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Accuracy of the actibelt® accelerometer for measuring walking speed in a controlled environment among persons with multiple sclerosis

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ABSTRACT

Background: Advances in portable sensor technology have opened an era for objective, real-life monitoring of walking speed in persons with multiple sclerosis (MS).
Purpose: The present study examined the accuracy of the actibelt® accelerometer for measuring walking speed during a standard 6-min walk (6MW) and the possibility that disability status influenced the degree of accuracy among persons with MS.
Methods: On a single testing session, 51 persons with MS and Expanded Disability Status Scale scores between 2.0 and 6.5 performed a 6MW while wearing an actibelt® in the body's sagittal symmetry plane and close to the body's centre of mass.
Results: All 51 participants completed the 6MW without stopping, falling, or any adverse events, and the actibelt® provided walking speed data for each of the participants. The actibelt® significantly overestimated walking speed (actual minus actibelt®) by a mean ± standard deviation of −0.12 ± 0.17 m/s for the overall sample ($p < 0.0001$). There was no significant overestimation in the sample with mild disability (−0.02 ± 0.11 m/s), but there was in the samples with moderate (−0.10 ± 0.16 m/s) and severe (−0.26 ± 0.12 m/s) disability.
Conclusion: The actibelt® is ready for real-life monitoring of walking speed in persons with mild MS, but caution is necessary when interpreting the accuracy of the walking speed data for those with MS who have moderate and severe disability.

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Walking speed has become recognized as a primary, objective outcome measure in clinical research and practice involving persons with multiple sclerosis (MS) [1]. This is often measured during performance tests such as the timed 25-foot walk (T25FW) or 6-min walk (6MW) that are undertaken in controlled, clinical settings [1,2]. The measurement of walking speed during such tests has limited validity for inferences about walking in the context of real life. Advances in motion sensor technology have provided an opportunity for the objective, real-life measurement of walking behavior among persons with MS [1,2]. For example, the actibelt® is an integrated platform that objectively measures the bodily movement of a person using a 3-dimensional accelerometer [3]. This accelerometer is hidden in a belt buckle and measures high-resolution (noise <0.01 g, 100 Hz in 3 axes) and long-term accelerations of the body's centre of mass during movement. The actibelt® provides walking speed as part of its output [4] and could be of great value for monitoring real-life walking speed in clinical research and practice involving persons with MS. The accuracy of the measure of walking speed provided by the actibelt® should be characterized under controlled conditions such as the 6MW and across levels of disability status as a precursor to its application under everyday life conditions. To that end, this study examined the accuracy of the actibelt® accelerometer for measuring walking speed during the 6MW and the possibility of differential accuracy as a function of disability status among persons with MS.

1. Method

1.1. Sample

The sample consisted of 51 persons with clinically definite MS who were recruited through referrals from three locally residing neurologists. The two criteria

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for inclusion were (a) capacity for independent ambulation or ambulation with an assistive device and (b) willingness to undergo testing.

1.2. Procedure

The procedure was approved by a University Institutional Review Board and all participants provided written informed consent. The data were collected on a single session. The participants initially provided demographic information and then underwent a neurological examination for generating an Expanded Disability Status Scale (EDSS) score [5]. This was followed by placement of the actibelt® around the participant's waist and completion of the 6MW protocol. All participants received $20 remuneration.

1.3. actibelt®

The 3-dimensional accelerometer of the actibelt® was attached to the patient's waist with a special buckle, such that the embedded measurement box containing the waterproof electronics was in the correct orientation, in the body's sagittal symmetry plane and close to the body's centre of mass. The actibelt® was switched on and off before each 6MW, and the exact beginning and end of every 6MW was marked with a standardized tapping protocol that allows for automated post-processing of the data. Data were downloaded to a local PC and uploaded to the central actibelt® web-server for off-line post-processing and feature extraction. An algorithm written in R [6] was used to calculate the time dependent walking speed in m/s for every single 6MW measurement sequence from the actibelt® raw data. There was no individualized calibration of the actibelt® nor were patient characteristics passed along with the actibelt® data. Walking speeds from the actibelt® analyses were returned to the independent team and were integrated into the study database for subsequent data analyses.

1.4. 6MW protocol

The 6MW was performed in a rectangular, carpeted corridor with hallways that exceed 50 m in length and that was clear of obstructions and foot traffic. We provided standardized instructions and emphasized walking as far and as fast as possible for 6 min [7] and participants used walking aids, if necessary, during the 6MW. One researcher followed along side of the participant for safety, while another researcher followed 1 m behind the participant and recorded the distance traveled (m) using a measuring wheel (Stanley MW50, New Briton, CT) [8]. The distance traveled was then converted into actual walking speed (m/s) for comparability with the actibelt® output.

1.5. EDSS

All participants underwent a comprehensive neurological examination and level of disability was quantified using the EDSS by an experienced neurologist. The EDSS is an ordinal scale that consists of eight Functional System scales, namely pyramidal, cerebellar, brainstem, sensory, bowel and bladder, visual, cerebral, and other [5]. The functional systems are scored from 0 (no disability) through 5 or 6 (maximal disability). The scores from the eight functional systems are then integrated into an EDSS score between 0 (normal) through 10 (death from MS) [5].

