

Capturing Ambulatory Activity Decline in Parkinson's Disease

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Background and Purpose: Relatively little is known about the natural evolution of physical activity-related participation restrictions associated with Parkinson's disease (PD). We examined this issue prospectively, using continuous monitoring technology to capture the free-living ambulatory activity of persons with PD engaging in life situations. We specifically sought (1) to explore natural, long-term changes in daily ambulatory activity and (2) to compare the responsiveness of ambulatory activity parameters to clinical measures of gait and disease severity.

Methods: Thirty-three persons with PD participated (Hoehn and Yahr range of 1–3). Participants wore a step activity monitor for up to 7 days at baseline and again at 1-year follow-up. Mean daily values were calculated for parameters indicative of amount, intensity, frequency, and duration of ambulatory activity. Clinical measures included the Unified Parkinson Disease Rating Scale, the 6-Minute Walk, and Maximal Gait Speed. Parametric tests for paired samples were used to investigate changes in ambulatory activity parameters and clinical measures.

Results: Participants had significant declines in the amount and intensity of daily ambulatory activity but not in its frequency and duration ($P < 0.007$). Declines occurred in the absence of changes in clinical measures of gait or disease severity. The greatest 1-year decline occurred in the number of daily minutes participants spent engaging in at least moderate-intensity ambulatory activity.

Conclusion: Continuous monitoring of ambulatory activity beyond mere step counts may serve as a distinct and important means of quantifying declining ambulatory behavior associated with disease progression or improved ambulatory behavior resulting from rehabilitation and medical and/or surgical interventions in persons with PD.

Key words: ambulatory activity, ambulatory monitoring, Parkinson's disease

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INTRODUCTION

A growing body of evidence reveals the benefits of routine exercise for persons with Parkinson's disease (PD), a progressive neurodegenerative disorder estimated to affect greater than 4 million people worldwide.¹ Recent meta-analyses and systematic reviews consistently demonstrate that persons with PD who participate in exercise programs have better quality of life, walking ability, balance, strength, flexibility, and cardiovascular fitness than those who do not exercise.^{2–5} Such evidence contributes to the acknowledgment in the healthcare community that exercise offers significant and clinically meaningful benefits to persons with PD, many of whom live longer than 20 years following initial diagnosis.^{1,6} In this regard, regular and sustained patterns of exercise behavior may be particularly useful to help slow long-term declines in functional mobility and activities of daily living.^{7,8} This proposition has not yet been investigated.

Future outcome studies of long-term exercise behavior of persons with PD are likely to be forthcoming. In the meantime, relatively little is known about the natural exercise habits and, in a broader context, the physical activity behaviors of persons with PD. Cross-sectional studies reveal that these individuals appear to be even less physically active than their neurologically healthy, relatively sedentary peers. Decline in physical activity with disease progression has been inferred from cross-sectional data^{9–11} but has not been measured prospectively. The extent to which persons with PD routinely participate in frequent and long periods of moderate- to vigorous-intensity physical activity also is unknown, especially in early to mid-stages of the disease when such behavior might slow the rate of functional decline.^{2,4,5} Finally, the prospect of progressive inactivity is of great concern among consumers and healthcare professionals alike because of its health implications^{12–14} and its potential association with accelerating disability.¹⁵

Continuous ambulatory activity monitoring provides a technology-based solution for quantifying the amount, intensity, frequency, and duration of exercise and physical activity behavior. Ambulatory activity refers to a subset of naturally occurring physical activity behaviors that require stepping (eg, walking, jogging, climbing stairs, mowing the lawn).¹⁶ In contrast to commonly used clinical measures (eg, Unified Parkinson Disease Rating Scale [UPDRS]; 10-meter walk test; 6-minute walk [6MW] test), which provide only a brief "snapshot" of function captured at one point in time, a continuously worn ambulatory activity monitor captures the ongoing and

evolving walking behavior of individuals engaging in life situations throughout the day within their customary home and community environment. The “free-living” focus of ambulatory activity monitoring is particularly relevant to the daily life experience of persons with PD, for whom medication, motor symptom, and mobility fluctuations may impact physical activity and exercise routines. As such, we presumed ambulatory activity measures to reflect a mobility component of the International Classification of Functioning, Disability and Health model “Participation” domain.^{16–19}

