INTRA-RATER AND INTER-RATER RELIABILITY OF A MODEL-BASED IMAGE-MATCHING MOTION ANALYSIS TECHNIQUE IN MEASURING ANKLE JOINT KINEMATICS

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The aim of this study was to assess the intra-rater and inter-rater reliability of the MBIM technique in measuring ankle joint kinematics. Three cadaveric below-hip specimens were prepared for performing full-range plantar/dorsiflexion, in/eversion and relative circular motion between the shank and foot segments. A detailed skeleton matching protocol was given to two researchers and each researcher performed the matching five times on each specimen. Intra-rater and inter-rater reliability were assessed with interclass correlation (ICC). The results showed excellent intra-rater reliability (ICC coefficient > 0.978) and excellent inter-rater reliability (ICC coefficient > 0.981). Therefore, the MBIM technique for analyzing ankle joint kinematics is repeatable and is a good motion analysis tool for sports science and sports medicine related research.

KEYWORDS: ankle joint movement, motion analysis technique

INTRODUCTION: Motion analysis is often used to measure the joint kinematics in sports science research. Motion analysis techniques must have good validity and reliability to ensure the data obtained are accurate and repeatable. Krosshaug and Bahr (2005) introduced a model-based image-matching (MBIM) technique for investigating human motion from uncalibrated video sequences and employed this technique to investigate knee joint kinematics in some sports injury incidents (Krosshaug et al. 2007). For measuring ankle joint kinematics, the validity of the MBIM technique has been demonstrated (Mok et al. 2009). However, since the MBIM technique requires manual skeleton matching, it depends on the researcher's ability to accurately match the orientation of each segment. As a result, measurement difference may exist within and between researchers. Before considering the MBIM technique as a reliable motion analysis tool, detailed matching instructions must be developed and its reliability must be assessed. Therefore, the aim of the present study was to assess the intra-rater and inter-rater reliability of the MBIM technique using a standard matching protocol proposed by our research team in measuring ankle joint kinematics.

METHOD: Three cadaveric below-hip specimens were prepared for testing. Each specimen was mounted on a jig in an upright position. Four high speed cameras (Casio EX-F1, Japan) were used to record the ankle motion in 30Hz with 640x480 resolutions from four different views. A static calibration trial in the anatomical position served as the offset position to determine the segment embedded axes of the shank and foot segment. The line connecting knee joint center and ankle joint center was the longitudinal axis of the shank segment (X1). The anterior-posterior axis of the shank segment (X2) was the cross product of X1 and the line joining the lateral femoral epicondyle and medial femoral epicondyle. The medial-lateral axis of the shank segment was the cross product of X1 and X2 (Wu et al. 2002).
Full-range plantar-flexion/dorsiflexion, inversion/eversion and shank circular motion were performed by moving the shank segment on the ankle joint manually. The ankle joint kinematics in each of the four views was analyzed using the MBIM technique (Krosshaug et al., 2005). Using a commercialized animation software Poser (Poser4, Curious Lab, US), a

virtual environment was built and matched with the video images in every camera view by adjusting the camera calibration parameters. A skeleton model (Zygote Media Group Inc, USA) was customized to match the anthropometry of the specimen. The skeleton model was matched frame by frame starting with the shank segment, followed distally by the foot and the toe segments. The joint angle time histories were read into Matlab (MathWorks, USA) with a customized script for data processing.
Two researchers, A and B, performed the manual skeleton matching process five times on each specimen. The researchers were with good human biomechanics knowledge and were trained to implement the skeleton matching with the same instructions (Table 1). In each frame, the skeleton model has to be matched such that it is in an anatomically accurate position and is contained within the image boundary (Figure 1). For plantar-flexion/dorsiflexion, inversion/eversion and internal/external rotation of the ankle joint, anatomical landmarks and joint orientations were used as indications of the direction of movement. Lastly, the motion of the skeleton model was reassessed for the whole video and adjusted frame by frame to ensure a smooth matched motion.

Table 1. Matching instructions given to researchers for the skeleton matching

	Item	Instructions
1.	General	(a) Within image boundaries
		(b) Anatomically correct
		(c) Smooth motion
2.	Plantar flexion/dorsiflexion	(a) Identify the long axis of the shank segment
		(b) Identify the long axis of the foot segment
3.	Inversion/eversion	(a) Identify the plantar foot
		(b) Regard foot segment as a rectangular board
4.	Internal/external rotation	(a) Identify the patella position
		(b) Identify the anterior edge of shank

Figure 1. Matching of the skeleton model by the MBIM technique.

