

Smart Insoles Enable Reliable Turn Analysis to Inform Gait Stability in Persons with Multiple Sclerosis

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Introduction

- Turning is a demanding daily task requiring balance and coordination; turning deficits are common in persons with MS (PwMS) and linked to falls [1].
- Clinical scales assess overall mobility but are not designed to capture turning quality [2].
- Wearable sensors can quantify turning [3], but most systems are lab-bound or require multiple sensors, making them less suitable for longitudinal monitoring.
- Smart insoles can detect turns and extract biomechanical features, but their clinical validity and reliability in PwMS remain unestablished.

Objectives

- Identify turning features that discriminate PwMS from healthy participants.
- Examine associations with clinical measures (EDSS, MSWS-12).
- Evaluate within-session reliability.

Methods

- **Participants**
 - 21 young healthy adults (10 F, 28 ± 7 y).
 - 18 PwMS (13 F, 54 ± 17 y; EDSS 4.0 [3.0–5.5]; MSWS-12 63.5 [29.2–72.9]; median [IQR]).
- **Protocol**
 - 500-m walk with 19 × 180° turns.
 - Smart insoles (Moticon, Germany; 50 Hz) recorded plantar pressure and inertial measurement unit (IMU) data, streamed to a gait analysis platform (Celestra Health Systems, Canada).
- **Turning Analysis**
 - Turns automatically detected; 90 features computed across four domains: spatiotemporal, IMU, force and frequency.
- **Statistics**
 - Group differences: independent t-tests (Welch's if unequal variances) and Mann-Whitney U.
 - Clinical associations: Spearman correlation with EDSS and MSWS-12 (PwMS only).
 - Within-session reliability: ICC(3,1) (two-way mixed effects, absolute agreement, single measurement) across the first 4 turns.

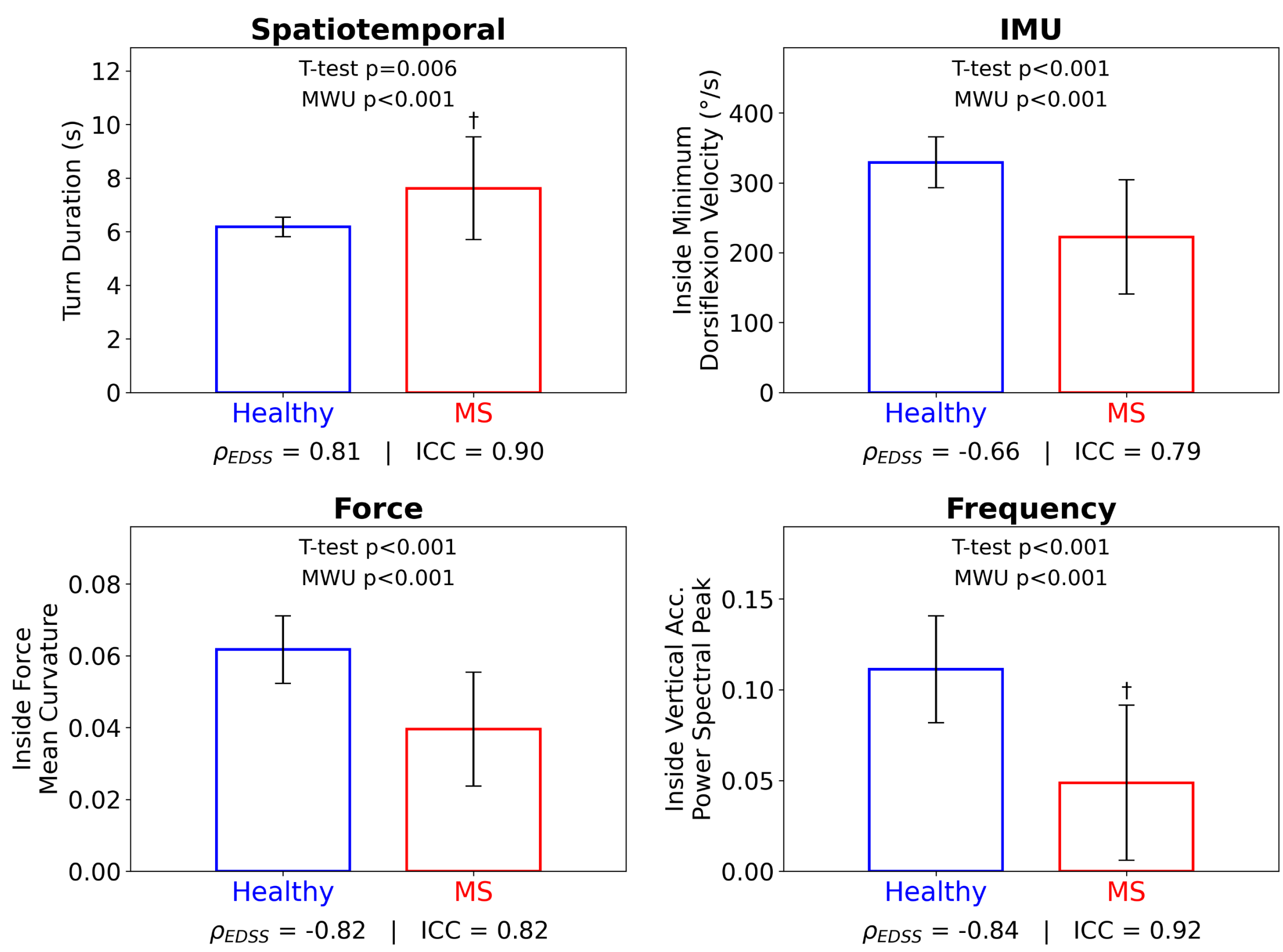
Table 1. Number of turning features per domain that significantly differed between healthy adults and PwMS (t-test, $p < 0.05$), correlated with EDSS (strong: $|r| \geq 0.60$; $p < 0.05$) and MSWS-12 (moderate-strong: $|r| \geq 0.40$; $p < 0.05$), and showed good-to-excellent within-session reliability ($ICC(3,1) \geq 0.75$). "Meets criteria" counts features satisfying all three criteria.

