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Comparing Trunk Kinematics Computed by Optical Marker-Based Motion Capture System and Inertial Measurement Units during Overground Trips

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Abstract:	Falls are the most common cause of non-fatal injuries, and trips are responsible for high percentages of those falls in the United States. Traditional method for estimating trunk kinematics during overground trips uses optical marker-based motion capture systems. However, their cost and space requirements can often be barriers in this research field. Inexpensive and portable inertial measurement units may be an appropriate alternative. This study compared trunk flexion angle and angular velocity at touchdown of the initial recovery step after laboratory-induced trips while walking captured by the optical marker-based motion capture system versus IMUs. Our results provide evidence that a sternum-worn IMU can provide trunk kinematic measurements of clinical relevance and may be used to provide meaningful data to understand kinematic responses to trips or trip-induced falls that occur in real life.

COMPARING TRUNK KINEMATICS COMPUTED BY OPTICAL MARKER-BASED MOTION CAPTURE SYSTEM AND INERTIAL MEASUREMENT UNITS DURING OVERGROUND TRIPS

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Falls are the most common cause of non-fatal injuries, and trips are responsible for high percentages of those falls, in the United States. A common method in research for measuring trunk kinematics during overground trips is to use a lab-fixed, optical, marker-based motion capture system. However, its cost and space requirements can often be barriers for its use. Inexpensive and portable inertial measurement units (IMUs) may be a viable alternative, especially if researchers endeavor to capture these data outside of the laboratory setting. The purpose of the study was to compare trunk flexion angle and angular velocity captured by IMUs to those captured by a gold-standard optical marker-based motion capture system during overground trips in a laboratory. Trunk kinematics were of interest based upon the importance of limiting trunk flexion kinematics in preventing a fall after tripping.

A convenience sample of 10 young adults (five females) with mean (SD) age = 22.1 (2.4) years, height = 1.71 (0.07) m, and mass = 71.8 (8.8) kg, was recruited from the university population. During a single experimental session, subjects were exposed to two laboratory-induced trips while walking on a walkway. Subjects wore a full-body fall protection harness attached to an overhead track along the walkway for safety in the event of an unsuccessful balance recovery. Body kinematics during the two trip trials were recorded by 10 reflective markers using a 13-camera optical motion capture system (Qualisys North America, Inc., Buffalo Grove, IL) and by three IMUs (Opal, APDM, Inc., Portland, OR). The markers were placed bilaterally at the acromion process, greater trochanter, top of the second toe, lateral malleolus, and calcaneus, while the IMUs were placed on sternum and top of feet. Both marker and IMU data were sampled at 128 Hz. Our dependent variables were trunk flexion angle and angular velocity at touchdown of the initial recovery step after tripping. For the optical marker-based motion capture system, the markers placed at the acromion processes and greater trochanters were used to create a local reference frame aligned with the trunk segment, and the Euler angle with respect to the medial-lateral axis was computed to determine trunk flexion angle. Trunk flexion angular velocity was a time derivative of the trunk flexion angle. The sternum IMU was worn using a sternum strap provided by the manufacturer. Acceleration and angular velocity data from the IMU were used to create a local reference frame aligned with the anatomical planes based on the method described in Cain et al. (2016). The orientation estimates from the sternum IMU were then used to calculate the Euler angle with respect to the medial-lateral axis for trunk flexion angle. Trunk flexion angular velocity was determined by the angular velocity data from the IMU after alignment with the anatomical planes. The markers and IMUs on feet were used to determine the time instant of touchdown of the initial recovery step after tripping. One trip trial from one subject was excluded from the final analysis due to a missed trip where the swing foot contacted the trip obstacle when the trip obstacle was not fully upright. A Bland-Altman plot was used to determine any systematic difference between the two motion capture systems (Bland & Altman, 2007). A line plot was used to illustrate differences between systems for each trip. A scatterplot was used to illustrate correlation between the two systems, along with a coefficient of determination (R^2).