Intra-rater reliability was assessed by comparing the results of the five matching trials on each specimen performed by each researcher. Inter-rater reliability was assessed by comparing the first matching trial performed on the same specimen between the two researchers. A work distribution graph is shown on Figure 2. Intra-rater and inter-rater reliability were assessed with interclass correlation (ICC), two-way mixed measures assuming the interaction effect is absent (Hopkins, 2000).

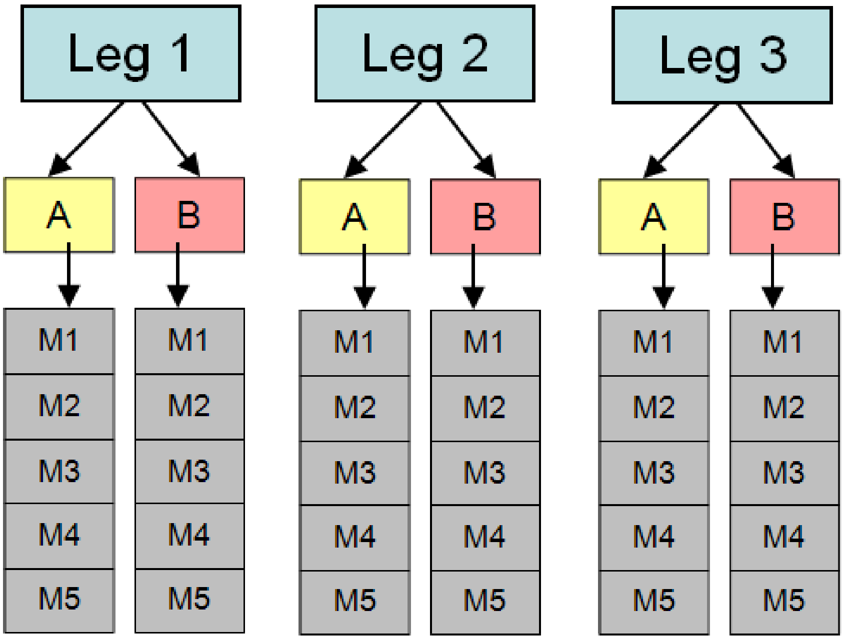

Figure 2. Work distribution of operator A and B on skeleton matching

RESULTS: The ICC coefficients for intra-rater reliability demonstrated excellent correlation (ICC coefficient > 0.978) between the kinematic data analyzed by the same operator (Table 2). For inter-rater reliability, the ICC coefficient also demonstrated excellent correlation (ICC coefficient > 0.981) between the kinematic data analyzed by the two operators (Table 3).

Table 2. Intraclass correlation for the intra-rater reliability of the kinematic data.

	Intraclass Correlation					
	Plantarflexion/dorsiflexion		Inversion/eversion		Internal/external rotation	
Researcher	A	B	A	B	A	B
Specimen 1	0.999	0.998	0.997	0.993	0.957	0.968
Specimen 2	0.997	0.999	0.999	0.999	0.991	0.987
Specimen 3	0.997	0.996	0.992	0.995	0.986	0.983
Average	0.998	0.998	0.996	0.996	0.978	0.979

Table 3. Intraclass correlation for the inter-rater reliability of the kinematic data.

	Intraclass Correlation		
	Plantarflexion/dorsiflexion	Inversion/eversion	Internal/external rotation
Specimen 1	0.987	0.972	0.956
Specimen 2	0.998	0.996	0.992
Specimen 3	0.996	0.994	0.995
Average	0.994	0.987	0.981

DISCUSSION: The aim of the present study was to assess the intra-rater and inter-rater reliability of the MBIM technique in measuring ankle joint kinematics. It is important to evaluate the repeatability of this technique since a manual skeleton matching process is required. Our research team has developed a standard protocol for analyzing ankle joint kinematics using the MBIM technique. Our protocol uses anatomical landmarks and joint orientations as indicators of joint movements to ensure matching accuracy.
Following our protocol, the average ICC coefficients for the intra-rater reliability were greater than 0.978 for all ranges of motion and the average ICC coefficients for the inter-rater

reliability were greater than 0.981 for three cadaveric specimens. These results imply that different trained researchers can produce the same results with excellent repeatability.
The MBIM technique is newly introduced and has the potential to be developed as a new on-field markerless motion analysis tool because calibrated capture volume and skin markers are not required. This technique can be used to analyze the kinematics of foot and ankle injuries from videos captured during televised sport events.

CONCLUSION: This study presented a model-based imaging-matching motion analysis technique in measuring ankle joint kinematics with excellent intra-rater and inter-rater reliability. This technique can reliably produce ankle joint kinematics profile from uncalibrated video sequences and can be used as an on-field markerless motion analysis tool to analyze real-game sporting motions.

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