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ORIGINAL ARTICLE

Locomotor Rehabilitation of Individuals With Chronic Stroke: Difference Between Responders and Nonresponders

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Abstract

Objectives: To identify the clinical measures associated with improved walking speed after locomotor rehabilitation in individuals poststroke and how those who respond with clinically meaningful changes in walking speed differ from those with smaller speed increases.

Design: A single group pre-post intervention study. Participants were stratified on the basis of a walking speed change of greater than (responders) or less than (nonresponders) .16m/s. Paired sample *t* tests were run to assess changes in each group, and correlations were run between the change in each variable and change in walking speed.

Setting: Outpatient interdisciplinary rehabilitation research center.

Participants: Hemiparetic subjects (N=27) (17 left hemiparesis; 19 men; age: 58.74±12.97y; 22.70±16.38mo poststroke).

Intervention: A 12-week locomotor intervention incorporating training on a treadmill with body weight support and manual trainers accompanied by training overground walking.

Main Outcome Measures: Measures of motor control, balance, functional walking ability, and endurance were collected at pre- and postintervention assessments.

Results: Eighteen responders and 9 nonresponders differed by age (responders=63.6y, nonresponders=49.0y, $P=.001$) and the lower extremity Fugl-Meyer Assessment score (responders=24.7, nonresponders=19.9, $P=.003$). Responders demonstrated an average improvement of .27m/s in walking speed as well as significant gains in all variables except daily step activity and paretic step ratio. Conversely, nonresponders demonstrated statistically significant improvements only in walking speed and endurance. However, the walking speed increase of .10m/s was not clinically meaningful. Change in walking speed was negatively correlated with changes in motor control in the nonresponder group, implying that walking speed gains may have been accomplished via compensatory mechanisms.

Conclusions: This study is a step toward discerning the underlying factors contributing to improved walking performance.

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Cerebrovascular accident is the leading cause of long-term disability in the United States.[1] Approximately 795,000 cerebrovascular accidents occur each year in the United States, with 6.5 million current noninstitutionalized stroke survivors,[1] and this number is growing with increased survivorship due to improved interventions.[2] Only approximately 50% of the survivors regain independent ambulatory ability by the end of rehabilitation,[3] and 73% have some degree of long-term disability.[4] Returning to prior level of function, most importantly independent ambulation, is the top priority for individuals in the first year poststroke.[5] This desire from patients, as well as the fact that locomotor ability is an important factor in determining the level of disability,[6] has led to an increased focus on interventions to improve walking performance.

Many different types of locomotor rehabilitation for individuals poststroke have been examined recently: exercise therapy,[7] lower extremity strength training,[8,9] functional electrical stimulation,[10] treadmill walking,[11,12] and locomotor training with

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treadmill and body weight support (BWS).[13,14] A recent critical review,[15] however, demonstrated that the outcomes were very similar to each other with regard to increasing posttraining walking speed. Given that different rehabilitation approaches are targeted at different deficits prominent in the poststroke population, one might assume that different mechanisms of response for increasing gait speed are associated with each. However, while it appears that these interventions are fundamentally different, the results on improving walking speed are strikingly similar. To date, very little information is available describing those who respond well to a given intervention (eg, achieve a clinically meaningful change in walking speed) versus those who respond less well. The large majority of rehabilitation interventions measure only functional behavioral outcome measures, and it is impossible to discern the underlying factors contributing to performance or develop adequate models for determining who should receive what kind of therapy or combination of therapies.

Measurement of locomotor rehabilitation outcomes requires a broad-based evaluation examining the multiple contributors to functional recovery, particularly if the goal is to distinguish the targeted aspects of rehabilitation that are associated with statistically and clinically significant responses to interventions. This evaluation should not only include functional measures such as timed movement tasks, endurance, and balance testing but also measures that allow for an understanding of underlying coordination and walking-specific motor control. The concept of task-specific motor control is still emerging,[16] but many recognize the need to provide quantitative evidence to document baseline levels and alterations in motor control.[17] Measures of walking-specific motor control include paretic propulsion (PP, defined as the percentage of the total propulsion that is generated by the paretic leg)[18] and the paretic step ratio (PSR, defined as the percentage of the stride length accounted for by the paretic step length)[19] and have been used to document motor control responses to locomotor interventions.[20-22] We contend that in addition to functional measures, motor control measures will assist in elucidating the factors underlying patterns of response to a locomotor rehabilitation intervention.

