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Does clinically measured walking capacity contribute to real-world walking performance in Parkinson's disease?

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ABSTRACT

Objective: The study examined how clinically measured walking capacity contributes to real-world walking performance in persons with Parkinson's disease (PD).
Methods: Cross-sectional baseline data (n = 82) from a PD clinical trial were analyzed. The 6-Minute Walk Test (6MWT) and 10-Meter Walk Test (10MWT) were used to generate capacity metrics of walking endurance and fast gait speed, respectively. An activity monitor worn for seven days was used to generate performance metrics of mean daily steps and weekly moderate intensity walking minutes. Univariate linear regression analyses were used to examine associations between each capacity and performance measure in the full sample and less and more active subgroups.
Results: Walking capacity significantly contributed to daily steps in the full sample (endurance: R^2=.13, $p < .001$; fast gait speed: R^2=.07, $p = .017$) and in the less active subgroup (endurance: R^2 =.09, $p = .045$). Similarly, walking capacity significantly contributed to weekly moderate intensity minutes in the full sample (endurance: R^2=.13, $p < .001$; fast gait speed: R^2=.09, $p = .007$) and less active subgroup (endurance: R^2 = .25, $p < .001$; fast gait speed: R^2 =.21, $p = .007$). Walking capacity did not significantly contribute to daily steps or moderate intensity minutes in the more active subgroup.
Conclusions: Walking capacity contributed to, but explained a relatively small portion of the variance in, real-world walking performance. The contribution was somewhat greater in less active individuals. The study adds support to the idea that clinically measured walking capacity may have limited benefit for understanding real-world walking performance in PD. Factors beyond walking capacity may better account for actual walking behavior.

1. Introduction

Walking limitations are one of the most disabling features of Parkinson's disease (PD) and a primary reason for seeking rehabilitation services [1–3]. Even early in the disease process, persons with PD demonstrate reduced walking capacity [4] and accumulate fewer daily steps than their healthy older adult counterparts [1–3,5]. Indeed, a naturalistic longitudinal study of persons with mild to moderate disease severity found a 12% reduction in daily steps and 40% reduction in daily moderate intensity walking minutes over one year [6]. Such decline is

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particularly concerning given that walking at higher intensities may produce substantial health benefits and have disease-modifying effects [6–9]. Moreover, PD interventions incorporating real-world walking practice show promise for improving function, reducing disability, and slowing the expected natural decline in daily walking activity [6,10].

Translation of evidence-based, walking interventions into clinical PD management faces an important practical challenge: monitoring walking activity in the real world requires equipment, data processing, time, and perhaps most importantly, patient adherence to wearing a monitoring device. Accordingly, clinicians may rely instead on standardized measures of walking *capacity* (e.g., walking endurance and fast speed), commonly understood as reflecting the highest probable level of environmentally-adjusted functioning at a given moment [11], to make inferences about real-world walking *performance* beyond the clinical spotlight. While both economical and practical, the validity of this approach is not well understood.

Relevant studies that might help generate testable hypotheses are relatively few and variable in scope. For example, a study of older adults (n = 112) found that clinically-measured walking speed seemed to better represent maximal number of steps in one walking bout (measured with a motion sensor over a 48 h period) in pre-frail and frail persons but not non-frail persons [12]. A study of persons post-stroke (n = 441), in which gait impairments and reduced walking activity were common, revealed clinically measured walking endurance to be the strongest predictor of functional ambulation category defined by number of daily steps measured with a user-worn activity monitor [13]. A study of persons with PD (n = 15) revealed that clinically measured gait speed was collectively faster than, but not correlated with, gait speed measured using a motion sensor in a home environment [14]. A separate study of persons with PD (n = 125) found no association between laboratory-based measures of gait with total daily physical activity measured with an accelerometer [15].

