



Mobility disability and the pattern of accelerometer-derived sedentary and physical activity behaviors in people with multiple sclerosis

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ARTICLE INFO

Available online 1 April 2015

Keywords:

Multiple sclerosis
Accelerometer
Sedentary behavior
Physical activity
Mobility disability

ABSTRACT

Objective. Low physical activity and high sedentary behavior levels are major concerns in persons with multiple sclerosis (MS) and these differ depending on the level of mobility disability. However, the manner in which daily activity is accumulated is currently unknown in this population.

Methods. A secondary analysis was performed on a combined data set of persons with MS from two previous investigations of physical activity and symptomatic or quality of life outcomes in the United States over a two year period (2007–2009). Mobility disability status was determined using the Patient Determined Disease Steps (PDDS) while activity behavior was objectively monitored using an ActiGraph accelerometer for 7 days.

Results. Persons with MS who have mobility disability were involved in sedentary behavior, light and moderate intensity activity for 65%, 34% and 1% of the day, respectively compared to 60%, 37%, and 3%, respectively in those without mobility disability ($p < 0.05$). Breaks in sedentary time did not differ by mobility disability status. Compared to those without mobility disability, the average number of sedentary bouts longer than 30 min was greater in those with mobility disability ($p = 0.016$).

Conclusion. Persons with MS with mobility disability are less active, engage in more sedentary behavior and accumulate prolonged sedentary bouts.

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Introduction

To date, there are a multitude of studies examining the total or overall amount of physical activity participation among those with multiple sclerosis (MS) (Cavanaugh et al., 2011; Motl et al., 2005; Ng and Kent-Braun, 1997). Very little is known about the way in which physical activity or sedentary behavior is accumulated (i.e. pattern of activity behavior) in MS. One recent study involving 24-hour monitoring of activity behavior reported differences in daily periods of activity between those with MS and healthy controls (Rietberg et al., 2014). That study did not include lengths of active or sedentary bouts or the influence of mobility disability on activity behavior.

Mobility disability (i.e., difficulty with walking) is one of the most frequent complications of MS, and is considered by a large majority of those affected as the “most challenging aspect of the disease” (LaRocca, 2011). The disease process results in progressive mobility disability that might be made worse by physiological deconditioning

associated with being less physically active and more sedentary (LaRocca, 2011; Motl and Goldman, 2011). Activity levels differ depending on the level of mobility disability (Cavanaugh et al., 2011; Rietberg et al., 2010). The current approach to activity promotion is to encourage 30 min of moderate intensity aerobic or resistance training 2 or more times per week (Canadian Society for Exercise Physiology, 2013). This approach demands moving enough to ‘break a sweat’ and is challenging for people who may have difficulty with mobility.

One strategy that may be more feasible is to target sedentary behavior in people with MS through the whole-of-the-day approach for activity promotion (Owen et al., 2010). This whole-of-the-day approach includes recommendations to reduce sedentary time, increase non-exercise physical activity (i.e., light intensity activity), and, where possible, increase moderate-to-vigorous physical activity (MVPA) (Manns et al., 2012; Owen et al., 2010). For example, Klaren et al. (2014) reported a 99 minute reduction in sitting time with people with MS following social cognitive theory-based Internet interventions. The reduction of sedentary behavior in particular is important because it makes up a major part of the day in the general population (e.g., 50–60%) (Dunstan and Owen, 2012). Sedentary behavior is defined as “any waking behavior characterized by energy expenditure ≤ 1.5 metabolic equivalents (METs) while in a sitting or reclining posture” (Sedentary

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Behaviour Research Network, 2012). Available evidence in people without mobility disability indicates that individuals who sit for prolonged periods have a greater risk of diabetes, high blood pressure, increased blood lipids and poorer long-term mortality outcomes, independent of physical activity status (Katzmarzyk et al., 2009; Swartz et al., 2011).

The manner in which daily activity is accumulated (i.e., pattern of activity) is important. Healy et al. (2008) reported beneficial associations between regular interruptions in sedentary time (i.e., with light intensity activity) and cardiometabolic markers (e.g., adiposity levels, triglycerides and 2-hour plasma glucose) (Healy et al., 2008). Targeting the pattern of sedentary behavior in persons with MS and increasing light intensity physical activity (i.e., standing up and taking steps frequently) throughout the day is a novel strategy that holds promise for improving cardiometabolic outcomes and health in persons with MS.

