

Objective and Reliable Assessment of Stair Performance in Multiple Sclerosis Using Smart Insoles

Mohammad H. Akhavanfar¹, Matthew P. Mavor², Gauruv Bose^{3, 4}, Heather J. MacLean^{3, 4}, Mark S. Freedman^{3, 4}, Ryan B. Graham^{2, 5}

¹Celestra Health Systems, Ottawa, Canada, ²School of Human Kinetics, Faculty of Health Sciences, University of Ottawa, Ottawa, Canada, ³Department of Medicine, University of Ottawa, Ottawa, Canada, ⁴Ottawa Hospital Research Institute, Ottawa, Canada, ⁵Ottawa-Carleton Institute for Biomedical Engineering, University of Ottawa, Ottawa, Canada

Introduction

- Stair ambulation demands greater motor control than level walking [1] and is particularly challenging for persons with MS (PwMS) [2].
- Clinical stair ratings are often subjective and give limited detail on how the task is performed [3].
- Smart insoles can detect stair ascent and descent while extracting biomechanical features, but their validity and reliability in PwMS remain unknown.

Objectives

- Identify stair features that discriminate PwMS from healthy adults.
- Evaluate within-session reliability.
- Examine associations with EDSS and MSWS-12.

Methods

- Participants**
 - 18 young healthy adults (8 F, 28 ± 7 y).
 - 10 PwMS (7 F, 49 ± 17 y; EDSS 3.5 [2.0–4.0]; MSWS-12 32.3 [10.4–50.0]; median [IQR]).
- Protocol**
 - A walking session that included at least two ascents and two descents of a 10-step staircase.
 - 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).
- Stairs Analysis**
 - Stair ascent and descent were detected automatically. Descent was not detected for 1 PwMS.
 - The middle six steps of each bout were analyzed. 76 features were computed across six domains: spatiotemporal, force, frequency, stride regularity, step symmetry, and asymmetry.
- 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) between the first two bouts in healthy adults (n = 18 ascent, n = 16 descent).

Table 1. Number of stair features per domain that differed between healthy adults and persons with multiple sclerosis (t-test, $p < 0.05$), and the number with good-to-excellent within-session reliability (ICC(3,1) ≥ 0.75).

Domain	Features	Ascent group difference	Ascent good-excellent ICC	Descent group difference	Descent good-excellent ICC
Spatiotemporal	11	5	3	0	9
Force	7	5	3	4	4
Frequency	12	3	2	1	10
Stride regularity	7	5	0	0	0
Step symmetry	7	7	0	1	1
Asymmetry	32	6	0	5	0
Total	76	31	8	11	24

Results

- 31 ascent features vs. 11 descent features differed between groups (Table 1).
- 24 descent vs 8 ascent features had good-to-excellent reliability (Table 1).
- Force-curve shape met all three objectives (Figure 1).
 - Ascent: group-based difference (Cohen's $d = 1.92$), MSWS-12 correlation ($\rho = -0.71$), and good reliability (ICC = 0.78).
 - Descent: group-based difference (Cohen's $d = 1.73$), MSWS-12 correlation ($\rho = -0.75$), and good reliability (ICC = 0.81).
- 12 features correlated with MSWS-12 in each direction.
- 4 ascent and 8 descent features correlated with EDSS.

Discussion

- Ascent had more features that differed between groups. Descent was the more repeatable activity (Table 1).
- Force-curve shape measure was the strongest measure in this study. PwMS had a smoother stance-force profile (Figure 1).
- The stronger MSWS-12 associations may reflect the questionnaire, since item 3 asks about stair-climbing ability.
- Limitations: young, non-age-matched controls; small sample; narrow disability range; single session.
- Future directions: larger sample size, longitudinal association with disease progression, compare free-living stairs versus supervised walking sessions.

