Supervised Insole Gait Analysis in MS Clinical Practice: A Cost-Effective Alternative

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Introduction

- Objectively assessing mobility in people with multiple sclerosis (PwMS) is essential for clinical evaluation and timely rehabilitation
- Conventional gait analyses demand costly, space-intensive equipment and specialized staff, limiting routine clinical use
- Supervised, smart insole-based methods may be a low-cost alternative that is suitable for clinical use

Objective

- To evaluate the validity of in-clinic standardized mobility assessments in PwMS using a smart Insole-based system (Insole)

Methods

Participants & Assessments

- 52 PwMS at the Technical University of Dresden (TUD) completed:
  - The 2-minute walk test (2MWT)
    - Comfortable walking speed
  - The timed 25-foot walk (T25FW)
  - 50-foot walks, under 2 conditions:
    - Comfortable walking speed
    - Dual-task (verbal & arithmetic)
- 46 PwMS (TUD) and 18 healthy individuals (University of Ottawa) performed 4 jump assessments:
  - 10-second hop test (10sHT)
  - Countermovement jump (CMJ), 3 repetitions
  - Single-leg countermovement jump on right & left legs (SLCMJ_R & SLCMJ_L), 3 repetitions each

Figure 1. Smart insoles.

Instrumentation

- Smart Insoles (ReGo, Moticon, Germany; 50 Hz; Figure 1) streamed raw pressure, gyroscope, and accelerometer data to a smartphone app (Celestra Health Systems, Canada)
- 2MWT distance and T25FW time measured using a wheel odometer and timing gate, respectively
  - GAITRite (GAITRite, USA; 120 Hz) measured walks (excl. 2MWT)
  - Force plates (AMTI; Bertec, USA; 1000 Hz) measured jumps

Methods (continued)

Insole Data Analyses

- Proprietary algorithms were employed to detect:
  - Gait events: heel strike (HES), foot on floor (FOF), heel rise (HER), & toe off (TOF) (Figure 2)
  - Jump phases: unweight, brake, propulsive, & flight (Figure 3)
- Global position was estimated using the Madgwick sensor fusion algorithm and zero-velocity updates [1]
- Spatiotemporal (ST; gait & jump) and kinetic (jump) metrics were computed and compared to reference data

Laboratory Data Analyses

- GAITRite software for gait ST metrics
- Force plate jump ST and kinetic metrics computed using custom Python algorithms [2]

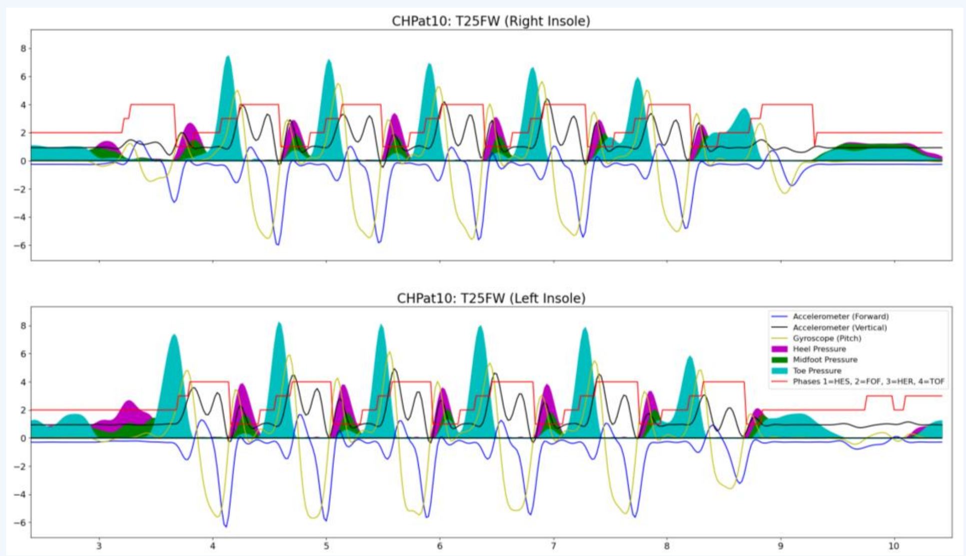

Figure 2. Depiction of the gait detection algorithm for the right (top) and left (bottom) Insoles during the T25FW.

