Distance-Induced Changes in Walking Speed After Stroke: Relationship to Community Walking Activity

Louis Awad, PT, PhD, Darcy Reisman, PT, PhD, and Stuart Binder-Macleod, PT, PhD

Background and Purpose: Physical inactivity is a major contributing factor to reduced health and quality of life. The total distance walked during the 6-Minute Walk Test is a strong indicator of real-world walking activity after stroke. The purpose of this study was to determine whether measurement of distance-induced changes in walking speed during the 6-Minute Walk Test improves the test's ability to predict community walking activity.

Methods: For 40 individuals poststroke, community walking activity (steps/d), the total distance walked during the 6-Minute Walk Test ($6MWT_{total}$), and the difference between the distances walked during the final and first minutes of the test ($\Delta 6MWT_{min6-min1}$) were analyzed using moderated regression. Self-efficacy, assessed using the Activities-specific Balance Confidence scale, was also included in the model.

Results: Alone, $6MWT_{total}$ explained 41% of the variance in steps/d. The addition of $\Delta 6MWT_{min6-min1}$ increased explanatory power by 29% ($\Delta R^2 = 0.29$, $P < 0.001$). The final model accounted for 71% of steps/d variance ($F_{4,32} = 19.52$, $P < 0.001$). Examination of a significant $6MWT_{total} \times \Delta 6MWT_{min6-min1}$ interaction revealed a positive relationship between $6MWT_{total}$ and steps/d, with individuals whose distances declined from minute 1 to minute 6 by 0.10 m/s or more presenting with substantially fewer steps/d than those whose distances did not decline.

Discussion and Conclusions: Coassessment of distance-induced changes in walking speed during the 6-Minute Walk Test and the total distance walked substantially improves the prediction of real-world walking activity after stroke. This study provides new insight into how walking ability after stroke can be characterized to reduce heterogeneity and advance personalized treatments.

Key words: *6MWT, endurance, human movement system, participation, physical activity*

(*JNPT* 2019;43: 220–223)

Department of Physical Therapy and Athletic Training (L.A.), Boston University, Boston, Massachusetts; Wyss Institute for Biologically Inspired Engineering (L.A.), Harvard University, Cambridge, Massachusetts; and Department of Physical Therapy (D.R., S.B.-M.), University of Delaware, Newark.

This study was funded by NIH grants R01NR010786 and 1KL2TR001411.

The authors declare no conflict of interest.

Correspondence: Louis Awad, PT, PhD, Department of Physical Therapy and Athletic Training, Boston University, 635 Commonwealth Ave, Rm 546A, Boston, MA 02215 (louawad@bu.edu).

ISSN: 1557-0576/19/4304-0220

DOI: 10.1097/NPT.0000000000000293

INTRODUCTION

Physical inactivity is a major contributor to reduced health and quality of life. Community-dwelling survivors of stroke indicate that a deficit in their ability to walk farther distances is a key factor limiting their engagement in home and community activities.[1] Likewise, better performance on clinic-based functional tests of long-distance walking capacity, such as the 6-Minute Walk Test (6MWT), predicts better community participation and reintegration after stroke.[2] Indeed, the total distance walked during the 6MWT is a strong predictor of real-world walking activity after stroke[3] and has served as the primary metric of interest recorded from this popular test; however, this metric fails to account for heterogeneity in how individuals achieve such distances.

In persons with multiple sclerosis,[4] polio,[5] and spinal muscular atrophy,[6] reduced 6MWT total distances are largely due to an inability to maintain an initially fast walking speed—that is to say, poor endurance. This presentation is likely the result of the pathological fatigue characteristic of these populations. In contrast, recent work in persons with stroke suggests that their inability to walk fast, even early in the walking bout, is the key cause of their reduced 6MWT distance.[7,8] Assessment of how speed changes over the duration of the 6MWT could provide insight into key factors that underlie long-distance walking impairment after stroke. Different rehabilitation targets may ultimately be necessary for those whose speed decreases during the test versus those who maintain a constant walking speed or increase their speed during the test.

This exploratory study evaluated whether distance-induced changes in speed during the 6MWT could specify patients' real-world walking activity better than their 6MWT total distance. Given that self-efficacy has recently been shown to play a role in mediating the relationship between physical capacity and walking activity,[9,10] our analysis also accounted for self-efficacy.