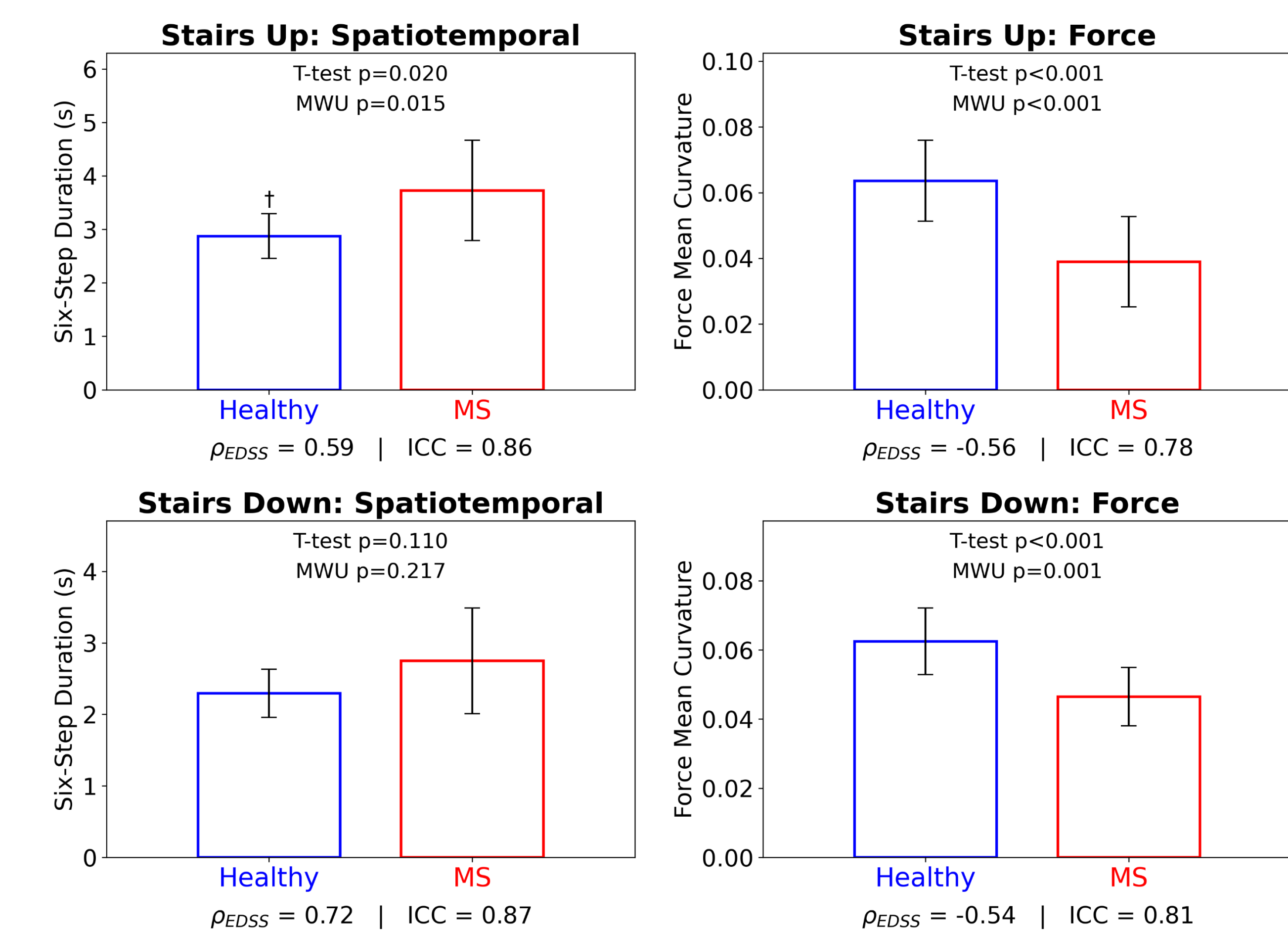


Figure 1. Six-step duration and mean force curvature during stair ascent (top) and descent (bottom) in healthy adults (blue) and PwMS (red), mean ± standard deviation.

References

- [1] Nadeau S, et al. (2003). Clin Biomech. 18(10):950–9. [2] Kline PW, et al. (2021). Gait Posture. 87:27–32. [3] Carpinella I, et al. (2018). IEEE Trans Neural Syst Rehabil Eng. 26(12):2324–32.

Disclosures

Competing interests: MA, MM, and RG hold shares in Celestra Health Systems; HM is the founder's spouse. **Funding:** NSERC IRAP (1019330). Mitacs Accelerate (IT28643), NSERC PDF, OCI Collaborate 2 Commercialize (35281)