Locomotor training (LT) is a rehabilitation intervention that includes stepping on a treadmill with BWS and therapist assistance as needed to generate appropriate stepping patterns. LT has generated much discussion and investigation in the past decade, including the recently completed Locomotor Experience Applied Post-stroke (LEAPS) randomized controlled trial.[23,24] In spite of these research efforts, little is understood regarding the difference between those individuals demonstrating clinically important improvements in walking speed and those who achieved minimal gains with LT. The purpose of this study was to demonstrate how those who respond with at least a minimally clinically important improvement in walking speed differ from those who do not. We hypothesized that individuals achieving clinically important changes in walking speed (ie, responders) would demonstrate significant increases in clinical gait, balance, and motor control and that changes in self-selected walking speed (SSWS) would be correlated with changes in these outcome measures. Furthermore, we hypothesize that responders will demonstrate significant improvements in measures of walking-specific motor control (PP and PSR), while those achieving minimal gains in walking speed (nonresponders) will do so without significant gains in motor control measures.

List of abbreviations:

ABC	**Activities-specific Balance Confidence Scale**
BBS	**Berg Balance Scale**
BWS	**body weight support**
DGI	**Dynamic Gait Index**
DSA	**daily step activity**
FCWS	**fastest comfortable walking speed**
FMA	**Fugl-Meyer Assessment**
FMA-S	**Fugl-Meyer Assessment−Synergy**
LEAPS	**Locomotor Experience Applied Post-stroke**
LT	**locomotor training**
MCID	**minimal clinically important difference**
MDC	**minimal detectable change**
PP	**paretic propulsion**
PSR	**paretic step ratio**
SSWS	**self-selected walking speed**
6MWT	**6-minute walk test**

Methods

Subjects

Twenty-seven individuals with hemiparesis (17 left hemiparesis; 19 men; age: 58.74±12.97y; 22.70±16.38mo poststroke) participated in a 12-week LT intervention. Inclusion criteria were stroke within the past 6 months to 5 years, residual hemiparesis in the lower extremity (Fugl-Meyer Assessment [FMA] lower extremity motor score of <34), ability to sit unsupported for 30 seconds, ability to walk at least 10 meters with maximum 1 person assist, self-selected 10-meter gait speed of <0.8m/s, and the ability to follow a 3-step command. All subjects passed an exercise tolerance test[25] to determine exercise safety prior to participation and provided written informed consent approved by the institutional review boards of the University of Florida and the Malcom Randall VA Medical Center.

Training intervention

Subjects participated in an LT program incorporating walking on a treadmill with BWS and manual trainers accompanied by training overground. The training program was developed concurrently with the recently completed LEAPS clinical trial, and it utilized a nearly identical protocol and clinical outcome measures.[23] The training of lab personnel and trainers was overseen by a LEAPS co-principal investigator (A.B.). The training sessions occurred 3 times a week for 12 weeks, mirroring the LEAPS protocol.[23] During each session, subjects participated in a total of 20 minutes of stepping on a treadmill with partial BWS.[26-28] Training began with a maximum of 40% BWS and progressed as tolerated to minimal BWS, while maintaining at least 5% BWS at all times. Step and postural training on the treadmill took place as close as possible to overground walking speeds that are normal for healthy age-matched controls (eg, 0.8−1.2m/s), with manual assistance provided by physical therapists at the hip and/or lower legs to approximate desired trunk, pelvis, and lower extremity kinematics and the spatiotemporal pattern of walking.[27]

Treadmill-based training was followed by 10 to 20 minutes of walking over ground to progress translation of newly trained skills to community environments. Overground walking trained dynamic balance and independence in walking, focusing on endurance, traversing various terrains, and negotiating obstacles.[23]

Data collection

All outcome measures were collected at both pretraining and posttraining assessments. Assessments were completed within 1 week of training initiation and completion.

