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Validation of a Speed-Based Classification System Using Quantitative Measures of Walking Performance Post-Stroke

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Abstract

Background—Self-selected walking speed has been used to stratify persons post-stroke to predict functional walking status and changes in status have been used to define clinical meaningfulness in rehabilitation trials. However, this stratification was validated primarily using self-report questionnaires.

Objective—This study aims to validate the speed-based classification system with quantitative measures of walking performance.

Methods—Fifty-nine individuals with chronic post-stroke hemiparesis (greater than six months post-stroke) participated. Spatiotemporal and kinetic measures included: paretic propulsion (Pp); paretic step ratio (PSR); and the paretic pre-swing percentage (PPS). Additional measures included synergy (FM-S) portion of the Fugl-Meyer Assessment and the average number of steps/day in the home and community measured with a StepWatch Step Activity Monitor. Participants were stratified by self-selected gait speed into three groups (household ambulators: < 0.4 m/s; limited community ambulators: 0.4–0.8 m/s; and community ambulators: > 0.8 m/s). Group differences were analyzed using a Kruskal-Wallis H Test with Rank Sums Test post-hoc analyses.

Results—Analyses demonstrated a main effect in all measures, but only steps/day and PPS demonstrated a significant difference between all three groups.

Conclusions—Classifying individuals post-stroke by self-selected walking speed is associated with home and community-based walking behavior as quantified by daily step counts. In addition, PPS distinguishes all three groups. Pp differentiates the moderate from the fast groups and may represent a contribution to mechanisms of increasing walking speed. Speed classification presents a useful yet simple mechanism to stratify those with post-stroke and may be mechanically linked to changes in PPS.

INTRODUCTION

Stroke is the leading cause of disability in the United States,[1] often leading to decreases in walking function with less than 50% of stroke survivors progressing to independent community ambulation.[2] Characterizing recovery and predicting functional return has proven difficult in this functionally heterogeneous population. However, self-selected walking speed has proven

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to be an important measure of stroke recovery because it is simple to measure, reflects both functional and physiological changes,[2, 3] remains reliable and sensitive to change even as recovery advances,[3] and is a predictor of health status.[4] Self-selected walking speed has been associated with discrimination of potential for rehabilitation,[3] prediction of falls and fear of falling,[5] as well as functional health in the aging population.[4]

In 1995, Perry established that walking speed was a valid predictor of community walking status: < 0.4 m/s predicts household walking; 0.4–0.8m/s predicts limited community walking; and > 0.8m/s predicts unlimited community walking.[2] Walking speed has subsequently become a method to stratify those with neurologic injury and an outcome measure in clinical trials.[6] Furthermore, progression from one speed-based category to another is associated with gains in self-reported measures of function and quality of life[7], and thus are clinically meaningful. However, use of gait speed to predict function and to define clinical meaningfulness has been limited to validation with questionnaires and clinical examinations[2, 7] and has not been validated with a quantitative measure of walking performance.

The purpose of this study was to validate speed-based classification of post-stroke function by examining a quantitative measure of amount of walking in the home and community. Furthermore, a secondary purpose was to concurrently examine specific measures related to post-stroke walking performance in order to explore the underlying mechanisms contributing to the speed-based classification system.

MATERIALS AND METHODS

Fifty-nine individuals with chronic (greater than six-months post-stroke) hemiparesis participated in one of two cross-sectional studies at the Palo Alto, CA (n=50) and Gainesville, FL (n=9) Department of Veterans Affairs (VA) Medical Centers. Participants had a history of a single unilateral stroke, were ambulatory without contact assistance, were able to follow a multiple step command, and did not have other medical issues interfering with their ability to walk. All participants signed written informed consent approved by either the Stanford University Administrative Panel on Human Subjects in Medical Research or the University of Florida Institutional Review Board/Gainesville VA Subcommittee for Clinical Investigation. The Palo Alto data were collected as part of a larger study that investigated the links between gait characteristics and bone density in chronic stroke survivors.[8]

Measures

Self-selected walking speed was measured while each participant walked on a 4.3 meter long GAITRite portable walkway system (CIR Systems, Inc). For the Palo Alto participants, bilateral ground reaction forces (GRF) were measured as each participant walked at their self-selected speed along a 10-meter walkway equipped with embedded force platforms (Advanced Medical Technology, Inc and Bertec). For the Gainesville, FL participants, GRF were measured while walking on a split-belt force plate instrumented treadmill (Techmachine, Inc).[9] Analysis of the GRF data have been described previously.[10]

A set of clinical and biomechanical walking performance variables were collected for all participants. These variables were selected to reflect the spectrum of walking abilities across the rehabilitation model as defined by the International Classification of Functioning, Disability, and Health (ICF).[11] Specifically, walking speed represents an activity-level measurement that predicts categorical performance level outcomes. To measure quantitative participation-level measures, each participant wore a Stepwatch Activity Monitor, (OrthoCare Innovations), which is established as a valid and reliable step counter for the stroke population.[12] Each individual wore the SAM during waking hours for at least five consecutive days in order to calculate the average number of steps/day in the home and community. Additionally, impairment-level measures were collected to investigate the mechanistic contributions to a speed-based functional classification. These measures include: 1) the synergy portion of the lower extremity Fugl Meyer Assessment (FM-S) that is dedicated to analysis of abnormal movement synergy patterns (excluding reflex and coordination/speed parameters);[13] 2) paretic propulsion (Pp)[10], defined as the percentage of total propulsion generated by the paretic leg; 3) paretic step ratio (PSR),[14] defined as the percentage of the stride length accounted for by the paretic step length; and 4) percentage of the gait cycle spent in paretic pre-swing (PPS).[15] Pp and PSR both have a normal value of 0.5, indicating that the paretic leg's step length and propulsion generated are symmetrical with the non-paretic leg. To account for deviations from normal <0.5 and >0.5, the absolute value of the deviation from 0.5 was used for data analysis.