METHODS

Forty community-dwelling individuals in the chronic phase poststroke completed all study procedures. All participants were able to walk 6 minutes without physical assistance. Cerebellar stroke, neglect or hemianopia, or comorbidities that limited walking ability were exclusion criteria. All procedures were approved by the University of Delaware's institutional review board, and written informed consent was obtained from all individuals.

All testing was conducted under the supervision of a licensed physical therapist. Assistive devices and orthoses were allowed if needed for safety. Participants' community walking activity[10] was measured using 2 or more days of recordings of steps walked per day (steps/d) made by a StepWatch Activity Monitor (Orthocare Innovations, Seattle, Washington) worn on the nonparetic leg during all walking activities. An average of 3.95 ± 0.19 days of walking activity were available across participants. The total distance walked during the 6MWT ($6MWT_{total}$), the difference between the distances walked during minute 6 and minute 1 of the test ($\Delta 6MWT_{min6-min1}$), and self-efficacy as measured using the Activities-specific Balance Confidence (ABC) scale[10] served as independent variables. Participants completed the 6MWT without verbal encouragement and with instructions to "cover as much distance as possible."[11]

Data Analysis

All analyses were conducted using commercially available software (SPSS version 24, IBM Corp., Armonk, N.Y., USA). Averages ± standard error are reported. Moderated regression evaluated changes to a steps/d model containing $6MWT_{total}$ and ABC score—variables known as key indicators of community walking activity after stroke.[3,10] Both ABC score and $6MWT_{total}$ were entered first, followed by $\Delta 6MWT_{min6-min1}$ and the $6MWT_{total} \times \Delta 6MWT_{min6-min1}$ interaction. All assumptions for regression were ensured. Centered variables were used to minimize multicollinearity. To minimize multicollinearity, all independent variables were mean centered such that each variable's new mean was zero. An examination of model residuals revealed 3 participants whose data were outliers that contributed to a violation of normality. Removal of these data points from the final analysis restored normality. It should be noted that $\Delta 6MWT_{min6-min1}$ was a major determinant of steps/d both with and without these outliers. Both the final model R^2 and the R^2 adjusted for sample size and the number of predictors (R^2_{adj}) are reported.[12] A significant $6MWT_{total} \times \Delta 6MWT_{min6-min1}$ interaction was examined within ±1 standard deviation of the moderator variables.[13,14] In addition, to facilitate clinical interpretation of the findings of the regression analysis, independent *t* tests compared subgroups of "endurant" and "nonendurant" individuals dichotomized on the basis of a distance-induced decline in long-distance walking speed of 0.10 m/s. More specifically, individuals with a decline in walking speed from minute 1 to minute 6 of the 6MWT that was 0.10 m/s or more were considered "nonendurant." All other individuals were considered "endurant." A cutoff of 0.10 m/s was selected on the basis of the findings of a recent systematic review reporting a 28- to 42-m minimal detectable change (MDC) for the 6MWT in people in the chronic phase of stroke recovery—or a 0.08 to 0.12 m/s change in long-distance walking speed. The 0.10 m/s cutoff is the midpoint of the MDC range reported.[15]

Table. Regression Model of Real-World Walking Activity

Model Statistics	Model Predictors	Predictor Statistics *B*	*P*
$R^2 = 0.42$	$6MWT_{total}$	0.56	0.00
$R^2_{adj} = 0.39$	ABC score	0.14	0.38
$F_{2,34} = 12.49$			
$P = 0.00$			
$R^2 = 0.71$	$6MWT_{total}$	0.55	0.00
$R^2_{adj} = 0.67$	ABC score	0.16	0.19
$F_{4,32} = 19.52$	$\Delta 6MWT_{min6-min1}$	0.64	0.00
$P = 0.00$	$\Delta 6MWT_{min6-min1} \times 6MWT_{total}$	− 0.46	0.00

Abbreviations: ABC, Activities-specific Balance Confidence; 6MWT, 6-Minute Walk Test; $6MWT_{total}$, total 6MWT distance; $\Delta 6MWT_{min6-min1}$, difference between the distances walked during minute 6 and minute 1 of the 6MWT.