Motor control

We utilized the lower extremity portion of the FMA (maximum score of 34)[29] as well as the subsection that examines the ability to perform voluntary isolated movement independent from mass patterns of whole-limb coactivation (Fugl-Meyer Assessment−Synergy [FMA-S], maximum score of 22) and excludes the reflex and coordination/speed parameters.[30] In addition, we measured PP,[18] the percentage of the anterior ground reaction force that is achieved by the paretic leg, and the PSR,[19] the percentage of the stride length accounted for by the paretic step to assess walking-specific motor control. PP was collected on an instrumented treadmill (Tecmachine),[a] and PSR was collected over ground on a sensored walkway (GAITRite).[b] For PP and PSR, the statistical analyses were based on the deviation from normal (.50).[16] Testing speeds were self-selected on both the treadmill and overground. Participants were allowed to use assistive devices during overground testing, but assistive devices were eliminated during treadmill testing and participants were secured to an overhead support providing no BWS. When possible, lower extremity bracing that immobilized the ankle was replaced by a stirrup support (AirCast)[c] to prevent inversion or eversion injuries.

Balance

The Berg Balance Scale (BBS)[31] and the Dynamic Gait Index (DGI)[32] were used to measure both general and task-specific balance, respectively. In addition, the Activities-specific Balance Confidence Scale (ABC)[33] was utilized to measure participant-perceived fear of falling.

Functional walking ability

We measured SSWS and fastest comfortable walking speed (FCWS) on a GAITRite[d] 5-meter sensored walkway.[34] SSWS and FCWS were determined each week of the intervention, and the average of 2 trials for each condition was used for data analysis. In addition, we captured daily step activity (DSA) over a 4-day period using the StepWatch Step Activity Monitor.[35,e]

Endurance

We utilized the distance covered in the six-minute walk test (6MWT)[36] as a measure of walking endurance.

Data analysis

Data were analyzed as a whole group as well as in groups on the basis of their response to the intervention as defined by the change in SSWS. Participants were stratified as a responder or nonresponder on the basis of change of $\geq$.16m/s in SSWS. The value of .16m/s has been determined as a minimal clinically important difference (MCID), as defined by a change in SSWS that is anchored to a decrease in disability (as measured on the modified Rankin Scale).[37] For the continuous variables (PP, PSR, SSWS, FCWS, DSA, and 6MWT), we utilized a 2-tailed independent samples *t* test to test for differences between the responder and nonresponder groups at baseline and a paired samples *t* test to test for differences in pretraining versus posttraining values for each group. PP and PSR were calculated on the basis of absolute value of the deviation from the symmetrical value of 0.5. For discrete variables (FMA, FMA-S, BBS, DGI, and ABC), the Mann-Whitney *U* test was used to compare the responders to the nonresponders at baseline, and the Wilcoxon signed rank test was used to compare pretraining to posttraining values. Correlations between changes in SSWS and other continuous variables were assessed using Pearson's correlational coefficient, while the correlations between changes in SSWS and discrete variables were assessed using Spearman's correlational coefficient. Significance for all tests was set at $P<.05$.

Results

There were 18 responders and 9 nonresponders. The responders included 14 men and 4 women, 11 with left hemiparesis, with a mean age of 63.61±12.24 years and mean chronicity of 22.88±17.02 months. The nonresponders included 5 men and 4 women, 6 with left hemiparesis, with a mean age of 49.0±8.28 years and mean chronicity of 22.33±16.0 months. Significant differences between the groups at baseline were age ($P=.001$), FMA score (responder = 24.67±3.66, nonresponder = 19.89±2.67, $P=.003$), and FMA-S score (responder = 16.50±2.94, nonresponder = 12.89±2.80, $P=.008$).

For the entire sample (N = 27), SSWS increased by .21m/s, which is both statistically significant and clinically meaningful. SSWS, FCWS, BBS, ABC, and the 6MWT values all improved significantly (table 1). Change in SSWS was significantly correlated with changes in FCWS ($r=.674$, $P<.001$) and PP change ($r=.467$, $P=.014$) but not with other collected measures.

The responders demonstrated an average improvement of .27m/s in SSWS as well as a significant improvement in all variables except for PSR ($P=.070$) and DSA ($P=.156$) (table 2). While there was a statistically significant increase in all 3 clinical balance measures, only 3 participants (of 17 responders with a baseline score below 19) crossed the threshold in the DGI score of 19 that is predictive of reduced falls risk in vestibular patients.[38] Only 5 of 17 responders (data were missing for 1 subject) completing the 6MWT exceeded 54.1-meter change, the minimal detectable change (MDC) established in those with stroke.[34] Similarly, only 7 of 18 responders improved on the ABC more than 13.8%, the established MDC value in those with stroke.[39] MDC and MCID values are not available for PSR, PP, FMA, FMA-S, and DSA. Changes in SSWS were correlated significantly only with changes in FCWS ($r=.533$, $P=.023$).

