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### Does a waist-worn ActiGraph accelerometer quantify community ambulation in persons with multiple sclerosis?

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**Abstract**—Accelerometry has been recognized as a method of objectively measuring community ambulation in persons with multiple sclerosis (MS). However, the assumption that walking itself serves as a major contributor to the accelerometer signal has yet to be tested. This study examined the assumption that community-based walking is a primary contributor to accelerometer output in MS. Ambulatory persons (5 males/17 females; 13 without aid/9 with aid) with MS wore a triaxial accelerometer (ActiGraph GT3X, Health One Technologies; Fort Walton Beach, Florida) as well as an IDEEA system (MiniSun, Inc; Fresno, Florida) over the course of a single day. Outcome measures for the accelerometer included movement counts/hour for the vertical, anterior-posterior, and mediolateral axes. Outcomes for the IDEEA system included percent time walking, sitting, and standing, as well as walking speed. Pearson product correlations ( $r$ ) were used to examine the associations between outcomes from the accelerometer and IDEEA system. Significant correlations were observed between percent walking time and movement counts/hour along the vertical ( $r = 0.84$ ) and anterior-posterior ( $r = 0.69$ ) axes. Significant correlations were further noted between movement counts/hour along the vertical axis and walking speed ( $r = 0.45$ ) and self-report walking impairment ( $r = -0.50$ ) and disability ( $r = -0.46$ ). Such observations further support accelerometry as an objective marker of community ambulation in persons with MS.

**Key words:** accelerometry, activity, ambulation, community ambulation, free living, locomotion, mobility, multiple sclerosis, outcome measures, walking.

**Abbreviations:** AP = anterior-posterior, EDSS = Expanded Disability Status Scale, ML = mediolateral, MS = multiple sclerosis, MSWS-12 = Multiple Sclerosis Walking Scale-12, SD = standard deviation.

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#### INTRODUCTION

The loss of walking is a common consequence of multiple sclerosis (MS). Nearly 85 percent of persons with MS identify walking problems as a primary limitation that affects functioning and activities of daily living [1–2]. By extension, the measurement of walking has become an important outcome in clinical research and practice in this population [3].

Accelerometry has been identified as an objective measure of community walking in neurological disorders, including MS [4–6]. This is important because most measures of walking in MS are performed in laboratory or clinical settings and suffer from poor ecological or real-world validity. Nevertheless, the application of accelerometry as an objective measure of community ambulation in MS rests on several tested and untested assumptions. Existing data indicate that movement or activity counts from an accelerometer worn around the waist capture inter- and intraindividual variation in overground walking within a clinical setting [7], accelerometer movement or activity counts over a 7 d period are associated with spatiotemporal parameters of gait [8], and walking is a primary self-selected physical activity among persons with MS [9]. One of the most important untested assumptions is that community walking itself is a major contributor to the accelerometer signal in persons with MS. There are no extant data indicating that the accelerometry signal results

predominantly from community walking in persons with MS. To that end, this investigation examined the association between community-based walking and movement (e.g., activity) counts recorded by a waist-worn accelerometer in persons with MS.

## METHODS

### Participants

The sample comprised 22 ambulatory persons (5 males/17 females) with a definite diagnosis of MS consistent with Poser and/or McDonald criteria [10–12]. Demographic information is provided in **Table 1**. Participants ranged in age from 23 to 64 yr with a mean of 46.9 yr (standard deviation [SD] = 11.7 yr). The average time since diagnosis was 11.0 yr (SD = 6.9 yr). Nine (41% of the sample) of the participants used a cane during testing as well as in everyday life. The sample had a range of Expanded Disability Status Scale (EDSS) scores between 0 and 6.0 (interquartile range = 2.5; median = 3.0).

**Table 1.**  
Demographics of 22 participants with multiple sclerosis.

Variable	Mean	Standard Deviation	Minimum	Maximum
Age (yr)	46.9	11.7	23	64
Yr-D <sub>x</sub>	11.0	6.9	1.0	23.0
EDSS <sub>SR</sub> (median IQR)	3.0	2.5	1.0	6.0
Assistive Device Usage (%)	41	NA	NA	NA

EDSS<sub>SR</sub> = self-report Expanded Disability Status Scale, IQR = interquartile range, NA = not applicable, Yr-D<sub>x</sub> = years since diagnosis.