Although none of the aforementioned studies [13–15] focused specifically on total daily steps and moderate intensity walking minutes, their results nonetheless suggested that the contribution of clinically measured walking capacity to real-world walking performance in persons with PD could be limited. The studies also suggested that the contribution of capacity to performance could depend on the walking metrics used and individual activity level. From a clinician's perspective, because persons with PD vary widely [16], a better understanding of how walking capacity might contribute differentially to walking activity in less and more active persons could improve the design and outcome measurement of real-world walking interventions.

The primary aim of this study was to determine the extent to which walking capacity might contribute to real-world walking performance in persons with PD. Capacity was operationalized as clinically measured walking endurance and fast gait speed. Performance was operationalized using real-world activity-based metrics of daily steps and weekly moderate intensity walking minutes. We hypothesized that walking capacity would contribute significantly to walking performance. However, based on prior stroke data [13] and knowing that other factors could contribute to performance [17,18], we anticipated a large amount of unexplained variance. In addition, as persons with PD are more vulnerable to declines in walking activity [6], we examined how the capacity versus performance relationship might differ between less active and more active individuals. Based on findings in older adults [12], we hypothesized that walking capacity would be a stronger contributor to walking performance in relatively less active persons with PD compared to their more active counterparts.

2. Methods

2.1. Study design and participants

This was a cross-sectional, secondary analysis of baseline walking capacity and daily walking activity data from a prospective, 12-month, single-blind, dual-site, randomized controlled trial examining the impact of mobile health technology on the daily walking behavior of persons with PD [19]. Participants in the parent study were adults with mild to moderate [20] idiopathic PD who were able to safely participate in a progressive walking and strengthening exercise program, excluding those with moderate to severe freezing of gait. The parent study was approved by the Institutional Review Board at Boston University and complies with the standards of the Declaration of Helsinski. Data used in the secondary analysis were collected between February 2019 and August 2021. The sample was comprised of 82 participants with complete baseline data for all pertinent variables.

2.2. Measures

2.2.1. Walking capacity

The 6-min walk test (6MWT) and 10-m walk test (10MWT) were used to measure walking capacity. Both measures are part of a standardized battery of walking assessments for persons with PD in rehabilitation settings [21]. The 6MWT is a valid and reliable metric of walking endurance, measured as the distance (m) a participant walks over a period of 6 min. The 6MWT has demonstrated excellent test-retest reliability in persons with PD [21]. Participants were instructed to cover as much ground as possible during one trial of walking back and forth around two cones placed 30 m apart. The 10MWT is a valid and reliable measure of gait speed (m/s) in persons with PD [21]. Two fast-paced trials were conducted using a 2-m acceleration phase, 6-m of timed ambulation, and a 2-m deceleration phase. The mean of the two trials was used in subsequent analyses.

2.2.2. Walking performance

The StepWatch 4 Activity Monitor (SAM; Orthocare Innovations, Mountlake Terrace, Washington) is an unobtrusive, user-worn, microprocessor-linked device that was used to capture walking activity in participants' real-world environments. The device was attached with velcro straps above the lateral malleolus of participants' less impaired lower extremity. The SAM combines acceleration, position, and timing information to count strides taken with the leg of attachment. Participants were instructed to wear the SAM for 7 consecutive days during all waking hours, except when showering/bathing or swimming, and to engage in their usual daily activities.

Using manufacturer software, a SAM was calibrated to each participant's gait pattern based on height, typical walking speed, and leg motion. Calibration accuracy was verified by research personnel who compared visual observation of participant steps taken over a short distance with the SAM-generated stride count. Monitors were configured to store stride counts in 1-min intervals. A stride count of zero was recorded for minutes in which no steps were taken. Collected data were downloaded to a computerized tablet.

Manufacturer software was used to generate values for daily number of strides and moderate intensity minutes (i.e., the number of minutes in which at least 100 steps were accumulated) [5]. Each daily record of walking activity was visualized graphically to verify its integrity and ensure that it was consistent with the number of daily steps and moderate-intensity minutes generated. Validity and reliability of the SAM for capturing stride counts have been demonstrated in persons with various neurologic disorders including PD [22].