While the nonresponder group is defined as those not achieving MCIDs in walking speed (fig 1), as a group they did demonstrate a statistically significant improvement in SSWS ($P<.001$) as well as significant improvements in the 6MWT ($P=.005$) (table 3). Change in SSWS for the nonresponder group was negatively correlated with the change in PP (Pearson's $r=-.684$, $P=.042$) (fig 2) and with the change in FMA score (Spearman $r=-.692$, $P=.039$). Only 1 individual in the nonresponder group improved more than the MDC for the ABC, 1 improved more than the MDC for the 6MWT, and all the nonresponders had posttest scores on the DGI of <19 at discharge.

Discussion

As a group, subjects with chronic stroke undergoing 36 sessions of locomotor rehabilitation demonstrated statistically significant improvements in SSWS while also demonstrating significant

Table 1 Effects of LT on group as a whole

Variable	Mean ± SD			*P*	Correlations Between Δvariable and ΔSSWS
	Pre	Post	Change		
SSWS	0.48±0.19	0.69±0.25	0.21±0.13	<.001*	NA
FCWS	0.72±0.30	0.90±0.35	0.18±0.15	<.001*	r=.674 (P<.001)*
PSR	0.09±0.09	0.07±0.12	−0.02±0.13	.558	r=−.238 (P=.231)
PP	0.22±0.15	0.21±0.15	−0.01±0.14	.669	r=−.467 (P=.014)*
BBS	46.4±5.9	48.6±6.6	2.2±3.4	.003*	r=.157 (P=.434)
DGI	13.2±3.3	14.8±3.8	1.7±5.0	.068	r=−.022 (P=.919)
ABC	69.4±15.0	74.8±16.6	5.4±14.4	.046*	r=.151 (P=.461)
FMA	23.1±4.0	23.9±4.3	0.9±2.5	.097	r=.351 (P=.072)
FMA-S	15.3±3.3	16.0±3.4	0.7±1.7	.062	r=.283 (P=.152)
DSA	2474.1±1617.2	2369.9±1229.8	−104.3±940.4	.608	r=−.272 (P=.221)
6MWT	619.5±290.8	773.8±288.09	154.3±171.1	<.001*	r=.336 (P=.086)

Abbreviation: NA, not applicable.
* Findings were significant at P<.05.

improvements in FCWS, BBS, ABC, and 6MWT values. The change of .21m/s in SSWS was clinically meaningful, while other group changes did not exceed MCID values (when MCIDs are available). Furthermore, the overall change in SSWS in patients with chronic stroke is comparable to the recently published LEAPS results in patients with subacute stroke (.23−.25m/s)[24] as well as previously conducted randomized trials (.16m/s[28] and .18m/s[40]). Changes in SSWS, however, correlated only with changes in FCWS and the nonsignificant improvements in PP. When the groups were stratified, all measures except PSR and DSA increased significantly in the responder group. Those with less than a .16m/s-change in walking speed increased SSWS significantly, but the only other measure that increased significantly was the 6MWT. Changes in SSWS were correlated with changes in PP and the nonsignificant changes in the FMA. Thus, changes found across the entire sample in the BBS and ABC appear to reflect changes in the responder group. Furthermore, specific to the nonresponder group, PP (one of our measures of locomotor-specific motor control) demonstrated a nonsignificant increase in the deviation from symmetry as a result of the intervention despite significant increases in SSWS. This nonsignificant change in PP was of greater absolute magnitude than the significant improvement in PP seen in the responder group.

Based on these data, there is no one specific variable that accounts for the improvement in walking speed in the responder group. Increases could be attributed to increases in motor control (PP, FMA), dynamic balance (BBT, DGI, ABC), or cardiovascular capacity and endurance (6MWT). Interestingly, DSA decreased nonsignificantly by 309 steps/d in the responder group, while the nonresponders had a nonsignificant increase of 442 steps/d. Also of note is that PSR did not change significantly in the responder group (P=.07), but the failure to demonstrate significant change is likely due to the high degree of symmetry seen at baseline in this sample.

