9977	0.9994	0.7667	0.987	0.9992	0.9207	0.949
test11	0.9998	*	0.6425	0.9996	*	0.9229	0.9989	*	0.9931	0.9987	*	0.9677	0.9986	0.6006	0.9294
test12	0.9999	*	0.7448	0.9997	0.5698	0.9232	0.9992	*	0.9959	0.9988	*	0.9665	0.9994	0.6303	0.949
test13	0.998	0.2694	0.6812	0.9982	0.3552	0.7181	0.9975	0.7609	0.8955	0.9971	0.6711	0.9223	0.9975	0.8104	0.5224
test14	0.9938	*	0.7022	0.9957	0.4228	0.8128	0.9987	0.798	0.8725	0.999	0.7336	0.9163	0.9986	0.85	0.6259

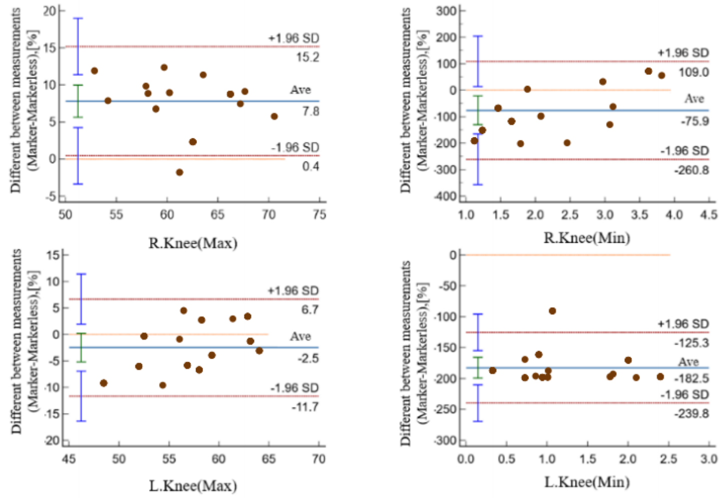

Figure 1: Differences between individual measurements of the maximum and minimum of knee flexion angles from both systems

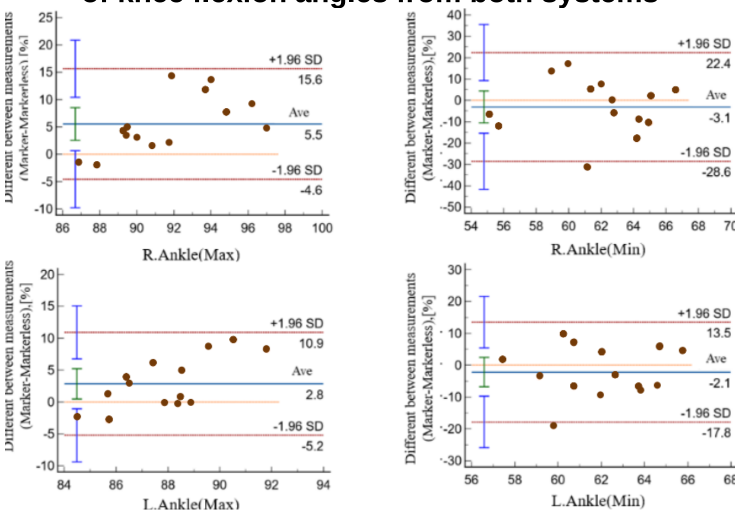

Figure 2: Differences between individual measurements of the maximum and minimum of ankle flexion angles from both systems

DISCUSSION: This study compared the kinematics of healthy human gait measured by a marker-based motion capture system and a markerless motion capture system, finding systematic differences between the markerless and marker technologies. Body landmarks data of X and Z coordinates were highly consistent between the two systems, as the curves demonstrated similar features and timing, leading to high CMC values, while data of Y coordinate showed low consistency. The Bland-Altman plots' results showed low agreement between individual measurements of the maximum and minimum of knee and ankle flexion angles from both systems against the average of the measurements. These findings are inconsistent with previous studies comparing alternatives to motion capture (Colyer et al., 2018), whether markerless motion capture system (FastMove) is a reliable tool in gait kinematics remains to be tested.

There are several potential sources of error that could affect the measurements from both systems. Marker-based kinematics are susceptible to marker placement variation, kinematic crosstalk, soft tissue artefact, and joint position regression errors. It has been shown that skin-mounted marker clusters move relative to the underlying bone during gait, with translations of up to 1.5 cm at the shank and 2.5 cm at the thigh, and rotations up to 8°. These tissue artefacts introduce unpredictable, subject- and task-specific errors of up to 3° in knee joint angles (Benoit et al.,2015). Markerless kinematics may also be affected by several factors. Firstly, during over-ground walking, the range of the movement of the Y coordinate was small, resulting in low CMC. The CMC of the Y coordinate right hip is extremely low, because the hip point has no obvious bony landmark, which can only be judged by experience. What's more, the participants wore mostly dark clothing during the test, which means dark attire provides a greater challenge for the markerless motion capture system due to reduced contrast. Additionally, while the markerless motion capture system is largely unrestricted with regards to the data collection environment, the data used in this study were collected in a laboratory space under poor indoor lighting conditions. Finally, the video data consisted of images recorded at 60 Hz, producing images that were somewhat low resolution and blurry at times. More appropriate video cameras would provide higher quality images and may improve tracking.

Future research can compare marker-based and markerless results for a larger sample of participants. Future research can also compare kinetic calculations (joint forces and torques) between the two systems.

CONCLUSION:

This study indicates that the tracking of the markerless motion capture system (FastMove) yet is not comparable to marker-based motion capture system in gait kinematics, which needs further improvement. The effects including the range of the movement, clothing, the data collection environment and the video data are currently being examined in greater depth. New algorithm should be used to improve the accuracy of data acquisition and the degree of automation of artificial intelligence system.

REFERENCES

Astephen, J.L., Deluzio, K.J., Caldwell, G.E., Dunbar, M.J., 2008. Biomechanical changes at the hip,kn ee, and ankle joints during gait are associated with knee osteoarthritis severity. J. Orthop. Res.26, 332 –341.

Benoit, D.L., Damsgaard, M., Andersen, M.S., 2015. Surface marker cluster translation, rotation, scalin g and deformation: Their contribution to soft tissue artefact and impact on knee joint kinematics. J. Bio mech. 48, 2124–2129.

Colyer, S.L., Evans, M., Cosker, D.P., Salo, A.I.T., 2018. A review of the evolution of vision-based moti on analysis and the integration of advanced computer vision methods towards developing a markerles s system. Sports Med.– Open 4, 24.

DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. Nat.Neurosci. 21, 1281.

Della Croce, U., Leardini, A., Chiari, L., Cappozzo, A., 2005. Human movement analysis using stereop hotogrammetry: Part 4: assessment of anatomical landmark misplacement and its effects on joint kine matics. Gait Posture 21, 226–237

Dumas, R., Camomilla, V., Bonci, T., Cheze, L., Cappozzo, A., 2014. Generalized mathematical repres entation of the soft tissue artefact. J. Biomech. 47, 476–481.

Leardini, A., Chiari, L., Croce, U.D., Cappozzo, A., 2005. Human movement analysis using stereophot ogrammetry: Part 3. Soft tissue artifact assessment and compensation. Gait Posture 21, 212–225.

Mathis, A., Mamidanna, P., Cury, K.M., Abe, T., Murthy, V.N., Mathis, M.W., Bethge, M., 2018.

Narayanan, U.G., 2007. The role of gait analysis in the orthopaedic management of ambulatory cerebr al palsy. Curr. Opin. Pediatr. 19, 38–43.