### Procedures

Upon arrival at the laboratory, participants provided demographic information and completed the self-reported EDSS [13–14] and the Multiple Sclerosis Walking Scale-12 (MSWS-12) [15]. The participants were then outfitted with a waist-worn triaxial accelerometer (ActiGraph GT3X, Health One Technologies; Fort Walton Beach, Florida) and an IDEEA system (MiniSun, Inc; Fresno, Florida). The GT3X accelerometer contains a solid-state, digital accelerometer that generates an electrical signal proportional to the force acting on it along three axes. The IDEEA system consists of 5 uniaxial accelerometers placed on the plantar surfaces of each foot, the anterior portions of each thigh, and centered on the sternum. Based on the activation pattern of the accelerometers, the accompanying software is capable of determining behaviors such as sitting, standing, and walking. The IDEEA system has evidence for its reliability and validity in both nondisabled and pathological populations [16–20]. Participants arrived at our laboratory early in the morning to accumulate a full day–s wear time of the accelerometers. Once outfitted with both the triaxial accelerometer and the IDEEA system, participants continued with a normal daily routine. Participants were instructed not to deviate from normal daily activities. Participants returned to the laboratory in the evening and had the equipment removed.

### Data and Statistical Analysis

Outcome measures for the accelerometer included activity counts/hour for the vertical, anterior-posterior (AP), and mediolateral (ML) axes. While step counts derived from an accelerometer are traditionally used to quantify physical activity levels, they only measure whether a step has taken place without providing information regarding the quality of the step. In contrast, activity counts took into account the binary event of a step as well as the quality/intensity of the step. Outcomes for the IDEEA system included percent time walking, sitting, and standing as well as walking speed (meters/minute). All analyses were completed using SPSS version 17.0 (IBM; Armonk, New York) and significance was noted at  $p < 0.05$ . Means and SD were calculated for all outcome measures. Pearson product correlations ( $r$ ) were used to examine the association between activity counts and behavior (e.g., walking, standing, and sitting). Values are reported as mean  $\pm$  SD.

## RESULTS

Wear times for the devices ranged from 6.0 to 10.1 h and average  $7.6 \pm 1.6$  h. Mean activity counts/hour along the vertical, AP, and ML axes were  $10,938 \pm 6,313$ ,  $15,803 \pm 6,583$ , and  $17,253 \pm 7,684$ , respectively. Participants sat  $61.3 \pm 16.9$  percent, stood  $23.6 \pm 13.8$  percent, and walked  $5.7 \pm 3.6$  percent of the time. Mean walking speed was  $57.6 \pm 13.2$  m/min. Mean self-perceived walking impairment was  $40.3 \pm 26.5$  based on MSWS-12 scores.

As reported in **Table 2**, percent time spent walking was significantly correlated with activity counts along the vertical ( $r = 0.84$ ) and AP ( $r = 0.69$ ), but not ML ( $r = 0.40$ ), axes. Percent sitting was significantly associated with activity counts along the AP ( $r = -0.54$ ) and ML ( $r = -0.64$ ), but not vertical ( $r = -0.39$ ), axes. Percent standing was significantly correlated with movement counts along the ML axis ( $r = -0.63$ ). Only movement counts along the vertical axis were significantly associated with walking speed ( $r = 0.45$ ), self-reported EDSS scores ( $r = -0.46$ ), and MSWS-12 scores ( $r = -0.50$ ). The amount of walking and walking speed were further associated with self-reported EDSS scores ( $r = -0.51$  and  $-0.57$ , respectively) and MSWS-12 scores (both  $-0.49$ ).