Identifying responders to an intervention may be critical for informing clinical decision making to choose a potential intervention or inform of potential adjuvant or combination therapies. The relatively smaller gain in SSWS in the nonresponder group may indicate that interventions such as LT are insufficient in some individuals. Additional outcome measures focusing on the spatiotemporal, kinematic, and kinetic factors contributing to increased walking speed could potentially elucidate underlying biomechanical predictors of the changes in walking speed, and future analyses should further investigate other possible underpinnings of improved walking function. Previous work by Mulroy et al[41]

Table 2 Outcomes for responders (subjects meeting or exceeding 16m/s change in SSWS postintervention)

Variable	Mean ± SD			*P*	Correlations Between Δvariable and ΔSSWS
	Pre	Post	Change		
SSWS	0.52±0.18	0.79±0.21	0.27±0.12	<.001*	NA
FCWS	0.80±0.28	1.04±0.30	0.24±0.12	<.001*	r=.533 (P=.023)*
PSR	0.09±0.11	0.04±0.04	−0.05±0.10	.070	r=.123 (P=.626)
PP	0.24±0.14	0.18±0.15	−0.06±0.08	.011*	r=−.161 (P=.523)
BBS	47.4±4.7	49.8±5.5	2.4±3.7	.017*	r=.396 (P=.104)
DGI	13.7±3.6	15.9±3.3	2.2±4.0	.046*	r=−.176 (P=.499)
ABC	68.1±14.6	76.2±15.2	8.2±14.2	.041*	r=.017 (P=.948)
FMA	24.7±3.7	26.1±3.2	1.4±2.6	.034*	r=.344 (P=.162)
FMA-S	16.5±2.9	17.5±2.4	1.0±1.7	.023*	r=.134 (P=.597)
DSA	2739.1±1749.7	2429.7±1235.6	−309.4±829.0	.156	r=−.096 (P=.725)
6MWT	677.2±303.4	873.2±248.1	196.0±199.6	.001*	r=.201 (P=.423)

Abbreviation: NA, not applicable.
* Findings were significant at P<.05.

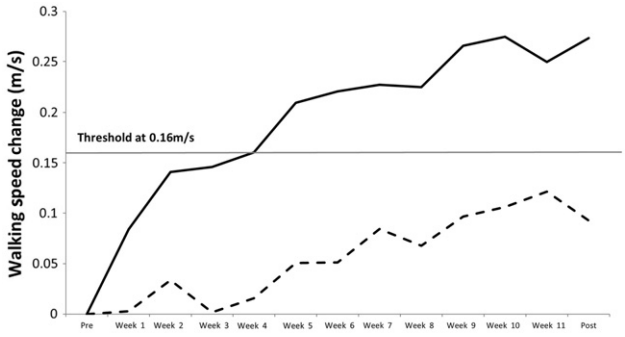

Fig 1 Differential SSWS changes in responders and nonresponders. Responders increased SSWS by an average of .27m/s while nonresponders increased SSWS by an average of .10m/s.

examined the gait parameters associated with gains in SSWS as a result of a task-specific training program finding that the "high-response group" demonstrated improved hip extension, hip flexion power, and intensity of soleus activity. While these results are promising, the high- and low-response groups were based on a change in SSWS needed to dichotomize the groups, resulting in a walking speed threshold of .08m/s, well below a value determined to be clinically meaningful.

The recently completed LEAPS trial in subacute stroke is the largest clinical trial to examine interventions for locomotor rehabilitation.[24] However, the outcome data collected during the LEAPS trial do not allow for examination of the mechanisms by which individuals responded, and only limited information can be gleaned regarding differences between groups that gained similar improvements in SSWS. In addition, from the LEAPS trial data, the outcome measures did not reveal how neuroplastic mechanisms or other mechanistic factors may have contributed to the treatment response. Therefore, it is unclear whether the outcomes were associated with recovery of premorbid behaviors or acquisition of compensatory behaviors. Within this context, we define recovery as successful task accomplishment using premorbid effectors, while compensation allows for functional success with altered effector usage when compared with premorbid or healthy control patterns.[42] The present study, which utilized exactly the same protocol and intervention as LEAPS, is capable of examining alterations in some measures of motor control and demonstrates that while some patients achieve significant changes in SSWS and improved motor control (eg, PP), others achieve significant gains in SSWS without these improvements, implying that the use of compensatory strategies may be involved in achieving these gains. Future analyses of spatiotemporal, kinematic, and kinetic variables may provide additional understanding of the mechanisms of response (and nonresponse).