Measurement of ambulatory activity with pedometer- or accelerometer-based technology has been described for multiple populations, including but not limited to older adults, stroke survivors, and persons with PD.^{11,20–27} Ambulatory activity most commonly has been characterized, in terms of overall amount, as the total number of steps accumulated over the course of a typical day. For persons with PD, for example, daily step accumulations have been reported to range from 2700 to 9000.^{11,27,28} Recent investigations, however, have used an expanded suite of parameters that show promise for more fully characterizing ambulatory activity in various populations.^{16,24,29} Parameters have included the intensity of activity (ie, step rate), frequency of activity (ie, total number of activity bouts),²⁸ and duration of activity (ie, total minutes of stepping or percentage of the day spent inactive). To our knowledge, no previous studies of persons with PD have described natural changes in the amount, intensity, frequency, and duration of ambulatory activity behavior that might occur over an extended period of time. Knowledge of natural changes in ambulatory activity would serve as an important foundation from which to develop activity-based interventions and prescriptions for persons with PD.

For these reasons, the broad objective of this prospective cohort study was to use accelerometer-based ambulatory activity monitoring to examine the detailed patterns of daily ambulatory activity of individuals with PD and to determine whether such measurement tools could capture longitudinal changes in ambulatory behavior. In our primary analysis, we examined the longitudinal change in the amount, intensity, frequency, and duration of ambulatory activity over 1 year. In our secondary analysis, we compared the changes observed in clinical measures of gait and disease severity with those observed with ambulatory activity parameters. We hypothesized that in comparison with those at baseline, participants at follow-up would demonstrate diminished ambulatory activity, as evidenced by accumulating fewer daily steps, spending a greater percentage of the day inactive, generating lower ambulatory activity intensity, and engaging in fewer bouts of activity. We also hypothesized that ambulatory activity parameters would be more responsive to longitudinal changes in disability than clinical measures of gait and disease severity.

METHODS

Study Design and Sample

Participants were recruited from movement disorders clinics and local support groups at Boston University and the University of Utah. Inclusion criteria included a diagnosis of idiopathic PD according to the UK Brain Bank Criteria,³⁰

modified Hoehn and Yahr (H & Y) stages I to IV, age 40 years or greater, living in the community (not institutionalized), and able to attend assessment sessions and provide consent. Participants were excluded if they had a diagnosis of atypical parkinsonism or H & Y stage 5 or had previous surgical management of their PD. Institutional review boards at each institution approved the study protocol. All participants provided informed consent following initial screening. The participants reported here formed a subset of participants from a previously described prospective longitudinal parent study³¹; details regarding the selection of this sample are provided in a later section (Data Management, Data Reduction, and Statistical Analysis).

Demographic and Clinical Measures

Demographic and clinical data were collected at baseline and at 1-year follow-up in outpatient settings. At both testing periods, timing of clinical testing (6MW and 10-meter walk tests) was standardized in that all subjects were tested in a dopamine replacement medication state that was scheduled 1 to 1.5 hours after they took their dopamine replacement medications. To ensure consistency of clinical testing procedures at each site, research personnel were provided with a manual of standard operating procedures and an instructional video that described the protocol for administering and scoring each clinical test for persons with PD. Before enrolling study participants, each evaluator rated the two video examples of patients undergoing testing on two occasions, separated by 1 week. We subsequently verified intrarater and interrater reliability of the measures. Intraclass correlation coefficients were calculated to examine the consistency of the measurements among raters. Separate intraclass correlation coefficient (1,4) calculations were performed for each physical performance measure, and these coefficients ranged from 0.64 to 0.89.

At baseline, demographic information, history of PD, exercise history, and other medical and surgical history were collected via personal interview, with use of standardized data forms. At 1 year, demographics and exercise behavior were confirmed with the participant. In addition, any changes in medication data (ie, drug name, dose, frequency, or levodopa equivalent daily dose [LEDD])³² or in medical and surgical history were recorded.