**Table 2.**  
Correlation coefficients between accelerometer, motor behavior, and disability.

Variable	Sitting (%)	Standing (%)	Walking (%)	Walking Speed	MSWS-12	EDSS <sub>SR</sub>
Vertical	-0.39	-0.26	0.84*	0.45*	-0.50*	-0.46*
AP	-0.54*	0.37	0.69*	0.01	-0.15	-0.20
ML	-0.64*	-0.63*	0.40	-0.23	-0.18	-0.08
Sitting (%)	—	-0.80*	-0.28	0.11	-0.16	-0.09
Standing (%)	—	—	0.19	0.11	-0.06	-0.09
Walking (%)	—	—	—	0.27	-0.49*	-0.51*
Walking Speed	—	—	—	—	-0.49*	-0.57*
MSWS-12	—	—	—	—	—	0.86*

\*  $p < 0.05$ .

AP = anterior-posterior axis of GT3X accelerometer, EDSS<sub>SR</sub> = self-report Expanded Disability Status Scale, ML = mediolateral axis of GT3X accelerometer, MSWS-12 = Multiple Sclerosis Walking Scale-12, Vertical = vertical axis of GT3X accelerometer.

## DISCUSSION

This investigation tested the assumption that a waist-worn accelerometer captures community walking behavior in persons with MS. To that end, the primary novel results were that activity counts along the vertical axis were associated with time spent walking as well as walking speed, disability status, and self-reported walking impairment. Collectively, this further indicates that accelerometry provides an objective measure of community ambulation in MS.

Conceptually, the degree of walking impairment in MS depends on the interplay among pathological, physiological, personal, and environmental parameters [6]. Yet, researchers and clinicians routinely measure walking impairment using the 500 m walk of the EDSS and timed walk tests [21–24]. The primary limitation of those measures involves performance under controlled, static circumstances. Such conditions reflect the effect of pathological, physiological, and personal factors on ambulatory impairment but do not account for additive influence of community or environmental factors. Consequently, those measures fail to reliably capture impairments in community-based ambulation. By comparison, the results from the current study suggest that accelerometry can capture the amount and quality of walking (e.g., speed) in a real-world environment. When considering the results of this study along with previous research [4,6–7,9], substantial evidence exists supporting the application of commercially available, waist-worn accelerometers for measuring community-based ambulation in persons with MS.

The findings of this study extend research examining accelerometry as an objective marker of walking impairment. For instance, data indicate that a waist-worn accelerometer is sensitive to intra- and interindividual variation in walking speed [7] and that accelerometer data collected over a 7 d period are related to gait kinematics [8]. Taking this into consideration, the results from the present study further suggest that accelerometry is an objective marker of community walking in MS because counts/hour along the vertical axis were associated with community-based ambulation captured by the IDEEA system.

Despite the novelty of the present findings, this investigation had some limitations. One of the limitations was that the results are dependent on the algorithm implemented by the IDEEA system to determine walking behavior. It is possible that implementation of a different algorithm to detect walking in the acceleration profiles of the IDEEA system could change the association between the amount and quality of walking in MS and the output of the ActiGraph accelerometer. Additionally, data collection was limited to a single day of testing, excluding the examination of day to day variations. Lastly, given that the sample had on average a relatively low level of disability (median EDSS of 3.0), the current observations may not apply to those with greater disability. Although this is a limitation, it is important to note that 41 percent of the current sample used an assistive device during walking and that the current observations are likely to extend to those with greater impairment. Further work is necessary to examine this possibility.

## CONCLUSIONS

The novel findings of this investigation are that the vertical signal from a commercially available, three-dimensional, waist-worn accelerometer is related to the amount and quality of walking in a real-world environment in persons with MS. Combined with recent research on accelerometry and walking impairment, the current results indicate that accelerometry provides an objective marker of walking impairments that occur within the community among persons with MS. Future work is needed to determine whether accelerometry is sensitive to changes in gait as a function of disease, rehabilitation, pharmaceutical treatment, and/or disability progression.

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### Author Contributions:

*Study concept and design:* J. J. Sosnoff, R. W. Motl.

*Acquisition of data:* M. K. Boes, M. J. Socie.

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