The objective of this study was to extend previous work on physical activity and sedentary behaviors in persons with MS by exploring the volume (sedentary, light intensity, MVPA and mean activity intensity) and pattern (breaks in sedentary time, sedentary and activity bout lengths) of accelerometer-derived activity behavior over 1 week of monitoring in a large sample of persons with MS ($n = 439$). We classified persons with MS by mobility disability status to enhance our understanding of the volume and pattern of activity behavior and how it might differ depending on disability status.

Methods

Participants

The study involved a secondary analysis performed on a combined data set of persons with MS from two previous investigations of physical activity and symptomatic or quality of life outcomes from 2007 to 2009 (Motl et al., 2009, 2010). The data from each investigation have been previously de-identified before being considered for amalgamation and combined analysis. Participants with MS were recruited through a research advertisement that was posted on the website of the National Multiple Sclerosis Society (NMSS) and through research advertisements distributed to 12 chapters of the NMSS, including the Greater Illinois, Gateway, and Indiana chapters. The common inclusion criteria for both investigations were (1) diagnosis of MS that was confirmed in writing by the patient's neurologist; (2) relapse free in the last 30 days; and (3) ambulatory with minimal assistance (i.e., walk independently or walk with a cane). The final sample included 439 persons

with MS, and all persons satisfied inclusion criteria and provided usable data for the analyses (i.e., ≥ 3 days of valid accelerometer data).

Measures

Activity behavior

Activity behavior was objectively measured with ActiGraph model 7164 accelerometers. All accelerometers were calibrated for accurate measurement prior to use by having laboratory staff members walk on a treadmill (4.8 km/h, 0% grade for 15 min) while wearing four to eight accelerometers on a belt around the waist. Accuracy was confirmed by $<10\%$ difference in average counts per minute across the 15-minute period of walking among the batch of accelerometers worn simultaneously. This calibration was undertaken to minimize variation among devices and inaccuracy as sources of error in the study outcomes. The ActiGraph model 7164 is a device that measures activity behavior by using a piezoelectric bender element that produces an electric signal proportionate to the force acting on it during movement. The electrical signal is digitally converted into activity counts, and then activity counts are amalgamated over one minute sampling intervals (i.e., 60 s epochs) with a standard drop time of 2 min. The drop time represents the tolerance or allowable amount of time that can break a sedentary or activity bout (Table 1).

Volume of activity behavior. The data from each participant's accelerometer were processed using the ActiLife software and exported into Microsoft Excel files representing wear time, mean activity intensity, time spent in sedentary, light intensity activity, and MVPA (Table 1) based on activity count cut-points for people with MS (i.e., ≥ 1722 counts/min) (Sandroff et al., 2012).

Pattern of activity behavior. The number of daily breaks, lengths of sedentary and activity bouts (Fig. 1) as well as number of long sedentary bouts (>30 min) were also determined from the Excel files. Definitions and cut points are provided in Table 1. Accelerometer wear time data were checked against participant recorded wear times from the log sheet, and only valid days (≥ 10 h of wear time without periods of continuous zeros exceeding 60 min indicative of compliance) were included in the analysis. Our analysis using ≥ 3 valid days of data is consistent with previous research by experts in the field that has yielded a median reliability estimate of 0.80 in persons with MS (Motl et al., 2007). This is

Table 1
Description of sedentary behavior and physical activity terms with cut points.