To quantify disease severity, we used the revised version of the UPDRS motor examination (part III), developed by the Movement Disorder Society (MDS-UPDRS). The scale was administered by trained research personnel. Validity and high internal consistency of this measure have been documented.^{33,34} Scores reflect the severity of impairment related to bradykinesia, tremor, rigidity, freezing, and postural control. Individual items are scored 0 (normal) to 4 (severe). Scores can range from 0 to 132, with higher scores designating greater disease severity. In addition, to quantify the MDS-UPDRS gait measurement, one gait-specific item was extracted from the MDS-UPDRS (ie, item number 3.10). This item asks the examiner to observe the participant walking at least 10 m (30 ft), turning around, and returning to the examiner. This item is intended to measure global limitations in multiple behaviors, including stride amplitude, stride speed, height of foot lift, heel strike during walking, turning, and arm swing.

Walking endurance was measured with the 6MW test, a measure of the distance a participant walks in 6 minutes. For the 6MW, participants were tested with use of the protocol outlined by the American Thoracic Society.³⁵ The 6MW distance is related to functional movement tasks and is an independent predictor of prognosis in older patients with comorbid conditions. The test-retest reliability of the 6MW test is high, ranging from 0.94 to 0.96, in older populations with various comorbid conditions including PD.^{36,37} Maximal pace gait speed was measured during a 10-m walk. Two trials were recorded, with the average of the trials used as the dependent variable. Gait speed provided a standardized measure of gait function that has been found to be reliable and is sensitive to change over a broad range of physical function in elderly individuals and persons with neurologic pathology.³⁶⁻³⁸

Ambulatory Activity Monitoring

For this study, we used the StepWatch 3 Step Activity Monitor (SAM; Orthocare Innovations, Mountlake Terrace, Washington) to capture ambulatory activity. The SAM is the size of a pager, weighs only 38 g, and for measurement purposes attaches at the ankle by means of Velcro closures. Once applied, it requires no maintenance by the user. The SAM is a microprocessor-linked unit that combines acceleration, position, and timing information to count complete gait cycles (strides) taken by the leg to which it is attached. The monitor records stride counts in 1-minute intervals synchronized to a 24-hour clock and stored on flash memory within the monitor. Each 24-hour day of recording produces a temporal series of 1440 1-minute intervals. During periods of inactivity, stride counts are recorded as 0. During activity, the number of counts recorded per 1-minute interval varies, depending primarily on the locomotor task characteristics. Previous research has supported the validity and reliability of the SAM in various diagnostic groups (eg, persons who have undergone amputation, have had a stroke, or have multiple sclerosis), even for individuals with slow or shuffling gait consistent with PD.^{20-22,24,25,39-42} The monitor is programmed with a standard computer via a USB-connected docking station that communicates with the SAM through an infrared link.

Activity monitors were given to participants at the time of clinical testing. Participants were instructed to wear the monitor during customary activity, including exercise, during waking hours for 7 consecutive days, except when bathing, showering, or swimming. Using the manufacturer software, study personnel configured monitors to record stride counts in 1-minute intervals, such that each 24-hour period produced a time series of 1440 values. By means of the SAM software, the monitor was set to the participant's height, typical walking speed (ie, slow, normal, fast), and leg motion (ie, dynamic/fidgety, normal, gentle/geriatric). For each participant, the settings on the SAM were the same at both baseline and the 1-year follow-up period. Participants wore the SAM on the ankle of the leg with least-severe motor impairment. The determination of the least-severe motor impairment was made by comparison of the score of lower-extremity items on the MDS-UPDRS motor subsection. Oral and written instructions were provided regarding proper SAM placement and wearing schedule. Optimal accuracy was verified during the first

minutes of recording by comparing monitor step counts, identified via a flashing indicator light, with visual observation. After wearing the monitor for 7 days, participants returned the monitor to the researchers either in person or through the mail in a preaddressed return envelope. Upon receipt of the returned monitor, research staff downloaded the monitor data to a personal computer for data reduction and analysis.

Data Management, Data Reduction, and Statistical Analysis

Demographic and clinical data for participants at each site were initially recorded on standardized study forms and then inputted and managed collectively with REDCap (Research Electronic Data Capture) electronic data capture tools hosted at The University of Utah. REDCap is a secure, Web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for importing data from external sources.⁴³

Subsequent to data entry, we confirmed the accuracy of data entry for every third participant by comparing electronic data with the original hard copy data. In addition, we selected additional files at random for similar review. Researchers at each site were notified of any discrepancies, and appropriate corrections were made. As a final data validation step, we reviewed descriptive statistics for all measures to ensure that there were no out-of-range values resulting from data entry errors.