Results show that most trunk kinematics estimates are within the 95% limits of agreement (Figure 1), and a line plot supports this finding by illustrating how close the trunk kinematics estimates are between the two systems (Figure 2). A scatterplot and coefficient of determination show a moderate correlation in the trunk kinematics estimates between the two systems, and that 54-62% of the variance in the marker estimates are explained by the variance in the IMU estimates (Figure 3). It should be noted that the trunk kinematics estimates from the two systems were not expected to be identical given 1) the trunk is not a rigid segment, 2) the four markers used with the optical motion capture system provided a global measure of overall trunk kinematics, while 3) the IMU on the sternum provided a more local measure of trunk kinematics. In addition, the differences between falls and recoveries in the mean trunk flexion angle and angular velocity at touchdown of the initial recovery step determined by markers from our study are comparable to the differences in the same estimates from prior studies (Table 1). Such results were also found between the same estimates captured by the IMU on the sternum and by markers in the prior studies as well as in our study (Table 1).

In conclusion, trunk flexion angle and angular velocity at touchdown of the initial recovery step after overground trips captured by IMUs are comparable to those captured by the optical marker-based motion capture system on the basis of our data. Our results provide evidence that a sternum-worn IMU can provide trunk kinematic measurements of clinical relevance and that it may enable assessment outside the laboratory to capture kinematic responses to real-life trips and falls.

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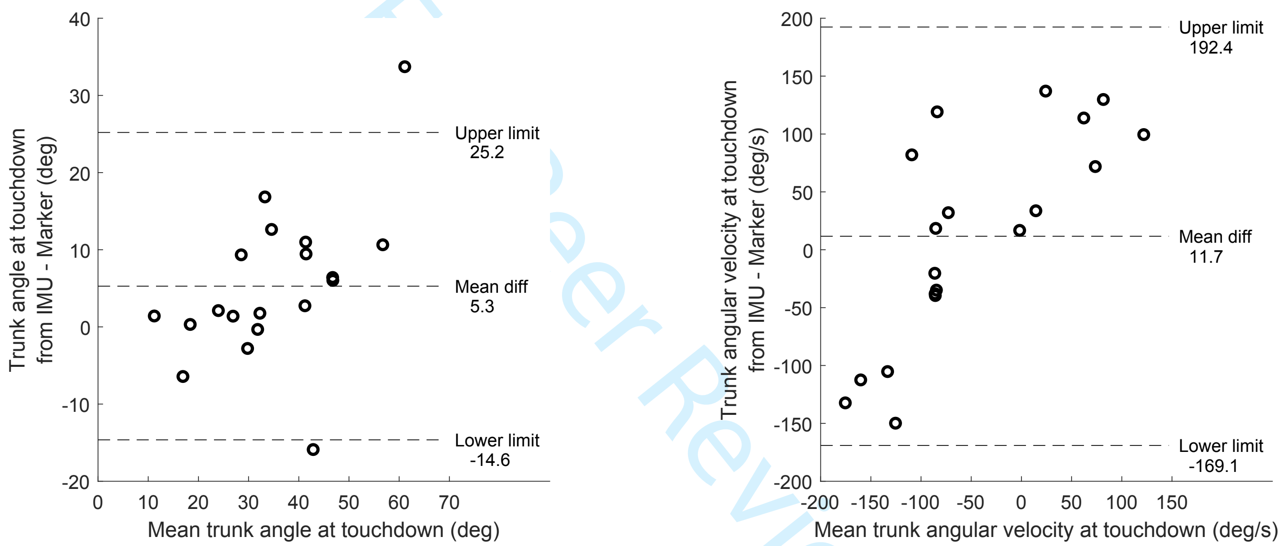

Figure 1. Bland-Altman plots with 95% limits of agreement. Each circle represents a single trip trial. Positive value means flexion.