Term	Definition	Accelerometer cut-point
<i>Volume</i>		
Sedentary time	Time in activities (sitting or lying) that do not increase energy expenditure substantially above the resting level (1.0–1.5 METs) (Sedentary Behaviour Research Network, 2012).	Total minutes < 100 counts/min (Healy et al., 2008; Matthews et al., 2008; Pate et al., 2008).
Light intensity activity	Activities that involve energy expenditure at the level of 1.6–2.9 METs.	100 to 1721 counts/min (Sandroff et al., 2012).
Moderate-to-vigorous intensity activity (MVPA)	Activities that involve energy expenditure above 3.0 METs.	≥ 1722 counts/min (Sandroff et al., 2012)
Mean activity intensity	Sum of daily activity counts/number of wear time minutes (Tudor-Locke et al., 2012).	N/A
<i>Pattern</i>		
Break in sedentary time	A defined point in time where there is a change from sedentary to a non-sedentary activity or an interruption in sedentary time (Healy et al., 2008). A break signifies the start of a bout.	Activity count change from < 100 to ≥ 100 counts. A break only occurs if the change in counts is sustained for more than 2 min.
Sedentary bout length	Consecutive minutes when count values fall into the sedentary range (< 100 counts/min). In this study drop time was 2 min (i.e. sedentary bout ends if there is a transition from sedentary to non-sedentary activity that is sustained for greater than 2 min).	Consecutive minutes with recorded counts of < 100 /min (if sustained for more than 2 min).
Activity bout length	Consecutive minutes when count values are above the sedentary range (≥ 100). Drop time was again 2 min (i.e. activity bout begins if there is a transition from sedentary to non-sedentary activity that is sustained for greater than 2 min).	Consecutive minutes with recorded counts of ≥ 100 /min if sustained more than 2 min.

MET, metabolic equivalent.

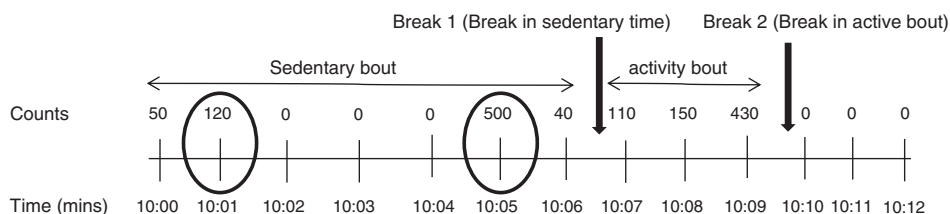


Fig. 1. Illustration of the determination of breaks and bouts by ActiLife software. This figure illustrates breaks (interruptions) in sedentary and active bouts. Counts above 100 sustained for a minimum of 2 min represent a break in a sedentary bout. Break 1 represents the end of the sedentary bout and the beginning of the active bout. Break 2 represents where the activity bout ends (because two or more minutes have counts that fall into the sedentary category), and the sedentary bout starts. The circled counts represent spikes of activity (minute with counts >100) lasting 1 min but were not considered a break because of drop time of 2 min.

considered acceptable for providing a reliable estimate of usual activity behavior (Masse et al., 2005).

Mobility disability status

Mobility disability status was determined using the Patient Determined Disease Steps (PDDS) which has strong correlation (0.78) with the Expanded Disability Status Scale (EDSS) (Learmonth et al., 2013). The PDDS is a self-report questionnaire for measuring the degree of mobility impairment from neurological disease using an ordinal scale of 0 (Normal) through 8 (Bedridden) (Motl et al., 2014). Individuals with a PDDS score of ≥ 3 were classified as having mobility disability as this is consistent with an EDSS score of 4.0 (Marrie et al., 2010).

Procedure

The same university institutional review board approved both studies and associated procedures. After the initial telephone contact, screening for inclusion, and return of informed consent and diagnosis of MS verification documentation, participants were sent an accelerometer, log sheet, instructions for wearing the device, and demographic and clinical disability questionnaires. Participants were given written and graphic instructions to wear the accelerometer on the provided belt around the waist over the non-dominant hip during all waking hours of a seven-day period, except when swimming, bathing, or showering. The seven-day period of monitoring has been standard in studies of physical activity based on accelerometry (Masse et al., 2005). Waking hours were defined as the moment of getting out of bed in the morning until the moment of getting into bed in the evening. Participants were asked to maintain usual levels of activity during this one-week period. A member of the research staff called to make sure the participants received the materials and understood the instructions. We further provided pre-stamped and pre-addressed envelopes for return postal service. After completing the measures and wearing the accelerometer for the one-week period, participants returned the study materials through the U.S. postal service. We contacted participants by telephone and e-mail as a reminder to return the study materials up to three times. We further collected any missing questionnaire data based on follow-up telephone calls. All participants received \$20 remuneration upon returning the study materials.

