Validation of an IMU wearable sensor for treadmill walking and stair ascent/descent

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Introduction: 100,000 total knee arthroplasty (TKA) procedures take place in the United Kingdom annually [1], and 94% of these procedures occur in individuals 50 years and older [2]. The need for home-based rehabilitation is high, however, compliance is low [2]. MotionSense™ (Stryker, US) is a wearable technology that remotely supports post-operative TKA rehabilitation by continuously monitoring knee motion remotely. This allows for personalised patient rehabilitation. However, validation of such devices against a gold standard measure across a broad range of activities of daily living is important for confident interpretation of resulting clinical data. The aim of this study therefore was to validate the accuracy of MotionSense™ against Vicon, a clinical motion capture standard.

Methods: Thirty-four healthy, able-bodied adults attended a laboratory session (Younger: n=20, age 24 ± 4 years, mean ± SD; Older: n=14, age 71 ± 5 years). Movement was tracked using Vicon motion analysis (100Hz) and MotionSense™ (~50Hz) wearable sensor. Plug-In-Gait lower body model was applied to determine knee flexion angles, while the sensor exported data in real time to a mobile device on which a proprietary algorithm determined knee angle. To time synchronise the technologies, MotionSense™ data were up-sampled to 100Hz, and cross-correlated. After a 1-minute acclimatisation period, 10 gait cycles were manually determined using heel strikes identified from foot marker trajectories via a bespoke graphical user interface. As the zero point for knee flexion depends both on marker and IMU placement, a bias was applied to the MotionSense™ data to account for any differences in calibration. The root mean square error (RMSE) between the technologies was determined. T-tests compared the older and the younger populations and significance was taken at the 5% level.

Results: For both age groups and for all activities the RMSE remained below 3° (Table 1, Figure 1A). No difference between older and younger participants was evidenced, despite older volunteers walking significantly slower than the younger volunteers (0.94 ± 0.12 ms-1 vs 1.17 ± 0.07 ms-1 , $p < 0.001$). The combined RMSE for all adults was 2.4° for walking, 2.7° for the stair ascent, and 2.59° for the stair descent.

Table 1. RMSE between Vicon and MotionSense™ for treadmill walking, stair ascent/descent for younger and older populations (mean ± SD)

	Younger	Older	Pooled
		RMSE (°)	
Walking	2.41 (0.85)	2.39 (0.68)	2.40 (0.77)
Stair Ascent	2.77 (0.83)	2.60 (0.96)	2.70 (0.88)
Stair Descent	2.41 (0.77)	2.83 (0.99)	2.59 (0.88)

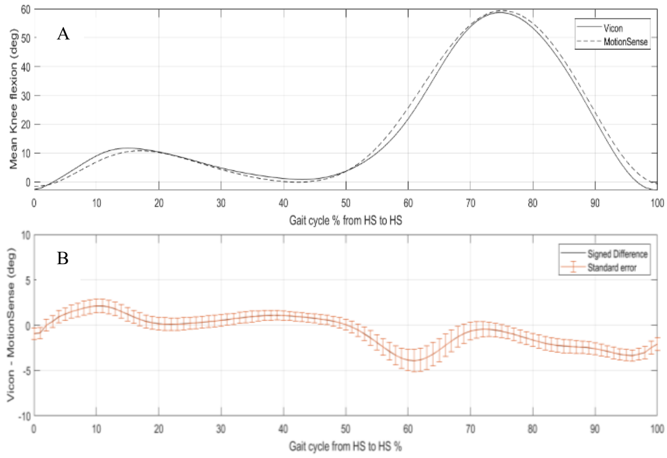

Figure 1. A) Comparison between the averaged Vicon and MotionSense™ measures for walking for young participants. B) Signed difference (mean ± SE) between Vicon and MotionSense™ for walking for young participants.

Discussion: The signed error increased during the swing phase of gait (Figure 1B). This may be due to high frequency transients. RMSE values indicate the MotionSense™ platform performs better in comparison to comparable systems [3,4]. MotionSense™ does not require any form of calibration from the user, and the algorithm out-performed one method which involved functional self-calibration movements [3].

References:

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