Analysing Sit-to-Stand and Sit-to-Walk Movements Using Ear-Worn IMUs

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Summary

Sit-to-stand (S2S) and sit-to-walk (S2W) are key functional movements used to assess balance control, falls risk and level of functional independence. While quantitative analysis of these movements has been extensively developed using optical methods, the need for specialist equipment restricts the scope of their implementation. This study compared acceleration data from an ear-worn inertial measurement unit (IMU) system to an optical gold standard, finding strong agreement for both tasks in forwards and upwards directions.

Table 1: Pearson's correlation coefficients between ear-worn IMU and C7 marker acceleration measurements in forwards and upwards directions during S2W and S2S.

Activity (Direction)	Left ear IMU vs left ear marker	Right ear IMU vs right ear marker	Left ear IMU vs C7 marker	Right ear IMU vs C7 marker
S2W (Forwards)	0.986	0.986	0.960	0.948
S2W (Upwards)	0.992	0.992	0.945	0.945
S2S (Forwards)	0.994	0.993	0.965	0.968
S2S (Upwards)	0.994	0.995	0.958	0.958

Introduction

S2S and S2W movements have been widely studied and adopted clinically. While they are frequently analysed qualitatively or using optical camera or motion capture systems, wearable IMU-based methods can be used in unrestricted settings, allowing more relevant data to be collected more often. With ear-worn electronic devices such as headphones and hearing aids used widely, this study investigated the use of an ear-worn, IMU-based system to analyse movement during S2S and S2W, comparing the resulting acceleration signals with optical tracking data for the Centre of Mass (CoM).

Methods

This study collected S2S and S2W data from 68 participants (mean age: 39.5 years, range: 21-85 years) including 42 women and 26 men. 19 suffered from condition affecting movement or balance, such as Parkinson's disease and BPPV.

Participants wore a custom headset with two IMUs positioned at the left and right ears, with a reflective marker placed on each IMU and the participants' C7 (acting as an estimator of CoM while providing good optical visibility [1]). They then performed three sit-to-stand movements and three sit-to-walk trials with several seconds of rest in between each trial, with marker and 9-axis IMU data collected simultaneously and sent to a laptop for post-processing.

The IMU data were processed using an error-state extended Kalman filter to determine the linear acceleration in the optical system frame. These were then compared to the double-differentiated trajectories of the respective markers placed on the IMUs and the C7 in the forwards and upwards directions by calculating the Pearson correlation coefficient between them.

Results and Discussion

The two leftmost columns of Table 1 illustrate the strong agreement between the ear-worn IMUs and markers ($r > 0.985$), demonstrating that the Kalman filter effectively models the linear acceleration of the system. The two rightmost columns then show the strong agreement between the IMU and back marker acceleration signals ($r \geq 0.945$), suggesting that the ear-worn system tracks the CoM well.

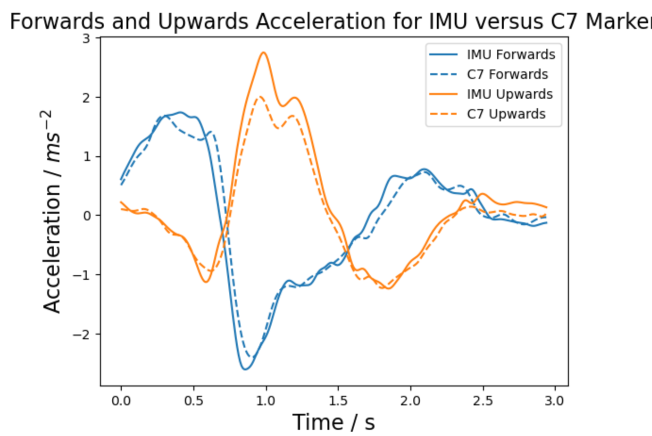

Figure 1: Acceleration signal comparison for an example trial.

Conclusions

The acceleration data from the ear-worn IMUs strongly matches that of the CoM, providing scope to derive accurate S2S and S2W movement metrics in natural settings.

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References

[1] Chandler EA et al. (2021). *Front. Neurol.* **12**