Data analysis

Participant characteristics (age, gender, ethnicity, marital status, occupation, MS type and duration) were reported by disability status. Chi square analysis was used to examine for differences between those with and without mobility disability. Further, multivariate regression analyses, adjusted for covariates (age, wear time and duration of MS) were used to determine if there were differences in accelerometer-derived variables by disability status. We used multiple regression to allow us to control for covariates that influence activity behavior (age, wear time and duration of MS). Significant covariates on univariate tests with activity behavior variables were included in the adjusted analyses. The variables sedentary time, light-intensity activity time and average sedentary bout length were additionally adjusted for MVPA whereas the average activity bout length and MVPA were adjusted for sedentary

time. Further adjustments for MVPA and sedentary time were necessary as both could be potential confounders. All analyses were done using STATA version 13 (Stata Corporation, College Station, TX) at a significance level of $p < 0.05$.

Results

In the total sample of 439 participants, 44% (194) had mobility disability (Table 2). Most participants (68%) were aged between 40 and 59 years with an average age of 47.3 ± 10.0 years. The sample was largely Caucasian (92%). Of those with mobility disability, 73% were within the age range of 40–59 years. Persons with MS aged 40 years and above had higher levels of mobility disability than individuals younger than 40 years ($p < 0.01$). A greater percentage of those with mobility disability had secondary progressive MS. Individuals with shorter time since diagnosis (less than 10 years) had lower rates of mobility disability (72%) compared with those who had been diagnosed with MS for more than 10 years.

Table 2
Participant characteristics.

	Full sample n = 439 % (n)	Mobility disability		p-Value
		Absent n = 245 % (n)	Present n = 194 % (n)	
Age (years)				
<20	0.2 (1)	0.4 (1.0)	0 (0)	
20–39	21.5 (94)	29.1 (71)	11.9 (23)	
40–59	67.8 (297)	63.9 (156)	72.7 (141)	<0.001
60–79	10.3 (45)	6.6 (16)	15.0 (29)	
>80	0.2 (1)	0 (0)	0.5 (1)	
Gender				
Female	84.7 (372)	85.3 (209)	84.0 (163)	0.710
Male	15.3 (67)	14.7 (36)	16.0 (31)	
Ethnicity				
Caucasian	92.5 (404)	94.2 (229)	90.2 (175)	0.113
Non-Caucasian	7.6 (33)	5.8 (14)	9.8 (19)	
Marital status				
Married	68.0 (298)	64.3 (157)	72.7 (141)	0.063
Non-married	32.0 (140)	35.7 (87)	27.3 (53)	
Occupation				
Unemployed	43.2 (188)	29.2 (71)	60.9 (117)	
Employed	56.8 (247)	70.8 (172)	39.1 (75)	<0.001
Type of MS				
Relapsing–remitting	90.4 (395)	95.5 (232)	84.0 (163)	
Secondary progressive	6.2 (27)	0.8 (2)	12.9 (25)	<0.001
Primary progressive	2.1 (9)	1.2 (3)	3.1 (6)	
Benign	1.4 (6)	2.5 (6)	0 (0)	
Duration of MS				
10 years or less	63.7 (279)	72.1 (176)	53.1 (103)	<0.001
Greater than 10 years	36.3 (159)	27.9 (68)	46.9 (91)	

Mobility disability absent, Patient Determined Disease Steps ≤ 2 ; mobility disability present, Patient Determined Disease Steps ≥ 3 .
p-Value represents difference between those with and without disability.

Table 3
Accelerometry results by disability status (adjusted for age, wear time, duration of MS and MVPA or sedentary time).

