The Agreement Between Wearable Sensors and Force Plates for the Analysis of Stride Time

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Stride time (ST) fluctuations contain long-term correlations and provide important information about locomotor health [1]. Linear and non-linear ST analysis methods have differentiated between healthy locomotor function and those at risk of falls [2], motor diseases [3] or with previous history of injury [4]. A recent systematic review reported that wearable sensors demonstrated excellent validity and reliability for calculating linear ST metrics, and poor-to-moderate validity and reliability for non-linear ST metrics [5]. A low number of high-quality studies, varying methods, and limited number of strides were cited as potential reasons for the findings. Therefore, this study aimed to assess the agreement between several wearable sensors and force plates in quantifying ST variability using published recommended methods [6].

Method: Sixteen participants (6 f/ 10 m, height 176 ± 9 cm, mass 77 ± 14 kg, age 25 ± 6 y) completed three sessions over three weeks. Procedures were approved by the the Departments of Defence and Veterans' Affairs and La Trobe University's Human Research Ethics Committee (#302-20). Participants completed a 12-min walking trial on a force-instrumented treadmill at a self-selected walking speed during each session. Four sensors (Vicon Blue Trident, Axivity, Xsens Dot, APDM Opal) [1000 Hz, 200 Hz, 120 Hz, 128 Hz] were attached to the heel of each participant’s boot, while a Plantiga sensor [500 Hz] was embedded in a custom insole. All time series were downsampled to 120 Hz. Heel contacts were identified from the force plates using detection of the peak anteroposterior centre of pressure displacement, whereas detection of the peak vertical acceleration data was used to identify heel contacts for the wearable sensors. ST was calculated as the time interval between successive heel contacts of the right foot. Linear measures included ST mean, standard deviation (SD), and coefficient of variation (CV), whereas non-linear measures included detrended fluctuation analysis alpha

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(DFA) and sample entropy (SampEn). Relative and absolute agreement was assessed using Pearson's *r* and intraclass correlation coefficients, respectively, comparing each metric calculated from the wearable sensors to that calculated from the force plates.

Results: The Opal APDM sensor had moderate-to-excellent agreement (*r* = 0.6 – 0.99) while the Axivity (*r* = 0.84 – 0.99), Blue Trident (*r* = 0.79 – 0.99), XSens DOT (*r* = 0.85 – 0.99), and Plantiga (*r* = 0.83 – 0.99) had good-to-excellent agreement across metrics when compared with the force plates (Fig. 1).

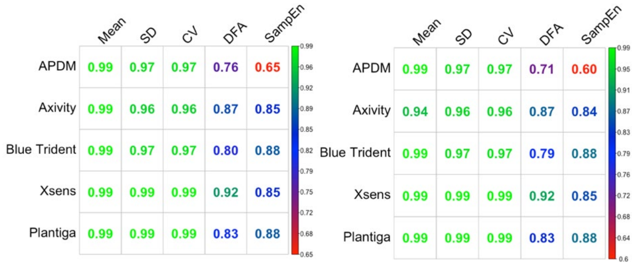

Fig. 1: Relative (a) and absolute (b) agreement of sensors and force plates in the calculation of

Conclusions: Non-linear methods exhibited reduced agreement (r 0.6 – 0.92) compared with linear methods (r 0.94 – 0.99), consistent with previous systematic reviews. Non-linear methods such as DFA and SampEn are more likely to be sensitive to error due to exploring the temporal structure of a time series rather than the magnitude of variability. The results show that wearable sensors could provide a portable, cost-effective solution to analyse ST using linear and non-linear methods.

1. Hausdorff, J.M., *Gait dynamics, fractals and falls: Finding meaning in the stride-to-stride fluctuations of human walking.* Human Movement Science, 2007. **26**(4): p. 555-589.
2. Hausdorff, J.M., D.A. Rios, and H.K. Edelberg, *Gait variability and fall risk in community-living older adults: A 1-year prospective study.* Archives of Physical Medicine and Rehabilitation, 2001. **82**(8): p. 1050-1056.
3. Zanardi, A.P.J., et al., *Gait parameters of Parkinson's disease compared with healthy controls: a systematic review and meta-analysis.* Sci Rep, 2021. **11**(1): p. 752.
4. Meardon, S.A., J. Hamill, and T.R. Derrick, *Running injury and stride time variability over a prolonged run.* Gait Posture, 2011. **33**(1): p. 36-40.
5. Kobsar, D., et al., *Validity and reliability of wearable inertial sensors in healthy adult walking: a systematic review and meta-analysis.* Journal of NeuroEngineering and Rehabilitation, 2020. **17**(1): p. 62.
6. Phinyomark, A., R. Larracy, and E. Scheme, *Fractal Analysis of Human Gait Variability via Stride Interval Time Series.* Frontiers in Physiology, 2020. **11**(333).

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