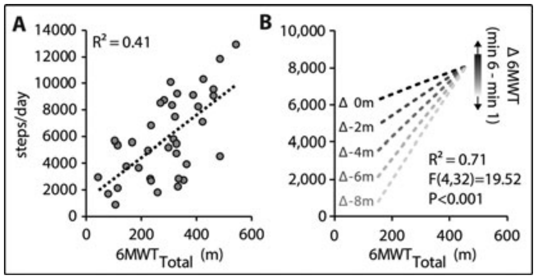

Figure 1. Relationships between (A) total 6MWT distance ($6MWT_{total}$) and community walking activity (steps/d) and (B) $6MWT_{total}$ and steps/d as moderated by distance-induced changes in speed, shown as the difference between the distances walked during minute 6 and minute 1 of the 6MWT ($\Delta 6MWT_{min6-min1}$). 6MWT, 6-Minute Walk Test.

RESULTS

Participants were 58.4 ± 1.6 years old, 2.9 ± 0.7 years poststroke, 35% right-side paretic, and 38% female. Their average lower-extremity Fugl-Meyer assessment score was 23.5 ± 0.9 and ABC score was 73 ± 3. They walked an average 5892 ± 513 steps/d, 292 ± 21 m during the 6MWT, and 3.5 ± 0.9 m less during minute 6 versus minute 1 of the 6MWT.

Both $6MWT_{total}$ ($R^2 = 0.41$, $P < 0.001$) and ABC score ($R^2 = 0.21$, $P = 0.004$) were each bivariately correlated with steps/d; however, in the final regression model, ABC score was not a significant independent predictor (Table). The addition of $\Delta 6MWT_{min6-min1}$ and the $6MWT_{total} \times \Delta 6MWT_{min6-min1}$ interaction explained an additional 29% of the variance in real-world community walking activity. The final model accounted for 71% of the variance ($R^2 = 0.71$, $F_{4,32} = 19.52$, $P < 0.001$).

In order of importance (based on an examination of βs, see the Table), $\Delta 6MWT_{min6-min1}$ and $6MWT_{total}$ were independent predictors. The interaction between these variables was also significant, indicating that the relationship between $6MWT_{total}$ and steps/d was moderated by $\Delta 6MWT_{min6-min1}$ (Figure 1). More specifically, as observed in Figure 1B, examination of the interaction revealed that lower $6MWT_{total}$ predicts fewer steps/d, with individuals whose distances decline during the test (ie, nonendurant individuals) presenting with the least steps/d. In contrast, individuals with minimal slowing during the 6MWT (ie, are more endurant) present with substantially more steps/d.

Figure 2A presents 6MWT and steps/d data for 2 individuals who exemplify the endurant and nonendurant subgroups.