	Mobility disability		p-Value
	Absent	Present	
	n = 245	n = 194	
	Mean (SD)	Mean (SD)	
<i>Accelerometer variables</i>			
Valid days	6.2 (0.1)	6.0 (0.1)	0.047
Wear time, min/day	840.7 (6.7)	827.5 (8.5)	0.026
<i>Volume</i>			
Sedentary time, min/day ^a	504.5 (4.8)	533.3 (5.4)	0.033
Light intensity activity, min/day ^a	311.4 (4.7)	283.7 (5.3)	0.035
Moderate-to-vigorous intensity activity (MVPA), min/day ^b	24.8 (1.0)	10.5 (1.2)	<0.001
Mean activity intensity, counts/min	293.7 (7.5)	201.6 (8.4)	<0.001
<i>Pattern</i>			
Breaks in sedentary time, n per day ^a	13.7 (0.2)	14.7 (0.2)	0.069
Average sedentary bout length, min ^a	23.8 (1.1)	24.2 (1.3)	0.752
Sedentary bout length >30 min, n per day ^a	4.3 (0.1)	5.1 (0.1)	0.016
Average activity bout length, min ^b	12.8 (0.1)	11.6 (0.1)	0.187

Mobility disability absent, Patient Determined Disease Steps ≤ 2 ; mobility disability present, Patient Determined Disease Steps ≥ 3 .

^a Sedentary time, light intensity, breaks in sedentary time, and sedentary bouts (adjusted for age, wear time, duration of MS and MVPA).

^b MVPA and activity bout (adjusted for age, wear time, duration of MS and sedentary time).

Volume of activity behavior

Activity variables for the full sample, stratified by mobility disability, are displayed in Table 3. Those with mobility disability were sedentary for 65% of the day (8.9 h) compared with 60% of the day (8.4 h) in those without mobility disability ($p = 0.033$). Participants with mobility disability were engaged in light intensity activity for an average of 34% of the day (4.7 h) as compared to 37% of the day (5.2 h) among those without mobility disability. MVPA made up only 1% (10 min) of the day among those with mobility disability as compared to 3% (25 min) in those without disability. The differences in light intensity activity and MVPA were significant. Mean activity intensity (average counts per minute over the monitored period) was significantly different between those with and without mobility disability (201.6 vs. 293.7 counts/min, respectively; $p < 0.01$). The influence of mobility disability (i.e. represented by individual PDDS scores) on activity behavior is illustrated in Fig. 2 (panels A, B, C). Time spent in sedentary behavior was longer while physical activity was shorter with higher levels of mobility disability except for PDDS of 6 (use of bilateral support or walker).

Pattern of activity behavior

The number of daily breaks in sedentary time and average length of sedentary and activity bouts did not differ by mobility disability status. The average number of sedentary bouts longer than 30 min was greater in those with mobility disability as compared to those without disability (5.1 vs. 4.3, respectively; $p = 0.016$). The influence of mobility disability on the pattern of activity behavior is illustrated in Fig. 2 (panels D, E, F). Breaks in sedentary time and the number of sedentary bouts greater than 30 min were larger while activity bouts were smaller with higher levels of mobility disability except for PDDS of 6.

Discussion

The current analysis was conducted to examine the volume and pattern of sedentary and physical activity behavior in persons with MS, classified by mobility disability status. The main findings are that

persons with MS with mobility disability: 1) spend a significantly greater percentage of their day in sedentary behavior; 2) are involved in significantly less physical activity (light intensity activity and MVPA); and 3) accumulate significantly more sedentary bouts greater than 30 min compared to persons with MS without mobility disability.

The percentage of sedentary behavior in persons with MS with mobility disability reported in this study is less than a previous study of persons with MS such that those with ambulatory limitation (Expanded Disability Status Scale (EDSS) scores > 4.5) were inactive for 85.3% of the day (Cavanaugh et al., 2011). However, different measurement devices were used and inactivity was defined as a stride count of zero, which includes standing (a non-sedentary behavior). Compared to persons with MS without mobility disability, data from a population representative sample shows that adults aged 46 years spend about 58% (8.4 h) of their day in sedentary behavior (Healy et al., 2011). This figure is similar to our findings in those without mobility disability.

Our results extend previous studies (Kos et al., 2007; Motl et al., 2005; Ng and Kent-Braun, 1997; Rietberg et al., 2014) demonstrating that physical activity levels are lower in persons with MS compared to the general population. In this study, we did not have a healthy control group, but reported the volume of physical activity (i.e. light intensity activity and MVPA) to be significantly less in those with mobility disability (PDDS ≥ 3) than those without disability. The mean activity intensity over the monitored period was particularly different between those with and without mobility disability (201.6 vs. 293.7 counts/min, respectively). This average intensity is also different from 62.8 counts/min reported in a study with stroke survivors (Rand et al., 2009), and 376 counts/min in healthy adults (Hagstromer et al., 2007). These findings suggest that persons with MS are generally more active than stroke survivors, but less active than the general population. An interesting finding in this study is that provision of gait aids that provide bilateral support (i.e. PDDS score of 6, use of walker) increases physical activity behavior in the MS population.