2.3. Statistical analysis

Study data were stored in a Research Electronic Data Capture (REDCap) database [23]. Statistical analyses were conducted using SPSS statistical software program version 26.0 (IBM Corp, Armonk, New York). Number of daily steps was calculated as twice the number of daily strides. Mean number of daily steps and moderate intensity walking minutes were calculated for subsequent analysis.

In examining walking capacity and performance variables for

normality, we determined that the data distribution of mean daily moderate intensity walking minutes was highly skewed to the right (i.e., most participants accumulated few, if any, moderate intensity minutes on at least some days). To reduce the impact of skew and day-to-day variation on subsequent analyses, we instead used the weekly sum of moderate intensity walking minutes as the variable of interest.

Based on an established classification framework [5] used in our previous work [19] we created subgroups of relatively less active (<7,500 daily steps) and more active (≥7,500 daily steps) participants. Descriptive statistics were used to characterize sample and subgroup demographics, disease severity, walking capacity and walking performance. Independent t-tests and chi-square tests were performed to compare subgroup baseline characteristics.

To examine the independent contribution of each walking capacity variable (i.e., 6MWT distance, 10MWT fast speed) to each walking performance variable (i.e., mean daily steps and weekly moderate intensity walking minutes), we conducted a series of four separate univariate linear regression analyses using the full sample ($\alpha = .05$). To examine how the capacity-performance relationship might differ between less active and more active individuals, we repeated the regression analyses for each subgroup.

To address our ongoing concerns regarding residual skewness of the weekly sum of moderate intensity minutes distribution, we repeated the regression analyses using the natural log transformed value of the variable. The resulting pattern of regression results was consistent with the original analyses; therefore, we elected to present below only the findings from the original analyses (i.e., using the non-transformed variable) to facilitate ease of interpretation and comparison to the other study outcomes.

3. Results

The full sample (n = 82) included older adults with mild to moderate PD (mean Modified Hoehn & Yahr stage = 2.3) (Table 1). The sample was somewhat active in terms of mean daily steps (7730.6 [3626.4]) [5] yet accumulated relatively few mean moderate intensity minutes (49.9 [67.2]) over the course of the week. There were no significant subgroup differences in demographics and disease severity, but as expected, the subgroups differed in terms of walking capacity and performance (Table 1).

Walking endurance and fast gait speed significantly contributed to daily steps in the full sample (6MWT distance accounted for 13% of the variance; 10MWT fast speed accounted for 7% of the variance) (Table 2). Walking endurance (6MWT distance) significantly contributed to daily steps in the less active subgroup, accounting for 9% of the variance (Table 2). Neither capacity metric (endurance or fast gait speed) significantly contributed to daily steps in the more active subgroup.

Walking endurance and fast gait speed significantly contributed to weekly moderate intensity walking minutes in the full sample (6MWT distance accounted for 13% of the variance; 10MWT fast speed accounted for 9% of the variance) (Table 3). Each walking capacity measure significantly contributed to weekly moderate intensity walking minutes in the less active subgroup (6MWT distance accounted for 25% of the variance; 10MWT fast gait speed accounted for 21% of the variance) (Table 3). Neither capacity metric significantly contributed to weekly moderate intensity walking minutes in the more active subgroup.

Table 1
Sample characteristics.

