# An Instrumented Shoe Insole Framework for Evaluating Healthy and Neurodegenerative Gait

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## Summary

The human gait pattern hosts a wealth of information about our health status; however, analyzing it is mainly limited to specialized laboratories not accessible to those who could most benefit. Wearable devices, such as instrumented shoe insoles, provide an opportunity for clinicians, rehab specialists, and patients alike to continuously monitor gait quality in free-living and clinical environments. The present work displays the efficacy of such a solution.

## Introduction

The human gait pattern is complex and sensitive to health changes, making it suitable for health monitoring [1]. Numerous spatiotemporal gait metrics differ between healthy participants (HP) and those with neurological conditions [2] and stages of progression [3]; however, obtaining these metrics typically requires access to motion capture (MoCap), which is not feasible for regular monitoring. Instrumented shoe insoles (Insoles) equipped with inertial measurement units (IMUs) and pressure sensors present a practical solution for unobtrusive gait quality monitoring outside of laboratory settings. Nevertheless, there are several challenges when collecting laboratory-quality metrics in free-living conditions: the environment is unknown; ambulatory activities are vast and unpredictable; gait detection must be reliable regardless of ambulatory ability, disability status, assistive device usage, and environmental conditions; analyses and sensor placement must be standardized; and adherence is necessary for any long-term solution to be viable. The purpose of this work is to present an Insole Framework (IF) that uses raw IMU and pressure data to detect activities, segment walking trials, perform gait detection, calculate spatiotemporal metrics and compare the obtained results to a MoCap system.

## Methods

Twenty-two HP, 19 people with multiple sclerosis (PwMS), and 10 people with Parkinson's disease (PwPD) were recruited to perform 6-metre walks in the MoCap lab and 500-metre and 125-metre (with stairs) walks outside the lab. For all walks, raw Insole data (ReGo, Moticon, Germany; 50 Hz) were captured by a smartphone application (Celestra Health, Canada); eight video cameras (Vue, Vicon, UK) analyzed via Theia 3D (HAS-motion, Canada; 50 Hz) and two force plates (4060 Bertec, USA; 1000 Hz) captured the 6-metre lab walks.

An artificial neural network (ANN) was trained to identify ambulatory activities: stand, walk, turn, stair ascend/descend. A logical gait detection algorithm used IMU and pressure data to identify gait phases: heel strike, foot on floor, heel rise, and toe off. Periods that the ANN identified as walking were split into 10-second segments for standardization from which spatiotemporal metrics were calculated, labelled as core (stride, stance, swing, step, and single/double support time, and stride length), percentage (temporal core divided by stride time), pace (cadence, stride velocity), and asymmetry (percent difference between legs for core and percent metrics). ANN performance, intraclass correlations ($ICC_{2,1}$) with consistency between systems, and within-technology between-population ANOVAs with a Bonferroni correction are presented.

## Results and Discussion

The ANN trained on all participants identified activities with an accuracy and F1-score of 94.6% and 94.5%, respectively. Higher performance was seen in population-specific models. The IF calculated all core and pace metrics with good to excellent reliability ($\geq 0.824$) compared to MoCap, regardless of neurological status. All gait metrics had moderate to excellent reliability for PwMS ($\geq 0.731$) and PwPD ($\geq 0.700$), while HP had moderate to good reliability for percent metrics (0.669-0.766) and poor to good reliability for asymmetry metrics (0.177-0.838), possibly due to low between-subject variability. Of the 19 metrics assessed, only stride length asymmetry had a different statistical interpretation between systems. Out of the 10 metrics with significant differences, the MoCap system showed no differences between PwMS and PwPD for stance, swing, and double support percent, while the IF did ($p < 0.0167$). Further, across all tests, $\eta^2$ values were relatively consistent between technologies; the average absolute $\eta^2$ difference across all tests was 0.046, suggesting both systems had a similar amount of explained variance for the captured group-based differences.

## Conclusions

Presented is a framework that analyzes human gait using instrumented shoe insoles similar to a MoCap system. The presented results instill confidence that our IF can calculate spatiotemporal gait metrics in healthy and dysfunctional gait, opening opportunities for longitudinal at-home monitoring and targeted clinical assessments. Future work will focus on employing the IF in free-living conditions, longitudinally evaluating HP to inform monitoring solutions, and creating dissemination tools for clinicians/patients to inform the prescription of and evaluate the effectiveness of interventions (i.e., exercise, assistive device, pharmacological).

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## References

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