This study is the first to address the pattern of activity in people with MS. Although the number of daily breaks in sedentary time did not differ by mobility disability status, the number of breaks in both those with (14.7) and without (13.7) mobility disability was lower compared to healthy individuals. Healy et al. (2011) reported 92.5 daily breaks in sedentary time in healthy adults. The average lengths of sedentary and activity bouts did not differ by mobility disability status; however, the number of long sedentary bouts of length greater than 30 min was significantly higher in participants with mobility disability. Prolonged bouts of sedentary behavior have been described to be particularly harmful (Healy et al., 2008). There is evidence that prolonged sedentary time is negatively associated with several cardiometabolic markers (e.g., waist circumference, HDL-cholesterol, C-reactive protein, triglycerides and insulin sensitivity) (Healy et al., 2011). However, transitions from sedentary to non-sedentary activities have been beneficially associated with these cardiometabolic markers (Healy et al., 2011). With regard to energy expenditure, previous studies indicate that standing up and walking for 1-min within a sedentary bout of 30 min will result in a net energy expenditure of 3.0 kcal and if sustained for 1 week will accumulate to 120 kcal (Swartz et al., 2011). Frequently interrupting sedentary time with light intensity activity with particular emphasis on long sedentary bouts deserves special attention.

The method for defining breaks and bouts during the accelerometer data management and analysis requires discussion. A break bounds the beginning and end of a bout (sedentary or active). The ActiLife software uses the measurement of drop time (i.e. the allowable amount of time that can break a sedentary bout). Drop time was set to 2 min; therefore a sustained bout (either as sedentary or active) of more than 2 min (Fig. 1) was required for a break to be recorded. This is the default setting on the ActiLife software and was recommended in validation studies (Masse et al., 2005). For example, if counts were above 100 for more than 2 min during a 5 minute period, this was considered a break in sedentary time in our analysis. By contrast, Healy and colleagues defined a