One hundred twelve participants from the catchment areas served by the respective data collection sites completed comprehensive baseline assessments for the parent study.³¹ Of these potential 112 potential participants, a subset of 57 wore the monitors at baseline. In addition to consent, the decision to give a participant a monitor was made by study personnel according to (1) the limited supply of monitors, (2) the availability of a monitor that day, (3) the participant's willingness to wear a monitor, and (4) the presence of cognitive or integumentary impairments that might interfere with the wearing protocol. At 1-year follow-up 90 participants remained in the parent study, and as a result of attrition from the parent study, there were 37 participants who wore the monitors at both the baseline and 1-year follow-up time periods. From this cohort, data-recording problems (eg, monitors worn incorrectly or computer docking-station issues) occurred with four individuals. Thus, we subsequently processed SAM data from 33 individuals for our analysis.

One investigator (J.T.C.) used SAM manufacturer software and a custom algorithm written in MatLab (Mathworks, Natick, Massachusetts) to transform recorded stride counts into step counts (ie, step count = stride count × 2) and to calculate mean daily values for variables characterizing the amount, intensity, frequency, and duration of daily ambulatory activity. Example graphic outputs of SAM are presented in the figure. The constructs assessed, the specific variables of interest within each construct, and the operational definitions for each of the dependent variables are summarized in Table 1. Daily values were calculated on the basis of 24-hour intervals,

including time spent sleeping or with the monitor off, from 12:00 AM to 11:59 PM. Daily values reflecting little or no activity, especially in comparison with a participant's typical daily

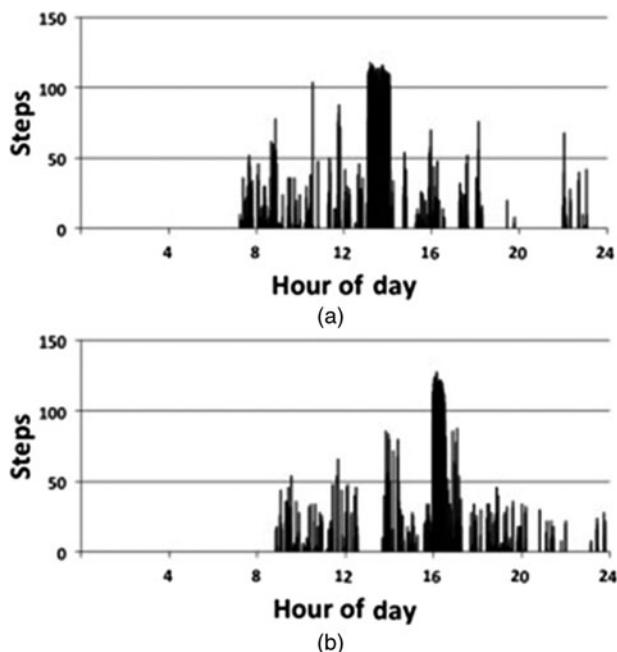


Figure. Representative 24-hour ambulatory activity records recorded from a single participant at (a) baseline and (b) 1-year follow-up. Both recordings were collected on the same day of the week. When comparing the graphics, note that the majority of the differences in step count can be accounted for by the reduced number of moderate-intensity minutes (ie, focal period of high step accumulation) during what presumably was the participant's daily exercise routine. The participant's baseline average values (7 days of recording) were as follows: Steps = 13,269; Peak Activity Index = 110.40 steps per minute; Maximum Output = 100.40 steps per minute; Moderate intensity minutes = 46.71; Number of Activity Bouts = 68; 76.90% of period spent inactive. The participant's 1-year follow-up average values (7 days of recording) were as follows: Steps = 9159; Peak Activity Index = 103.00 steps per minute; Maximum Output = 93.00 steps per minute; Moderate-intensity minutes = 27.43; Number of Activity Bouts = 55; 83.00% of period spent inactive.

values, were excluded from the analysis under the assumption that the participant forgot to wear the monitor.

Point estimators of central tendency and dispersion as well as interval estimators were calculated for demographic, clinical, and ambulatory activity parameters to describe characteristics for the total sample and separately for baseline and 1-year follow-up. All dependent measures were subjected to tests of the assumptions of parametric statistical tests. Tests of differences between baseline and 1-year follow-up were performed with paired *t*-tests and use of a preset level of significance of $\alpha < 0.05$. Corrections for multiple comparisons were performed within each category of variables. In addition, strength of effect size estimators (percent change and Cohen's *d* effect sizes) were calculated for all measures. All data were analyzed with the statistical software program IBM SPSS Statistics, Version 19.0.

