Validity and Reliability of a new digital insole system (WalkinSense) for spatiotemporal variables at different speed & slope conditions

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Summary

This study evaluated the validity and reliability of the WalkinSense system (WSS) as a portable alternative to instrumented force plates for measuring spatiotemporal gait variables. Data from 101 participants across varying speeds and slopes were analysed, with reliability tested in a subset of 50 participants. The results showed good to excellent agreement, low measurement errors, and high reliability for most variables, particularly stride time and stride length. The WSS demonstrated high accuracy and sensitivity to detect change under diverse walking conditions, making it suitable for real-world applications.

Introduction

The evaluation of spatiotemporal variables during walking is crucial for detecting abnormal gait patterns and quantifying improvements from interventions, particularly in the rehabilitation of patients with orthopaedic conditions. Currently, these assessments are primarily conducted in laboratory settings. However, monitoring gait in natural environments during daily activities could provide clinicians with more relevant insights. Instrumented shoe insoles offer significant potential for use outside the lab. This study aims to evaluate the validity and reliability of a novel digital health solution, the WSS, which integrates pressure-sensitive insoles with inertial measurement units.

Methods

Data were collected from 101 healthy participants (50% female) under various speed and slope conditions (3 km/h, 4.5 km/h at 0°/±3°/±6°, 6 km/h, and 9 km/h). Spatiotemporal variables were recorded simultaneously using an instrumented treadmill and the WSS. Metrics were averaged over the total number of participant steps. Mean bias between systems was assessed using Bland-Altman analyses for each condition and variable. Agreement was evaluated based on predefined thresholds: excellent (<5%), good (<10%), acceptable (<15%), and poor (>15%). Additionally, mean absolute percentage error (MAPE) scores and intraclass correlation coefficients (ICC 3,1) were calculated. Reliability was assessed in 50 participants through repeated data collection one week later, using ICC (2,1), Bland-Altman plots, Standard Error of Measurement (SEM), SEM%, Minimal Detectable Change (MDC), and MDC% calculations.

Results and Discussion

All spatiotemporal variables, except double support time, exhibited good or excellent agreement, low MAPE scores, and high ICC values for walking speeds. For running (9 km/h), the WSS showed acceptable to good agreement. Bland-Altman plots indicated no systematic bias across conditions. The WSS demonstrated excellent reliability for most variables, with stride time and stride length showing the highest consistency. Double support time, however, had relatively lower reliability. SEM and MDC values were low for most variables, indicating minimal measurement error in test-retest measurement and high sensitivity to detect change. Table 1 presents the validity and reliability results of the WSS at 4.5 km/h and 0° slope as examples from the broader dataset.

Conclusions

The WSS demonstrates high validity and reliability for most spatiotemporal variables under various conditions, except at 9 km/h. These findings suggest the system is suitable for accurately measuring gait metrics during walking and delivering consistent results in real-world applications.

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Table 1: Examples of validity and reliability results at 4.5 km/h and 0° slope.

	Validity (n =101)			**Reliability (n = 50)**				
Spatiotemporal variables	Mean ± SD percentage differences [95% limits of agreement]	MAPE	ICC 3,1	ICC 2,1	SEM	SEM %	MDC	MDC %
Stance time (s)	1.329 ± 1.993 [-2.577 to 5.236]	1.8	0.94	0.88	0.003	0.405	0.008	1.121
Swing time (s)	-2.801 ± 3.999 [-10.638 to 5.037]	3.2	0.84	0.86	0.002	0.506	0.005	1.402
Stride time (s)	-0.068 ± 0.170 [-0.402 to 0.266]	0.1	0.99	0.93	0.003	0.277	0.008	0.767
Stride length (m)	-0.290 ± 1.370 [-2.976 to 2.395]	0.9	0.97	0.91	0.005	0.332	0.012	0.921
Double support time (s)	5.787 ± 8.048 [-9.987 to 21.560]	8.7	0.69	0.75	0.004	1.231	0.011	3.411