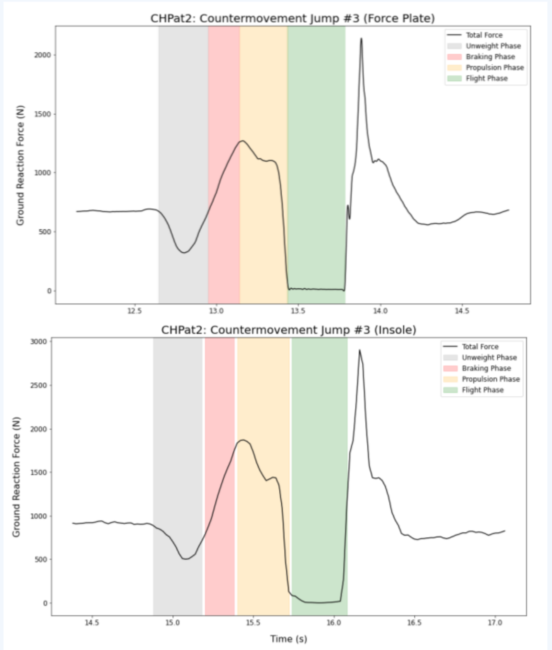

Figure 3. Depiction of the jump phase detection algorithms for force plate (top) and Insole (bottom) during the same CMJ.

Results

Gait

- Swing, single-support, and double-support time differ between devices ($p \leq 0.027$; Table 1); no other metrics differed ($p \geq 0.069$)
- Main effect of trial type on all metrics ($p \leq 0.004$)
- No device x trial type interaction for any metric ($p \geq 0.493$)
- 2MWT mean absolute error for distance = 4.4 m (2.7%)
- T25FW mean absolute error for time = 0.2 s (4.0%)

Results (continued)

Table 1. Mean (standard deviation) of the ST metrics averaged between sides and across T25FW, normal, and dual task walking trials for both systems.

Metric	Insole	GAITRite
Cadence (steps/min)	113.22 (14.36)	113.02 (15.83)
Stride Velocity (m/s)	1.27 (0.35)	1.31 (0.37)
Stride Length (m)	1.32 (0.26)	1.37 (0.27)
Step Time (s)	0.54 (0.08)	0.55 (0.09)
Stride Time (s)	1.09 (0.17)	1.08 (0.18)
Swing Time (s) *	0.40 (0.05)	0.39 (0.04)
Stance Time (s)	0.69 (0.13)	0.70 (0.15)
Single-Support Time (s) *	0.41 (0.05)	0.39 (0.04)
Double-Support Time (s) *	0.28 (0.10)	0.32 (0.18)

** Devices statistically different at a = 0.05*

Jump

- Good to excellent agreement between the force plate and Insole (ICC(3,k) ≥ 0.75) for 15 of 17 metrics (9 of 9 ST metrics; 6 of 8 kinetic metrics) when averaged across all jump assessments
  - Propulsive impulse and average positive power ICC(3,k) ≤ 0.54

Conclusion

- Insole-derived measures demonstrated good to excellent agreement or no statistical difference for 22 of 28 metrics across walking and jumping assessments
  - Differences are not considered clinically meaningful (< 5%)
  - E.g., Swing time differs by less than 1 Insole frame
- This Insole-based system can be employed for objective mobility assessments in neurorehabilitation and MS outpatient care
- Increases accessibility to a variety of mobility assessments, such as the Dresden Multidimensional Walking Assessment [2, 3]
  - Not limited to pre-defined capture volumes
  - Removes reliance on inaccessible devices and analyses

References

[1] Madgwick et al., 2020, *IEEE/ASME Trans. Mechatronics*, *25*(4):2054-2064.
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