RESULTS

Sample Characteristics

The sample included 22 men and 11 women, with a baseline mean (SD) age of 67.06 (8.75) years and a mean duration from diagnosis of 4.44 (4.21) years. At baseline, most participants had mild to moderate disease severity (Table 2): 3/33 (9%) were in Modified H & Y stages 1 and 1.5; 24/33 (76%) were in stages 2 and 2.5; and 6/33 (18%) were in stage 3. At the 1-year follow-up, the subdivision of Modified H & Y stages was as follows: 1/33 (3%), stages 1 and 1.5; 29/33 (88%), stages 2 and 2.5; and 3/33 (9%), stage 3. The majority of participants reported exercising on a regular basis at both baseline and the 1-year follow-up (25/33 [76%] and 26/33 [79%], respectively).

Ambulatory Activity Parameters

Participants generally complied with wearing ambulatory activity monitors as instructed for an entire week (mean [SD] days of wear = 6.7 [1.1] at baseline and 6.4 [1.0] at 1 year). In a few cases, participants decided on their own to wear the monitor 1 or 2 additional days. In a few other cases, activity data from a particular day were excluded because of absent or minimal activity in comparison with all other days.

The amount of ambulatory activity (ie, mean daily steps) and all of the intensity-of-activity measures (ie, moderate-intensity minutes, peak activity index, and maximum output) demonstrated significant declines between baseline and 1-year

Table 1. Constructs and Operational Definitions for Ambulatory Activity Variables^a

Activity Construct	Variable	Operational Definition
Amount Intensity	Steps	The total number of strides recorded from the leg on which the sensor was worn, multiplied by 2
	Peak Activity Index	The mean step rate (in steps per minute) during the 30 most active minutes of the day, regardless of when these minutes occurred
	Maximum Output	The mean step rate (in steps per minute) during the 30 most active consecutive minutes of the day
Frequency	Moderate Intensity Minutes	Number of minutes in which participants recorded greater than 100 steps
	Number of Activity Bouts	The number of 1-minute intervals that the participant went from being inactive (step count = 0) to being active (step count > 0)
Duration	Duration of Activity	The number of daily minutes of step activity
	Percentage of Day spent Inactive	The number of minutes in which no steps were recorded, divided by 1440 minutes and then multiplied by 100

^aThese variables have been used in some form in the referenced studies.^{16,18,19,22,24,28,44}

Table 2. Clinical and Ambulatory Activity Data at Baseline and at 1-Year Follow-up^a

Variable	Baseline Mean (SD) [95% Confidence Interval]	One year Mean (SD) [95% Confidence Interval]	Magnitude of Change (% Change / Effect Size ^b)
Hoehn and Yahr Stage (median [min–max])	2.0 (1–3)	2.0 (1.5–3)	
LEDD, mg	303.03 (294.38) [197.77–408.29]	423.49 (359.66) [296.13–550.84]	28/0.37
Steps ^c	10,261.15 (4332.56) [8625.22–11,645.97]	9159.44 (3534.21) ^d [7887.20–10,325.44]	–12/0.28
Minutes	347.76 (107.51) [305.90–391.57]	323.82 (91.62) [289.86–353.44]	–7/0.24
Percent time inactive	78.53 (6.93) [76.34–81.20]	80.14 (5.90) [78.22–82.30]	–2/0.25
Bouts of activity	67.89 (14.64) [62.12–72.48]	66.45 (12.10) [61.02–70.09]	–2/0.11
Moderate intensity minutes	22.49 (24.16) [13.69–30.39]	16.07 (18.68) ^d [9.16–22.12]	–40/0.30
Peak Activity Index	89.46 (19.32) [82.61–96.31]	84.93 (17.60) ^d [78.69–91.17]	–5/0.25
Maximum output	65.22 (26.20) [55.93–74.52]	59.20 (23.72) ^d [50.79–67.61]	–10/0.24
MDS-UPDRS motor subsection	28.18 (8.56) [25.15–31.22]	28.52 (11.71) [24.36–32.67]	–1/0.03
MDS-UPDRS Item 3.10 (median [min–max])	1 (0–2)	1 (0–2)	
6-minute walk, m	480.52 (135.61) [432.43–528.60]	495.96 (154.60) [440.23–551.71]	3/0.11
Maximal Gait Speed, m/s	1.77 (.50) [1.56–1.95]	1.74 (.53) [1.60–1.96]	–2/0.06

Abbreviations: LEDD, levodopa equivalent daily dose; MDS, Movement Disorder Society; UPDRS, Unified Parkinson Disease Rating Scale.