Characteristics	Full Sample (n = 82)	Less Active Subgroup (n = 44)	More Active Subgroup (n = 38)	p-value
Age (years)*	67.4(8.4)	68.3(8.9)	66.6(7.9)	.367
Race**				.448
Asian	1(1.2)	0(0)	1(2.6)	
Black/African American	4(4.9)	3(6.8)	1(2.6)	
Hispanic/Latino	1(1.2)	1(2.3)	0(0.0)	
White	75(91.5)	39(88.6)	36(94.7)	
>One Race	1(1.2)	1(2.3)	0(0.0)	
Gender**				.441
Male	49(59.8)	28(63.6)	21(55.3)	
Female	33(40.2)	16(36.4)	17(44.7)	
MDS UPDRS III	37.2(11.9)	39.2(13.5)	35(9.6)	.128
Modified Hoehn & Yahr**3				.369
2	39(47.6)	19(43.2)	20(52.6)	
2.5	32(39.0)	17(38.6)	15(39.5)	
3	11(13.4)	8(18.2)	3(7.9)	
Walking Capacity*				
6MWT (m)	445.5 (106.1)	410.8(109.1)	485.8(87.8)	.001
10MWT Fast (m/s)	1.6(.3)	1.5(.3)	1.7(.3)	.016
Walking Performance*				
Daily Steps	7730.6 (3626.4)	5286.5(1713.5)	10560.7 (3169.8)	<.001
Weekly Mod Intensity Min	49.9(67.2)	20.2(31.7)	84.3(80.3)	<.001

*Mean(SD); **Frequency count (% of sample or subgroup); 10MWT, 10-m Walk Test; 6MWT, 6-Minute Walk Test.

4. Discussion

This cross-sectional study found that clinically measured walking capacity (i.e., endurance and fast gait speed) significantly contributed to real-world walking performance (i.e., daily steps and weekly moderate intensity walking minutes) in a sample of relatively older persons with mild to moderate PD. However, as hypothesized, a large portion of the variance in walking performance was unexplained by either capacity measure. Nonetheless, walking capacity explained more variance in a less active subgroup compared to a more active subgroup of participants.

A lack of translation from clinic to community suggests that behavior evaluated in a standardized setting may not be generalizable to a person's natural environment [24]. Based on this idea, several potential reasons may have accounted for the unexplained variance in walking performance. First, as is common in clinical practice, we administered the standardized capacity measures in a clinic setting, without the added complexity of dynamic real-world environments [14,25]. In previous studies, walking capacity tended to exceed what was typical of a person in the home and community environment, where reductions in walking speed and increased walking variability were more characteristic [14,15,26]. Second, capacity values may have been confounded by the Hawthorne effect [14,15,26,27], whereas walking performance was unsupervised, self-initiated, and embedded in behavioral context. Third, given the loss of automaticity inherent in PD [28], the goal-oriented,

Table 2
Contribution of walking capacity measures to daily steps.[a].

	Daily Steps				
	B	β	R^2	95% CI	p
6MWT					
Full Sample	12.30	.36	.13	(5.21, 19.40)	<.001
Less Active	4.777	.30	.09	(.11, 9.43)	.045
More Active	2.46	.07	.005	(-9.72, 14.64)	.684
10MWT Fast Speed					
Full Sample	2997.21	.26	.07	(544.13, 5450.28)	.017
Less Active	1236.35	.24	.06	(-331, 2803.71)	.119
More Active	225.41	.02	.00	(-3607.96, 4058.79)	.91

[a] Univariate linear regression analyses ($\alpha = .05$) of the contribution of the 6-min walk test distance (6MWT) and 10-m walk test fast gait speed (10MWT) to daily steps for the sample (n = 82), less active subgroup (<7,500 steps/day; n = 44), and more active subgroup (≥7,500 steps/day; n = 38).

Table 3
Contribution of walking capacity measures to weekly moderate intensity walking minutes.[a].