DATA ANALYSIS—Participants were stratified into three functional groups by self-selected gait speed per the Perry classifications: the household ambulators walked < 0.4 m/s (n=13, mean=0.29 m/s); the limited community ambulators walked from 0.4 to 0.8 m/s (n=23, mean=0.65 m/s); and the community ambulators group walked faster than 0.8 m/s (n=23, mean=1.08 m/s). Group analysis was completed using a non-parametric Kruskal-Wallis H Test with Rank Sums Tests post-hoc analyses. Alpha for both main effects and post-hoc analyses was set at p=0.05. All statistics were run using SPSS version 14.0 (SPSS, Inc.). Correlations between self-selected walking speed and both steps/day and PPS were analyzed using a Pearson's correlation coefficient.

RESULTS

The sample consisted of 59 individuals (48 male; ages = 61.9 ± 10.8 (SD) years; time since stroke (yrs) = 4.05 ± 3.72; affected side: left = 29). The average self-selected walking speed was 0.74 m/s ± 0.33 and the average Fugl-Meyer score was 25.59 ± 5.69.

Group Analysis

All measures demonstrated consistent progression towards normal values as speed increased from the slow to moderate to fast groups (Table 1). There was a significant main effect for all measures (Table 1).

Post-Hoc Analysis

The household ambulators were significantly different from the limited community ambulators in both steps/day and PPS. Steps/day, PPS, and Pp distinguished between limited and unlimited community ambulators. Thus, only the steps/day and PPS measures were significantly different between all three groups (Table 1). Self-selected walking speed was significantly correlated with steps/day ($r = 0.687$, $p<0.001$) and PPS ($r = -0.674$, $p<0.001$).

DISCUSSION

Stratifying individuals post-stroke based on self-selected walking speed is associated with home and community walking behavior as measured by steps/day. Perry previously provided evidence that walking speed predicts community walking ability,[2] but the current study examines this association using quantitative measures of self-selected walking behavior. Previous research demonstrates that in the stroke population, daily step counts are more sensitive to changes than traditional walking outcome measures such as endurance and the Functional Independence Measure.[16]

Additionally, PPS differentiated all three of the speed-based groups, confirming previous research demonstrating that PPS was prolonged in those with slower gait speed.[15] However, this previous work was limited to small sample sizes in the limited community ambulation group (n=5) and community ambulation group (n=1). [15]

While this study incorporates data collected in two different laboratories, spatiotemporal and steps/day measures were collected with the same instrumentation (GAITRite and SAM), both of which are valid when compared to gold standards.[12, 17] GRF data collection differed slightly, with the CA setting having a traditional laboratory with force plates embedded in the floor while the FL setting houses the force plates under moving treadmill belts. Thus, a potential limitation of this study is the calculation of paretic propulsion from treadmill walking (all other measures were performed overground) in a subset of patients (n=9), as some investigators have argued that TM walking differs from overground walking.[18] However, a recent analysis of the kinematic and kinetic differences between treadmill and overground environments demonstrated that all differences, even if statistically significant, were within the variability witnessed in normal gait variability.[19] Therefore, we felt justified collapsing the data from both laboratories into one data set for the examination of the paretic propulsion.

Walking speed is a complex behavior, and multiple variables may contribute to speed-based classification levels. In this analysis, the only mechanical variable that differentiated all three speed-based groups was PPS, but Pp also distinguished the limited community from the community ambulators. Further investigation needs to be completed to further examine the relationship between mechanical variables and walking speed to determine the most efficient manner in which clinicians can facilitate meaningful changes in walking speed.

Our study supports the utilization of a walking speed based classification by validating with a quantitative measure (steps/day) of home and community walking performance. Classification of walking performance based on walking speed has recently been employed as the primary outcome measure in a randomized clinical trial for post-stroke locomotor rehabilitation in an effort to equate increases in walking speed with a clinically meaningful finding. Specifically, an increase from one functional category to another (e.g. less than 0.8 m/s to greater than 0.8) is defined as a clinically meaningful transition to more fully independent ambulation based on Perry's earlier work.[2] Moreover, walking speed is quick and easy to measure and demonstrates excellent inter- and intra-rater reliability.[20] In conclusion, speed classification presents a useful yet simple mechanism to stratify those with post-stroke and may be mechanically linked to changes in PPS.

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Table 1

Group Averages, Standard Deviations, and Post Hoc Analyses for Dependent Variables. **Bold** denotes significant main effect.

Group	Steps/day	FM Synergy	Paretic Propulsion	PSR	PPS%
Household (Group 1)	1411 ± 803	13.6 ± 4.7	32.8% ± 14.7	10.3% ± 10.4	31.5% ± 14.7
Limited Community (Group 2)	2668 ± 1193.3	16.9 ± 3.8	23.0% ± 15.1	5.3% ± 5.1%	16.8%± 3.5
Community (Group 3)	3659 ± 1447.4	18.9 ± 3.3	13.3% ± 11.0	2.4% ± 2.0	13.9%± 2.3
Kruskal-Wallis H Test	**p<0.001**	**P=0.002**	**p=0.003**	**p=0.05**	**p<0.001**
Post Hoc: 1 and 2	**p=0.004**	p=0.081	p=0.112	p=0.202	**p<0.001**
Post Hoc: 2 and 3	**p=0.027**	p=0.057	**p=0.024**	p=0.106	**p=0.003**

FM: Fugl-Meyer

Paretic Propulsion: (expressed as deviation from 50%)

PSR: Paretic Step Ratio (expressed as deviation from 50%)

PPS: Paretic Pre-Swing (expressed as percentage of the gait cycle)