Validating a Novel E-textile Foot Centre of Pressure Sensor for Biomechanical Data Collection in the Field

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Summary

A prototype E-textile insole foot sensor is presented and touchdown, toe-off and the anterior/posterior centre of pressure (CoP) as measured by the sensor are compared to gold standard measurement using a force plate. Accurate identification of touchdown and toe-off timings was possible up to 80% of the time using the sensor, whilst CoP showed a good visual match with an average RMSE between gold standard methods and the scaled sensor outputs of 69.5 ± 25.3 mm.

Introduction

Whilst biomechanical data collected in the laboratory setting is robust and well documented [1], often there is a requirement to collect data in a field setting – for example, for ecological validity or to replicate some tasks or settings that are not possible in a laboratory. In this work we present a novel E-textile foot sensor worn under the foot whilst shod with the aim of identifying parameters associated with gait such as touchdown, toe-off and the centre of pressure location. This sensor may be used to provide real time feedback for assistive exoskeletons, or to provide data for biomechanical analysis and presents a more robust system for capturing data than current field systems.

Methods

The prototype sensor is an e-textile insole (Intelligent Textiles Ltd) in two sizes (UK 6 and 10) that provides a sensor voltage based on the average of a grid of fabric switches with a larger voltage associated with switches further anterior. Twelve participants took part in the study (4 female, 8 male; age: 29 ± 6 years; height 177.3 ± 7.5 cm; mass 76.8 ± 6.3 kg; foot size UK 8.5 ± 2). Foot sensor and force platform data (AMTI BMS400600, AMTI, USA) were collected synchronously in Vicon Nexus (v 2.16; Vicon Motion Systems Ltd, UK) at 1000 Hz). Ten trials were collected at three speeds: walk, fast walk and jogging with one stance phase collected for each trial. Data were analysed in MATLAB (The MathWorks, Inc., MA, USA). To compare to the CoP as measured by the force plate, sensor voltage was scaled using a linear calibration factor, determined by minimizing the RMSE across all trials. The points of touch down and toe off were determined by identifying signal changepoints and peaks in the sensor voltage and the frame identified was compared to a gold standard method (force plate GRFz > 10 N).

Results and Discussion

The calibration factor providing the best match between the sensor and force plate data across the entire data set was 72.2 $mm \cdot V^{-1}$. This resulted in an average RMSE across all trials of 69.5 ± 25.3 mm, with the best match trial reporting an RMSE of 36.81 mm. The sensor displayed a consistent trend for increasing output levels that mirror the increasing CoP values observed during foot contact with the ground (Figure 1). However, there was some inter-individual variation in the sensor response around touchdown and toe-off. Also, the sensor output level tended to prematurely drop prior to toe-off. These effects are due to the sensor grid coverage under the foot and highlight the importance of matching foot size to the sensor size appropriately. Touchdown was identified within 5 ms of the gold standard method 43% of the time, and within 10 ms 60% of the time. However, 33% of trials had a discrepancy greater than 41 ms (Table 1). The mean difference between the two measures was 47.0 ± 191ms with the large standard deviations indicating the large number of trials with a high error in detection between the two methods. Toe-off was identified within 5 ms of the gold standard method 35% of the time, and within 20 ms 70% of the time. However, 22% of trials had a discrepancy greater than 41 ms, the average difference between the two measures was 4.8 ± 80.6 ms, with the large standard deviations indicating the large number of trials with a high error in detection between the two methods.

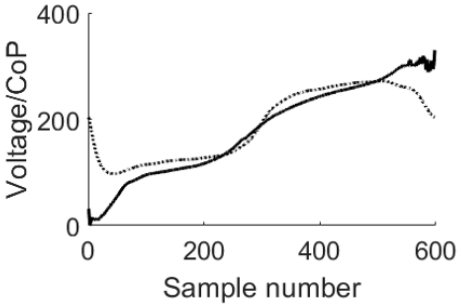

Figure 1: representative example of measured CoP (solid line) and calibrated sensor voltage (dashed line).

Conclusions

The novel foot sensor shows promise in its ability to detect features of gait and does track CoP, however, design refinements are proposed to enable gait events to be detected with good agreement to gold standard methods.

Acknowledgments

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References

[1] Robertson G et al. (2014) *Research Methods in Biomechanics*; Human Kinetics