	Weekly Moderate Intensity Minutes				
	B	β	R^2	95% CI	p
6MWT					
Sample	.03	.36	.13	(.01, .06)	<.001
Less Active	.02	.50	.25	(.01, .03)	<.001
More Active	.02	.13	.02	(-.03, .06)	.454
10MWT Fast Speed					
Sample	9.08	.30	.09	(2.57, 15.60)	.007
Less Active	6.32	.46	.21	(2.55, 10.10)	.002
More Active	4.09	.10	.01	(-9.81, 17.99)	.554

[a] Univariate linear regression analyses ($\alpha = .05$) of the contribution of the 6-min walk test distance (6MWT) and 10-m walk test fast gait speed (10MWT) to weekly sum of moderate intensity walking minutes for the sample (n = 82), less active subgroup (<7,500 steps/day; n = 44), and more active subgroup (≥7,500 steps/day; n = 38).

attention-demanding context of standardized clinical walking measures (e.g., cover as much ground as possible in 6 min) may also have influenced their values, thereby affecting the association of capacity with performance.

In addition, participant walking performance was likely to have been influenced by wide array of environmental (e.g., amount of living space; community walkability), psychological (e.g., motivation; self-efficacy), and behavioral (e.g., lifestyle; customary activities) factors [17,18]. Such factors, while uniquely influencing each participant, may have had differential effects on less and more active subgroups. Our results suggested, for example, that walking capacity may more tightly constrain real-world walking performance in relatively less active persons. The findings supported prior work in older adults proposing a capacity threshold, beyond which improvements in capacity may not yield higher levels of performance [12].

Overall, our results suggested that a person's capacity to walk a maximum distance or speed does not necessarily reflect natural walking activity in their daily lives. The finding differs from previous studies in persons post-stroke, where walking endurance (i.e., 6MWT) was a strong individual predictor of natural walking activity [13]. A potential reason for this difference could be that there are more overt gait impairments in persons post-stroke, which may be the primary limiting factor of walking capacity and performance. In addition, our sample was a relatively high functioning group of persons with PD, as we excluded persons with more disabling gait impairments (e.g., freezing of gait).

Our findings expanded the body of evidence in PD supporting the idea that walking capacity measures alone are not standalone surrogates of real-world walking. Accordingly, clinicians should consider routinely employing digital health technology to directly capture patient walking performance. Though barriers certainly exist (e.g., cost, time, feasibility), advances in wearable sensors have made them increasingly accessible for clinical use. Many smart phones, for example, capture, store, and visualize step data that at a minimum could be used to engage patients in conversations about healthy walking habits. When used systematically, wearable sensors show promise for providing useful outcome data with which to measure the effect of walking practice interventions [6,29].

4.1. Limitations

Our study had several limitations. First, inferences regarding causality could not be made due to its cross-sectional design. Second, the skewed distribution of moderate intensity minutes posed challenges for the interpretation of linear regression analyses. To accommodate for skew, we analyzed the weekly sum of moderate intensity minutes and conducted additional regression analyses using the natural log transformed value of the variable. Third, although the StepWatch Activity Monitor has been validated for use in persons with PD, there was still the potential for inaccuracy. Fourth, although potentially relevant, our regression analyses did not include other potential factors (e.g., environmental, psychological, behavioral) that might have contributed to walking performance. In addition, the study focused on capacity measures that emphasized walking endurance and fast speed. Other facets of capacity (e.g., self-selected gait speed, balance, functional mobility, etc.) may have stronger contributions to real-world walking activity. Lastly, the relative homogeneity of the sample (i.e., participants were mostly white, highly educated, somewhat active, with mild to moderate disease severity) and the high activity level of some individuals in the more active subgroup limited the generalizability of the results to the broader population of persons with PD.

5. Conclusions

Clinically measured walking capacity (i.e., endurance and fast gait speed) appears to be an important, albeit modest, indicator of real-world walking performance (i.e., daily steps and weekly moderate intensity walking minutes) in persons with mild to moderate PD. The relationship between walking capacity and performance may be even weaker in relatively more active persons. Factors beyond walking capacity (e.g., personal, environmental) may better account for walking behavior in environments beyond the clinical spotlight. Real-world walking performance may need to be directly measured to be captured accurately.

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