While walking speed has been identified as the sixth vital sign,[43] we have yet to determine the appropriate diagnostic test of neuromotor deficits that cause reductions in speed.[44] Detailed analyses will assist clinicians and researchers to individualize treatment and progress beyond the application of singular approaches to walking rehabilitation, which largely ignore patient-specific needs of those undergoing locomotor rehabilitation after stroke.[45] This sample reflects individuals with initial SSWS varying from .18m/s to .79m/s, demonstrating widely different responses to the intervention (see fig 2), and the response to the intervention (change in SSWS) was not associated with the baseline walking speed ($r=.161$, $P=.423$). Therefore, establishing a multidimensional framework on the basis of detailed and specific measurement will assist in identifying the most critical limiting factor(s) for locomotor recovery and select from a variety of available interventions.[45,46]

Study limitations

The results of this study are limited by the sample size, which precludes the ability to perform regression analyses with sufficient variables to adequately predict the increase in walking speed as the result of the intervention. Furthermore, we conducted multiple tests of group comparisons and correlations between changes in variables, but we did not adjust our alpha level for multiple comparisons because we expect these interrelated variables to change systematically. However, all P values are provided for both group comparisons and correlational analyses, allowing the strength of the evidence to be assessed. If adjustment for multiple comparisons had been performed, the alpha level would have decreased to .005, and the significant findings in the responder group would have been limited to SSWS, FCWS, and the 6MWT. In the nonresponder group, only SSWS and the 6MWT would have demonstrated significant changes. Future work should

Table 3 Outcomes for nonresponders (subjects who did not achieve ≥.16 change in SSWS postintervention)

Variable	Mean ± SD			P	Correlations Between Δvariable and ΔSSWS
	Pre	Post	Change		
SSWS	0.40±0.21	0.50±0.22	0.10±0.05	<.001*	NA
FCWS	0.59±0.32	0.63±0.29	0.04±0.10	.282	$r=.138$ ($P=.723$)
PSR	0.08±0.05	0.13±0.18	0.05±0.17	.414	$r=-.514$ ($P=.157$)
PP	0.18±0.16	0.26±0.14	0.08±0.18	.223	$r=-.684$ ($P=.042$)*
BBS	44.2±7.6	46.1±8.1	1.9±2.9	.075	$r=-.261$ ($P=.498$)
DGI	12.0±2.3	12.3±3.9	0.3±6.5	.686	$r=-.324$ ($P=.478$)
ABC	72.2±16.3	71.6±2.2	−0.6±14.7	.575	$r=-.120$ ($P=.778$)
FMA	19.9±2.7	19.7±3.0	−0.2±1.9	.669	$r=-.692$ ($P=.039$)*
FMA-S	12.9±2.8	12.9±3.0	0.0±1.7	.943	$r=.226$ ($P=.558$)
DSA	1767.4±987.9	2210.2±1315.4	442.7±1076.7	.360	$r=.041$ ($P=.938$)
6MWT	510.7±244.6	604.7±288.0	94.0±74.4	.005*	$r=.416$ ($P=.266$)

Abbreviation: NA, not applicable.
* Findings were significant at $P<.05$.

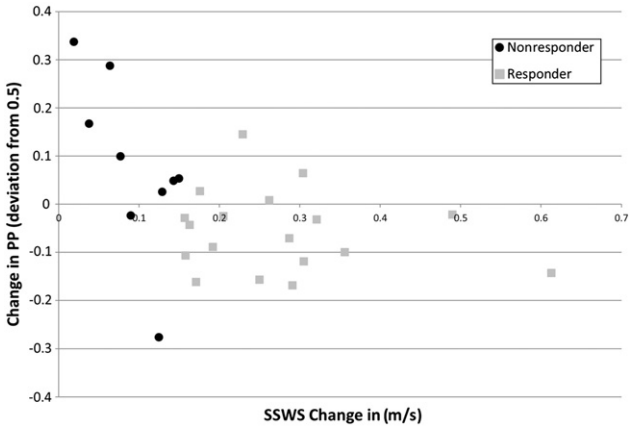

Fig 2 SSWS and PP change in responders and nonresponders. While there is no significant relation between change in PP and SSWS in the responder group, there is a significant negative relation in the nonresponder group ($r=-.684$, $P=.042$). This relation demonstrates the importance of PP; while overall PP was reduced in nonresponders, improved PP (reduction in the deviation from .50) is associated with walking speed changes.