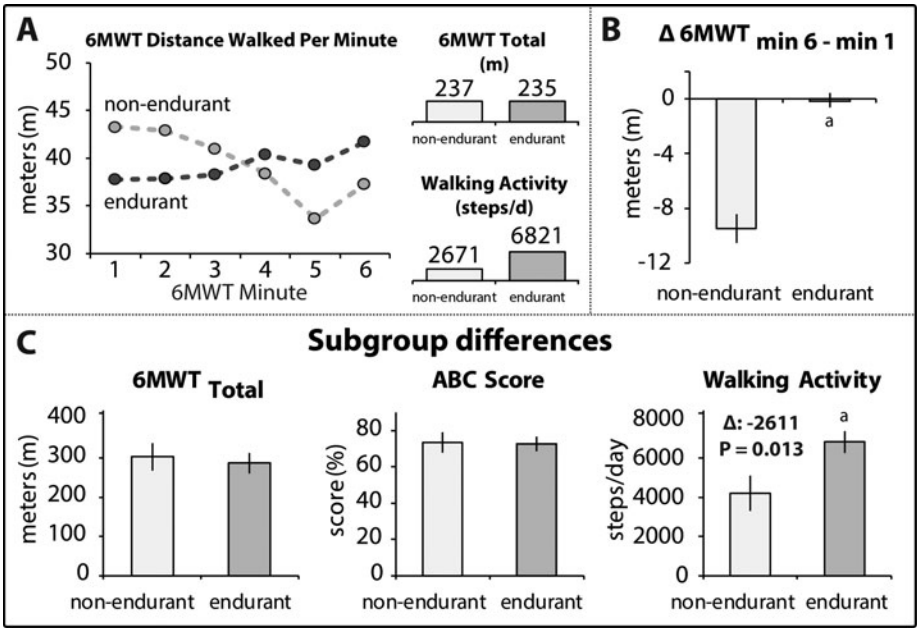

Figure 2. (A) Distance walked per minute, total 6MWT distance ($6MWT_{total}$), and community walking activity (steps/d) for 2 participants that exemplify the (B) nonendurant (ie, those with a reduction in speed $\geq$0.10 m/s) and endurant (ie, those with a reduction in speed <0.10 m/s) subgroups. (C) $6MWT_{total}$, self-efficacy (ABC score), steps/d for each subgroup. $^{a}P < 0.05$. ABC, Activities-specific Balance Confidence; 6MWT, 6-Minute Walk Test.

Pairwise comparisons of the endurant (N = 24) and nonendurant (N = 13) subgroups (Figure 2B) revealed substantial differences in steps/d ($P = 0.013$) but not $6MWT_{total}$ or ABC score (Ps > 0.05) (Figure 2C). The nonendurant subgroup walked 62% less steps/d than the endurant subgroup (4198 ± 909 vs 6810 ± 546 steps/d)—a difference that would lead to different functional classifications of "most limited community ambulator" for the nonendurant subgroup and "least limited community ambulator" for the endurant subgroup.[3]

DISCUSSION

The total distance walked during the 6MWT has been shown to be a strong predictor of real-world community walking activity after stroke.[2,3] This study builds on this prior work, motivating the coassessment of total 6MWT distance and distance-induced changes in walking speed to better explain the walking activity of community-dwelling individuals poststroke. Indeed, the model presented in this study explained 71% of variance in steps/d—a substantially higher percentage than other recent work examining other factors (eg, single- and dual-task gait speed, self-efficacy, and balance) that has ranged from 36% to 61% of variance explained.[2,9,10,16]

An assessment of distance-induced changes in walking speed provides insight into locomotor deficits underlying physical inactivity that are not reflected in the total distance walked. Indeed, poststroke heterogeneity is a likely reason for the importance that distance-induced changes in speed has in our model. That is, an individual with a fast initial speed that declines over the duration of the test (ie, fast but not endurant) and an individual with a slow initial speed that is maintained over time (ie, slow and endurant) may each present with comparable 6MWT distances despite having inherently different impairments in gait mechanics, walking efficiency, or cardiovascular capacity—the variables that ultimately serve as intervention targets.

Nonphysical factors may also explain distance-induced changes in walking speed during the 6MWT. Reduced motivation may lead to distance-induced slowing in a person who otherwise has the capacity to maintain his or her speed for the duration of the test. Likewise, a competitive person may be motivated to operate at a higher percentage of his or her physiological reserve over the duration of the test. In this vein, Danks et al[9] show that another nonphysical factor, balance self-efficacy, influences real-world walking activity. Among patients with high physical capacity, those with high self-efficacy presented with more real-world walking activity than those with low self-efficacy. Our finding that self-efficacy was not a significant predictor in our model is not necessarily suggestive of reduced importance in determining physical activity after stroke; rather, it may be the result of substantial overlap in the variance explained with the 6MWT (eg, Danks et al[9] did not include $6MWT_{total}$ in their model). Further study into the mediating roles that physical and nonphysical factors (eg, motivation and self-efficacy) play in the relationship between distance-induced changes in walking speed and real-world physical activity is highly warranted to elucidate mechanisms and identify specific treatment targets.

Limitations

The generalizability of this exploratory study is limited to higher-functioning community-dwelling individuals poststroke capable of completing a 6MWT without assistance.

Moreover, these findings may not extend to studies administering the 6MWT without the instruction to "cover as much distance as possible." In addition, we only investigated the effect of differences in walking speed from minute 1 to minute 6 of the 6MWT. Assessment of differences in speed between other minutes may provide additional information that can characterize people poststroke. Finally, participants' real-world ambulatory activity was computed from an average of 4 days of measurement. Additional days of measurement may have provided a more stable assessment; however, recent work has shown that 2 to 3 days of measurement may be sufficient in persons poststroke.[3,16]

CONCLUSIONS

This study demonstrates that assessment of distance-induced changes in speed during the 6MWT explains real-world ambulatory activity after stroke better than the total distance walked—a finding of importance, given the relationships between physical activity and health and quality of life. Given the relative ease by which assessment of distance-induced changes in walking speed during the 6MWT can be made, this study motivates consideration of this variable when the goal of intervention is to improve real-world walking activity.