^aPositive values of percent change indicate improvement, whereas negative values indicate worsening. Mean daily values are presented for ambulatory activity parameters.

^bEffect sizes are reported as the Cohen *d*.

^cSteps are calculated by multiplying the recorded strides by 2 to reflect the steps taken by both limbs.

^d*P* < 0.007.

follow-up (*P* < 0.007; Table 2). Neither the frequency of activity (ie, total bouts of activity) nor the duration of activity (percent of day inactive) changed significantly. The percent decline for the variables ranged from 2% (percent of day inactive) to 40% (moderate-intensity minutes), whereas the Cohen's *d* effect sizes ranged from 0.13 to 0.27. An example of a decline in moderate-intensity minutes is illustrated in the figure.

Clinical Measures of Disease Severity and Gait

None of the clinical measures changed significantly at the 1-year follow-up compared with the baseline assessment. The motor subsection score of the MDS-UPDRS increased by 0.33 points over the course of 1 year. Item 3.10 of the MDS-UPDRS (Gait) showed no change, whereas the 6MW distance increased by 15 m and the maximal gait speed declined by 0.03 m/s from baseline to 1-year follow-up. The percent change for the variables ranged from a 1% decline (motor subsection of MDS-UPDRS) to a 3% improvement (6MW distance), whereas the Cohen's *d* effect sizes ranged from 0.03 to 0.11 (Table 2).

DISCUSSION

The general hypothesis that drove the design of this study was that objective measures representing natural ambulatory behavior, such as multiday ambulatory activity monitoring, would be more responsive to the progression of disability in persons with PD than "snapshot" clinical measures of gait and disease severity. To test this hypothesis, we used currently existing technology (ie, SAM) to examine the longitudinal change over 1 year in parameters characterizing the overall amount, intensity, frequency, and duration of ambulatory activity. As hypothesized, our sample of individuals with PD collectively displayed diminished ambulatory activity at follow-up, as revealed in the lower daily accumulation of steps and reduced intensity of stepping activity. Our hypotheses regarding the frequency and duration of daily ambulatory activity were not supported.

Recently, Tudor-Locke and colleagues^{12,13,45,46} calculated that 7000 to 11 000 steps per day would encompass at least 30 minutes of moderate activity (>100 steps per minute) on top of habitual daily activity and meet public health guidelines for healthy older adults. In our opinion, activity guidelines based only on the *amount* of activity (eg, steps per day) represent a myopic view of exercise prescription, especially in populations for which the *intensity* of activity is of particular concern. We employed 3 measures to fully capture this construct. Peak Activity Index served us as a measure of capacity, as defined in the International Classification of Functioning, Disability and Health framework, by representing an ideal 30-minute period of relatively most intense activity. Maximum output served us as a measure of performance by representing the actual period of most intense activity. Moderate-intensity minutes served us as an indicator of the extent to which participants achieved recommended levels of daily physical activity according to public health guidelines.^{12,13,45,46}

Our analysis revealed that the overall amount of daily activity for our participants declined 11% or approximately 1000 steps per day on average. By extension, a rough estimate of their projected cumulative decline could be on the order of 1 day's worth of baseline activity (ie, approximately 10 000 steps) every 10 days or over 1 month of baseline activity (approximately 300 000 steps) each year. An identical magnitude of decline was observed for the maximum output parameter of activity intensity, but the decline was less for peak activity. Most alarming, however, was the relatively large reduction (ie, 40%) in the number of daily minutes in which participants appeared to engage in at least moderate-intensity ambulatory activity (ie, step rate >100 steps per minute). The decline equated, on average, to approximately 6.4 minutes per day or, by extension, nearly 45 minutes per week, and was sufficient to drop participation in moderate-intensity physical activity well below recommended public health guidelines.⁴⁷ While previously unreported, the responsiveness of this variable represents a parameter worthy of future research as a measure

of change (either of decline as a measure of disease progression or of improvement with intervention) in the intensity of ambulatory activity.