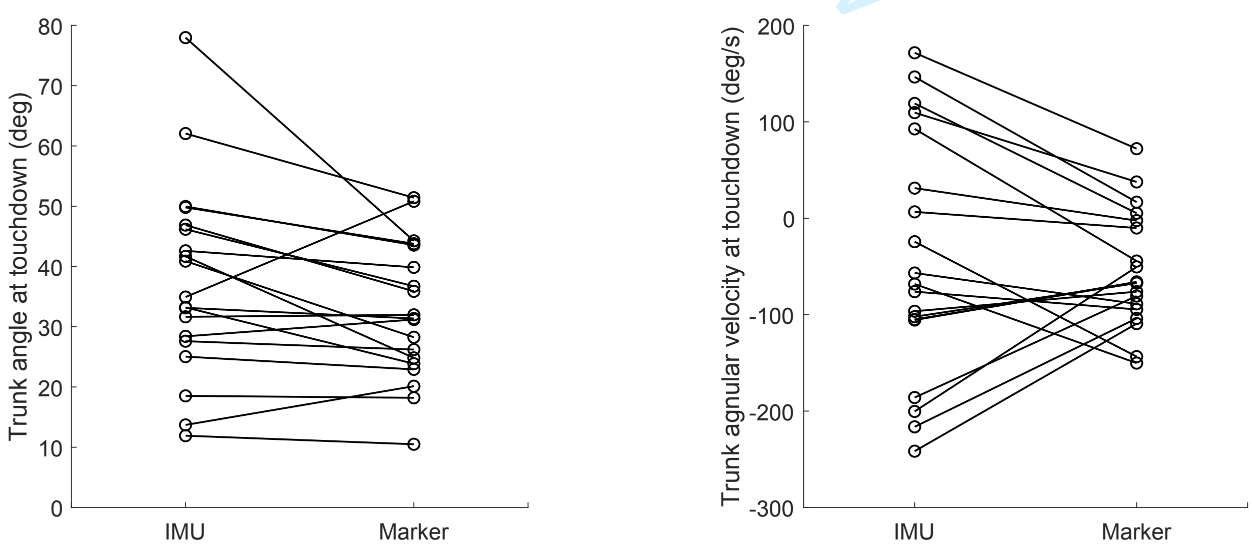

Figure 2. Line plots. Each line represents a single trip trial. Positive value means flexion.

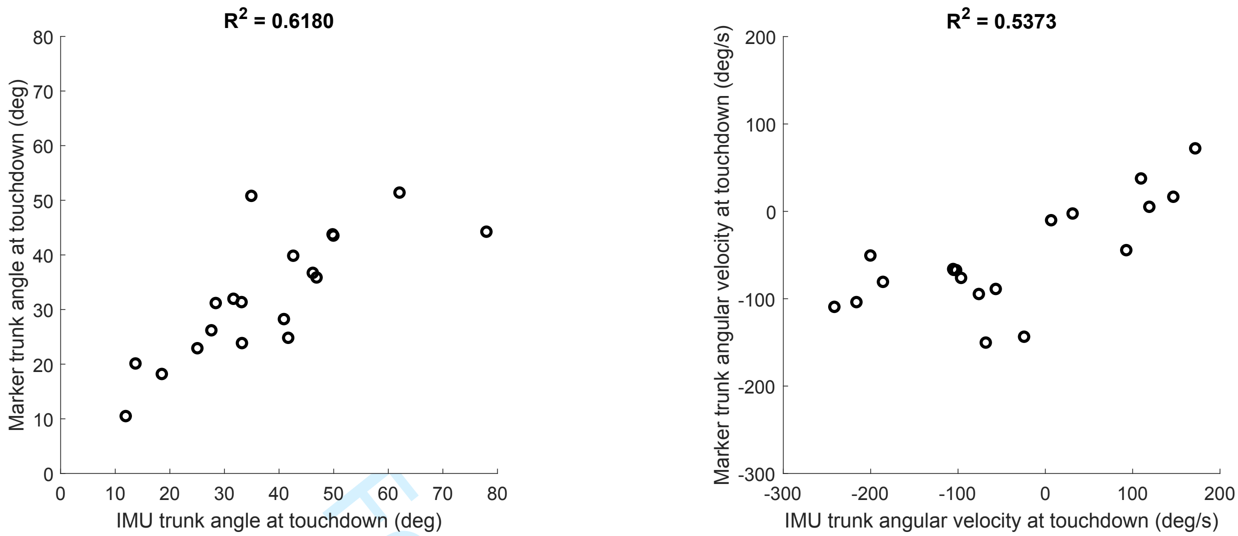

Figure 3. Scatterplots with coefficient of determination (R^2). Each circle represents a single trip trial. Positive value means flexion.

Table 1. Mean trunk flexion angle and angular velocity at touchdown of the initial recovery step from previous studies where an optical marker-based motion capture was used and the current study where both optical marker-based motion capture and IMU were used.

Reference	Trunk flexion angle at touchdown (deg)			Trunk flexion angular velocity at touchdown (deg/s)		
	Fall	Recovery	Difference	Fall	Recovery	Difference
Pavol et al. (2001)	40	26	14	68	-34	102
Grabiner et al. (2012)	37	22	15	40	-13	53
Current study: marker	40	30	10	4	-69	73
Current study: IMU	46	36	10	24	-60	84