1.6. Data analysis

All data analyses were conducted using PASW Statistics for Windows, Version 18.0. Descriptive statistics are presented in text and tables as mean (M) ± standard deviation (SD). We performed one-way analysis of variance (ANOVA) for examining differences in walking speed across groups (3 levels of disability status) with post-hoc analyses involving an automatic Bonferroni correction of alpha. We then computed the difference between actual and actibelt® walking speed (actual minus actibelt®) and compared this value against zero in the overall sample and samples who differed in disability status using one-sample t-tests. This was followed by a one-way ANOVA for comparing the difference between actual and actibelt® walking speed across groups (3 levels of disability status) with post hoc analyses involving an automatic Bonferroni correction of alpha. The scatter plot along with line of best fit and 95% confidence limits are provided in a figure as a visual illustration of the association between actual and actibelt® walking speed. Linear regression analyses were then conducted by regressing actual walking speed (dependent variable, DV) on actibelt® walking speed (independent variable, IV) in the entire sample and then in the subsamples who differed in disability status. We inspected the R^2 value for the strength of association and the SEE as an indication of accuracy. We then generated Bland–Altman plots of the difference between actual and actibelt® walking speed and the mean of actual and actibelt® walking speed in the overall sample for examining systematic patterns of error in estimation; the plot further included lines representing the average difference and ±2 SD of the average difference. We finally examined the association of the difference between actual and actibelt® walking speed and the mean of actual and actibelt® walking speed as well as EDSS scores in the overall sample using Pearson product-moment correlation coefficients (r).

2. Results

2.1. Sample characteristics

The mean ± SD age of the sample was 53.1 ± 11.3 years and the gender distribution was predominantly female (43 women/8 men). The sample primarily had a relapsing-remitting clinical course (n = 45, 88% of cases) with a mean ± SD disease duration of 13.4 ± 9.4 years. Of the 51 persons, 44 or 86% were on a disease-modifying therapy. Based on a neurological examination, the median EDSS score was 4.0 with a range between 2.0 and 6.5. This range of EDSS scores permitted formation of three groups consisting of mild (n = 21, EDDS = 2–3.5), moderate (n = 13, EDDS = 4.0–5.5), and severe (n = 17, EDDS = 6.0–6.5) disability consistent with benchmarks in epidemiological studies of MS [9]. The median Pyramidal and Cerebellar Functional System scores from the EDSS were both 2.0 with a range between 0 and 3. Of the 51 participants, 17 used a walking aid during the 6MW; this included 14 devices for single point assistance (i.e., cane or crutch) and 3 devices for two-point assistance (i.e., walker).

2.2. Actual 6MW performance

All 51 participants completed the 6MW protocol without stopping, falling, or any adverse events. The actual walking speed was 1.19 ± 0.35 m/s and approximated a normal distribution with minimal skewness (0.01) and kurtosis (0.08). Actual walking speed differed significantly across the three disability status groups, $F(2,48) = 32.46$, $p = 0.0001$. Post hoc analysis identified statistically significant differences in walking speed between each of the three groups; the descriptive statistics are provided for the three groups in Table 1. These data provide the benchmark for comparison of values from the actibelt® overall and across levels of disability status.

2.3. actibelt® performance

The actibelt® provided walking speed data for all 51 participants who completed the 6MW protocol. The walking speed from the actibelt® was 1.30 ± 0.23 m/s and approximated a normal distribution with minimal skewness (0.10) and kurtosis (1.12). The walking speed from the actibelt® differed significantly across disability status, $F(2,48) = 19.80$, $p = 0.0001$. Post hoc analysis identified statistically significant differences in walking speed from the actibelt® between each of the three groups; the descriptive statistics are provided for the three groups in Table 1. Interestingly, actual walking speed from the 6MW had 61% increased relative precision (based on ratio of low/high F-statistics) compared with

Table 1
Actual walking speed, actibelt® walking speed, and the difference in walking speed during the 6-min walk test for the overall sample with MS and across three subsamples based on levels of disability status.

Parameter	Overall sample (n = 51)	Mild disability (n = 21)	Moderate disability (n = 13)	Severe disability (n = 17)
Actual walking speed (m/s)	1.18 (0.35)	1.45 (0.23)	1.19 (0.22)	0.85 (0.23)
Actibelt® walking speed (m/s)	1.30 (0.23)	1.47 (0.20)	1.29 (0.10)	1.11 (0.19)
Difference between actual and actibelt® (m/s)	−0.12 (0.17)	−0.02 (0.11)	−0.10 (0.16)	−0.26 (0.12)

Note: Values in table are mean (SD); mild disability has EDSS scores of 2–3.5; moderate disability has EDSS scores of 4–5.5; severe disability has EDSS scores of 6–6.5.

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