Taken together, our data from these parameters revealed a mixed picture of activity intensity at baseline and at follow-up. Mean daily moderate-intensity minutes, if extrapolated to a 7-day period, would suggest that our sample at baseline met public health recommendations for accumulating 150 minutes of at least moderate-intensity weekly physical activity. However, peak index values were well below the 100 steps per minute value that would equate to 30 minutes of daily moderate-intensity activity. Thus, our data suggest that participants in our sample, although considered "active" by some standards,^{13,14} may not have been sufficiently active at intensity necessary to promote optimal general health. Furthermore, considering previous evidence suggesting the potential benefits of vigorous exercise for persons with PD,^{2–5} the participants in our sample may not have been engaging in activity sufficiently intense to alter the expression of PD in their lives. Further investigation of this proposition is warranted.

Relative Responsiveness of Ambulatory Activity Measures Compared With Clinical Measures

Because PD is a neurodegenerative disease, the severity of motor deficits worsens over time. The LEDD increase from baseline to 1 year suggests that the neurologists treating these participants felt that progression of motor signs warranted an increase in medication dosages. The LEDD increase may have contributed to the stability of the "snapshot" measures of motor severity (ie, MDS-UPDRS motor score) and clinical gait function (ie, 6MW distance and Maximal Gait Speed). In essence, therefore, the LEDD increase may have masked the progression of body structure and function impairments and activity limitations. These results are consistent with previous research in other neurologically impaired populations that show a change over time in ambulatory activity parameters.^{24,44} To our knowledge, however, our study is unique in that it documents natural declines in function potentially associated with disease progression, whereas other studies have described improvements in function (eg, the recovery of ambulatory ability from spontaneous recovery and rehabilitation after stroke or the response to a short-term gait intervention in persons with PD).^{24,44}

Limitations and Future Directions

Although novel, these results should be interpreted with caution. The sample recruited for this study, by design, included only independently ambulatory persons with PD living in the community. Participants were required to have cognitive abilities necessary to comply with the study protocol, including wearing and returning the monitor, performing the clinical tests, and returning for follow-up visits. These constraints produced 33 participants, who, because of their relatively active profiles, may have led us to underestimate the magnitude of natural ambulatory activity decline. In addition, although ambulatory activity metrics have the potential to reveal much about ongoing and evolving ambulatory behavior, we sampled our participants at only two time points, separated by 1 year; therefore, our study was limited by low resolution. Future

studies of the longitudinal progression of ambulatory activity should consider larger, more diverse samples of persons with PD and should measure ambulatory activity at multiple time points.

The monitor utilized for this study was worn at the ankle and was limited in the data that it could gather. In an effort to gain insight into one means of measuring ambulatory activity, we chose the SAM over pedometers and other waist-worn monitors that include accelerometers and gyroscopes. By doing so, we limited our ability to examine the time spent participating in other activities (eg, sitting, laying down). If future research questions require examination of the time spent in varied body positions other than gait, then other monitors should be used.

Lastly, because our sample included individuals with potential gait deviations, the accuracy inherent in the SAM monitor was a necessary requirement for the study. For clinicians, however, pedometers may prove to be a more cost-effective solution to ambulatory monitoring in clinical settings. When comparing step counts to those in published studies, clinicians should pay special attention to what monitor is used. Unilateral ankle-worn monitors gather data from only 1 limb, and therefore the step count must be multiplied by 2 to accurately report the overall bilateral step count. In contrast, waist-worn monitors or pedometers measure steps taken with both legs.

CONCLUSIONS

This study used ambulatory monitoring to provide previously unreported documentation of the natural 1-year decline in ambulatory activity in a sample of persons with mild to moderate PD. Specific decline was noted in the amount and intensity of daily ambulatory activity, but not in its frequency and duration. Study findings support previous suggestions regarding the use of ambulatory activity monitoring to track the extent to which persons with PD meet public health recommendations for physical activity.^{20,22} In the future, natural history data, especially when collected over multiple years, may provide important targets to document the effectiveness of physical therapy interventions.

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