Domain	Features (n)	Group difference	Strong EDSS correlation	Moderate-strong MSWS-12 correlation	Good-excellent ICC	Median ICC	Meets criteria
Spatiotemporal	16	16	15	16	15	0.92	14
IMU	32	17	14	12	8	0.37	8
Force	10	9	10	10	4	0.71	4
Frequency	32	30	30	24	28	0.9	28
Total	90	72 (80%)	69 (77%)	62 (69%)	55 (61%)	0.79	54 (60%)

Results

- 72 (80%) features differed between groups, including all spatiotemporal, 9/10 force and 30/32 frequency features, but only 17/32 IMU features.
- 69 features strongly correlated with EDSS ($|r| \geq 0.60$); 62 moderately-to-strongly correlated with MSWS-12.
- 55 features showed good-to-excellent reliability ($ICC \geq 0.75$).
- 54 features met all three criteria, led by spatiotemporal (14/16) and frequency (28/32) features.

Figure 1. Example turning features from each domain in healthy adults (blue) and PwMS (red), mean ± SD. PwMS took longer to turn (7.6 ± 1.9 vs 6.2 ± 0.4 s), with lower dorsiflexion velocity, smoother force profiles (lower force curvature) and lower vertical acceleration spectral power on the inner foot. "Inner" refers to the foot on the inside of the turn. † indicates a non-normal distribution (Shapiro-Wilk $p < 0.05$).



Discussion

- Turning reveals MS-related impairment: 80% of features distinguished PwMS from healthy adults.
- Features are consistent from turn to turn: 61% showed good-to-excellent reliability.
- Spatiotemporal and frequency features were best at distinguishing groups, relating to disability measures, and were reliable (14/16 and 28/32).
- Turning features are more associated with clinician-reported outcomes than self-reported outcomes: 77% correlated strongly with EDSS vs 32% with MSWS-12.
- Limitations: young, non-age-matched controls; small sample; single session.
- Future directions: longitudinal association with disease progression, association with fall risk.

References

[1] Adusumilli G, et al. (2018). PLoS ONE. 13(6):e0198178., [2] Meyer-Moock S, et al. (2014). BMC Neurol. 14:58., [3] Spain RI, et al. (2012). Gait Posture. 35(4):573–8.

Disclosures

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