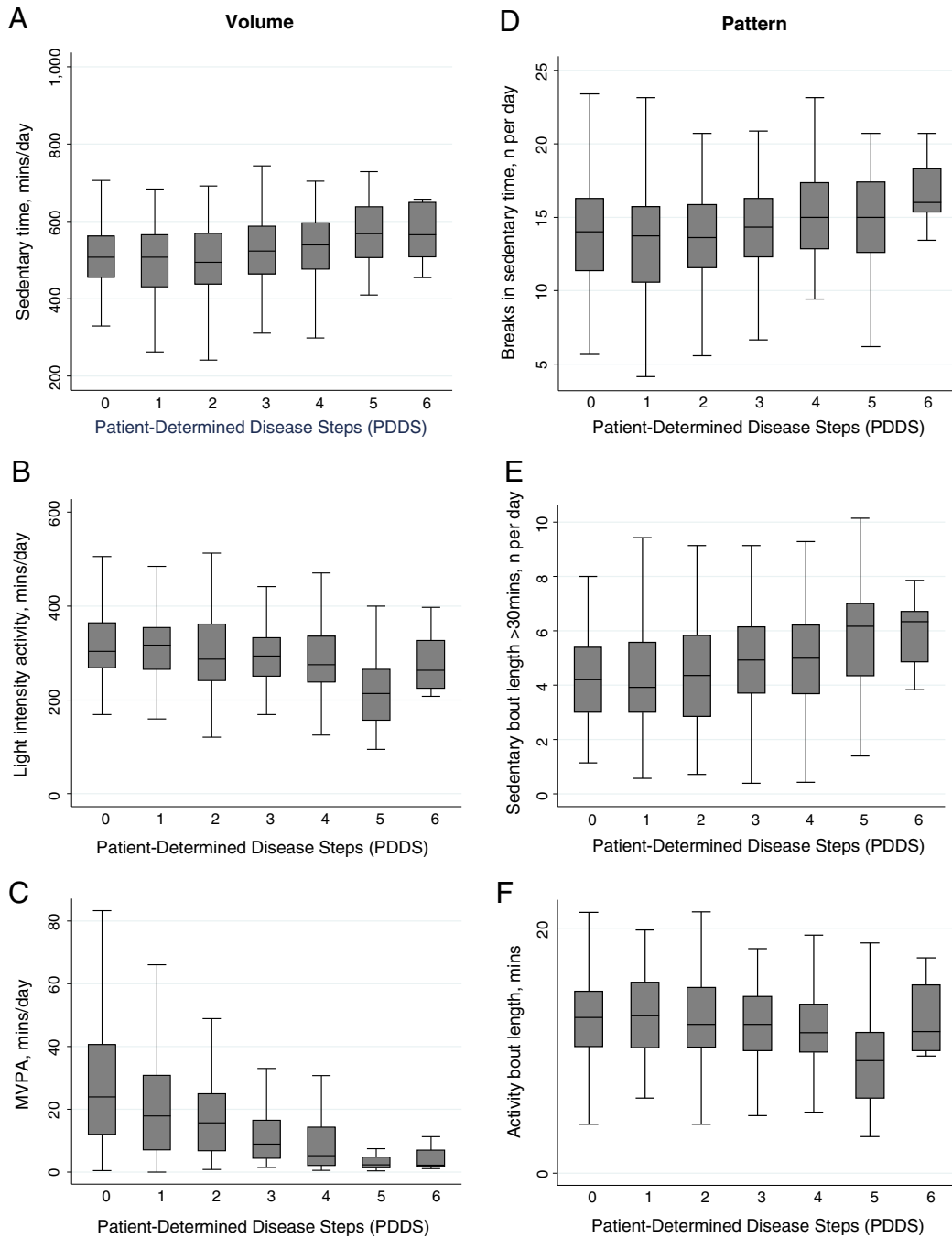


Fig. 2. The influence of mobility disability, as characterized by individual PDDS scores, on activity behavior. Notes: MVPA, moderate-to-vigorous physical activity; PDDS (Patient Determined Disease Steps).

PDDS scores	Number of persons with MS
0: Normal	113
1: Mild disability	78
2: Moderate disability	54
3: Gait disability	78
4: Early cane	84
5: Late cane	25
6: Bilateral support	7
7: Wheelchair/Scooter	-
8: Bedridden	-

break as “interruption in sedentary time, or a transition from a sedentary (<100 counts/min) to an active state (≥ 100 counts/min) for a minimum of 1 min” (Healy et al., 2008, 2011). The benefits of 2 minute interruption in sedentary time on postprandial glucose and insulin have been reported previously (Dunstan et al., 2012). Future studies will be required to examine differences in the pattern of activity (bouts and breaks) between drop times set at zero and at 2 min to see how this will improve our understanding of what truly constitutes a break.

The strengths of this study lie with the objective measurement of activity behavior and the large sample of persons with MS. Objective measurement reduces the bias associated with self-report, whereas the large sample allowed us to control for covariates in the analysis and provide more trustworthy estimates. Some limitations of ActiGraph accelerometers include misclassification based on cut-points. The commonly accepted cut-point of <100 counts/min for sedentary behavior may actually represent light intensity activity for people with mobility disability. In a bid to avoid misclassification for physical activity behaviors, we used cut-points of ≥ 1722 counts/min for MVPA specific to the MS population (Sandroff et al., 2012), but researchers have not tested cut-points for sedentary behavior in MS. One limitation of this study is that the large sample allowed for the identification of statistically significant, yet small differences in sedentary and physical activity behaviors between disability categories, but such differences might not be biologically or behaviorally meaningful.

Conclusion

Persons with MS with mobility disability are less active, engage in more sedentary behavior and accumulate prolonged sedentary bouts compared to those without mobility disability. These findings underscore the need for interventions to reduce sedentary time and increase non-exercise physical activity in people with MS with mobility disability.

Funding

This research was funded, in part, by grants from the National Institute of Neurological Disorders and Stroke (NS054050) and National Multiple Sclerosis Society (RG 3926A2/1).

Conflict of interest statement

The authors declare that there are no conflicts of interests.

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