focus on the neuromechanical determinants of walking, such as biomechanical analyses of kinematics, kinetics, and electromyographical data.

Conclusions

To the best of our knowledge, this investigation is the first to address locomotor outcomes within the context of those who achieve clinically meaningful changes in walking speed. While the results do not address predictors of change in walking speed, we observe that responders demonstrate significant and clinically meaningful changes in a variety of clinical outcome measures, motor control, clinical balance measures, balance confidence, and walking endurance. Nonresponders, however, only increased SSWS and endurance. Interestingly, DSA decreased in the responder group and increased in the nonresponder group, although neither approached statistical significance. Factors contributing to home and community DSA are poorly understood, and additional work is necessary to understand how to maximize DSA through rehabilitation interventions. Because the current data do not predict a priori responders versus nonresponders, future work is also needed to identify those ideally suited for interventions and who might benefit from specific collaborative therapies.

Suppliers

a. TECMACHINE filiale HEF Groupe, Rue Benoit Fourneyron, 42166 Andrezieux Boutheon, France.
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References

1. Centers for Disease Control and Prevention. FastStats − cebrovascular disease or stroke. Available at: http://www.cdc.gov/nchs/fastats/stroke.htm. Accessed December 14, 2010.
2. Goldstein LB, Bushnell CD, Adams RJ, et al. Guidelines for the primary prevention of stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke 2011;42:517-84.
3. Jorgensen HS, Nakayama H, Raaschou HO, Olsen TS. Recovery of walking function in stroke patients: the Copenhagen Stroke Study. Arch Phys Med Rehabil 1995;76:27-32.
4. Gresham G, Duncan PW, Stason WB. Post stroke rehabilitation guidelines technical report. Rockville, MD: Agency for Health Care Policy and Research; 1995.
5. Bohannon RW, Andrews AW, Smith MB. Rehabilitation goals of patients with hemiplegia. Int J Rehabil Res 1988;11:181-3.
6. Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. Stroke 1995;26:982-9.
7. Olney SJ, Nymark J, Brouwer B, et al. A randomized controlled trial of supervised versus unsupervised exercise programs for ambulatory stroke survivors. Stroke 2006;37:476-81.
8. Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B. Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. Arch Phys Med Rehabil 1999;80:1211-8.
9. Teixeira-Salmela LF, Nadeau S, McBride I, Olney SJ. Effects of muscle strengthening and physical conditioning training on temporal, kinematic and kinetic variables during gait in chronic stroke survivors. J Rehabil Med 2001;33:53-60.
10. Burridge JH, Taylor PN, Hagan SA, Wood DE, Swain ID. The effects of common peroneal stimulation on the effort and speed of walking: a randomized controlled trial with chronic hemiplegic patients. Clin Rehabil 1997;11:201-10.
11. Macko RF, Ivey FM, Forrester LW, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. Stroke 2005;36:2206-11.
12. Ada L, Dean CM, Hall JM, Bampton J, Crompton S. A treadmill and overground walking program improves walking in persons residing in the community after stroke: a placebo-controlled, randomized trial. Arch Phys Med Rehabil 2003;84:1486-91.