ACKNOWLEDGMENTS

The authors thank Tamara Wright, PT, DPT, and Margie Roos, PT, DPT, PhD, for data collection.

REFERENCES

1. Combs SA, Van Puymbroeck M, Altenburger PA, Miller KK, Dierks TA, Schmid AA. Is walking faster or walking farther more important to persons with chronic stroke? *Disabil Rehabil*. 2013;35(10):860-867. doi:10.3109/09638288.2012.717575.
2. Fulk GD, Reynolds C, Mondal S, Deutsch JE. Predicting home and community walking activity in people with stroke. *Arch Phys Med Rehabil*. 2010;91(10):1582-1586. doi:10.1016/j.apmr.2010.07.005.
3. Fulk GD, He Y, Boyne P, Dunning K. Predicting home and community walking activity poststroke. *Stroke*. 2017;48(2):406-411. doi:10.1161/STROKEAHA.116.015309.
4. Leone C, Severijns D, Doležalová V, et al. Prevalence of walking-related motor fatigue in persons with multiple sclerosis: decline in walking distance induced by the 6-Minute Walk Test. *Neurorehabil Neural Repair*. 2016;30(4):373-383. doi:10.1177/1545968315597070.
5. Vreede KS, Henriksson J, Borg K, Henriksson M. Gait characteristics and influence of fatigue during the 6-Minute Walk Test in patients with post-polio syndrome. *J Rehabil Med*. 2013;45(9):924-928. doi:10.2340/16501977-1209.
6. Montes J, McDermott MP, Martens WB, et al. Six-Minute Walk Test demonstrates motor fatigue in spinal muscular atrophy. *Neurology*. 2010;74(10):833-838. doi:10.1212/WNL.0b013e3181d3e308.
7. Altenburger PA, Dierks TA, Miller KK, et al. Examination of sustained gait speed during extended walking in individuals with chronic stroke. *Arch Phys Med Rehabil*. 2013;94(12):2471-2477. doi:10.1016/j.apmr.2013.06.015.
8. Awad LN, Reisman DS, Wright TR, Roos MA, Binder-Macleod SA. Maximum walking speed is a key determinant of long distance walking function after stroke. *Top Stroke Rehabil*. 2014;21(6):502-509. doi:10.1310/tsr2106-502.
9. Danks KA, Pohlig RT, Roos M, Wright TR, Reisman DS. Relationship between walking capacity, biopsychosocial factors, self-efficacy, and walking activity in persons poststroke. *J Neurol Phys Ther*. 2016;40(4):232-238. doi:10.1097/NPT.0000000000000143.
10. French MA, Moore MF, Pohlig R, Reisman D. Self-efficacy mediates the relationship between balance/walking performance, activity, and participation after stroke. *Top Stroke Rehabil*. 2016;23(2):77-83. doi:10.1080/10749357.2015.1110306.
11. Dunn A, Marsden DL, Nugent E, et al. Protocol variations and Six-Minute Walk Test performance in stroke survivors: a systematic review with meta-analysis. *Stroke Res Treat*. 2015;2015:484813. doi:10.1155/2015/484813.
12. Yin P, Fan X. Estimating R^2 shrinkage in multiple regression: a comparison of different analytical methods. *J Exp Educ*. 2001;69(2):203-224. doi:10.1080/00220970109600656.
13. Awad LN, Palmer JA, Pohlig RT, Binder-Macleod SA, Reisman DS. Walking speed and step length asymmetry modify the energy cost of walking after stroke. *Neurorehabil Neural Repair*. 2015;29(5):416-423. doi:10.1177/1545968314552528.
14. Cohen J, Cohen P, West SG, Aiken LS. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. 3rd ed. Mahwah, NJ: Lawrence Erlbaum Associates Publishers; 2003.
15. Salbach NM, O'Brien KK, Brooks D, et al. Considerations for the selection of time-limited walk tests poststroke. *J Neurol Phys Ther*. 2017;41(1):3-17. doi:10.1097/NPT.0000000000000159.
16. Feld JA, Zukowski LA, Howard AG, et al. Relationship between dual-task gait speed and walking activity poststroke. *Stroke*. 2018;49(5):1296-1298. doi:10.1161/STROKEAHA.117.019694.