13. Sullivan KJ, Knowlton BJ, Dobkin BH. Step training with body weight support: effect of treadmill speed and practice paradigms on post-stroke locomotor recovery. Arch Phys Med Rehabil 2002;83:683-91.
14. Sullivan KJ, Brown DA, Klassen T, et al. Effects of task-specific locomotor and strength training in adults who were ambulatory after stroke: results of the STEPS randomized clinical trial. Phys Ther 2007; 87:1580-602.
15. Dickstein R. Rehabilitation of gait speed after stroke: a critical review of intervention approaches. Neurorehabil Neural Repair 2008; 22:649-60.
16. Bowden MG, Clark DJ, Kautz SA. Evaluation of abnormal synergy patterns poststroke: relationship of the Fugl-Meyer Assessment to hemiparetic locomotion. Neurorehabil Neur Repair 2010;24:328-37.
17. Nadeau S, Duclos C, Bouyer L, Richards CL. Guiding task-oriented gait training after stroke or spinal cord injury by means of a biomechanical gait analysis. Prog Brain Res 2011;192:161-80.
18. Bowden MG, Balasubramanian CK, Neptune RR, Kautz SA. Anterior-posterior ground reaction forces as a measure of paretic leg contribution in hemiparetic walking. Stroke 2006;37:872-6.
19. Balasubramanian CK, Bowden MG, Neptune RR, Kautz SA. Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. Arch Phys Med Rehabil 2007;88: 43-9.
20. Kesar TM, Perumal R, Reisman DS, et al. Functional electrical stimulation of ankle plantarflexor and dorsiflexor muscles: effects on poststroke gait. Stroke 2009;40:3821-7.
21. Hase K, Suzuki E, Matsumoto M, Fujiwara T, Liu M. Effects of therapeutic gait training using a prosthesis and a treadmill for ambulatory patients with hemiparesis. Arch Phys Med Rehabil 2011;92:1961-6.
22. Westlake KP, Patten C. Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke. J Neuroeng Rehabil 2009;6:18.
23. Duncan PW, Sullivan KJ, Behrman AL, et al. Protocol for the Locomotor Experience Applied Post-stroke (LEAPS) trial: a randomized controlled trial. BMC Neurol 2007;7:39.
24. Duncan PW, Sullivan KJ, Behrman AL, et al. Body-weight-supported treadmill rehabilitation after stroke. N Engl J Med 2011;364:2026-36.
25. Yates JS, Studenski S, Gollub S, et al. Bicycle ergometry in subacute-stroke survivors: feasibility, safety, and exercise performance. J Aging Phys Act 2004;12:64-74.
26. Hesse S, Bertelt C, Jahnke MT, et al. Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. Stroke 1995;26:976-81.
27. Plummer P, Behrman AL, Duncan PW, et al. Effects of stroke severity and training duration on locomotor recovery after stroke: a pilot study. Neurorehabil Neural Repair 2007;21:137-51.
28. Visintin M, Barbeau H, Korner-Bitensky N, Mayo NE. A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. Stroke 1998;29:1122-8.
29. Fugl-Meyer A, Jaasko L, Leyman I, Olsson S, Seglind S. The post-stroke hemiplegic patient: a method of evaluation of physical performance. Scand J Rehabil Med 1975;7:13-31.
30. Kautz SA, Brown DA. Relationships between timing of muscle excitation and impaired motor performance during cyclical lower extremity movement in post-stroke hemiplegia. Brain 1998;121:515-26.
31. Berg K, Wood-Dauphinee S, Williams JI. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. Scand J Rehabil Med 1995;27:27-36.
32. Jonsdottir J, Cattaneo D. Reliability and validity of the dynamic gait index in persons with chronic stroke. Arch Phys Med Rehabil 2007; 88:1410-5.
33. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. J Gerontol A Biol Sci Med Sci 1995;50A:M28-34.
34. Kuys SS, Brauer SG, Ada L. Test-retest reliability of the GAITRite system in people with stroke undergoing rehabilitation. Disabil Rehabil 2011;33:1848-53.
35. Macko RF, Haeuber E, Shaughnessy M, et al. Microprocessor-based ambulatory activity monitoring in stroke patients. Med Sci Sports Exerc 2002;34:394-9.
36. Fulk GD, Echternach JL, Nof L, O'Sullivan S. Clinometric properties of the six-minute walk test in individuals undergoing rehabilitation poststroke. Physiother Theory Pract 2008;24:195-204.
37. Tilson JK, Sullivan KJ, Cen SY, et al. Meaningful gait speed improvement during the first 60 days poststroke: minimal clinically important difference. Phys Ther 2010;90:196-208.
38. Whitney SL, Hudak MT, Marchetti GF. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. J Vestib Res 2000;10:99-105.
39. Botner EM, Miller WC, Eng JJ. Measurement properties of the Activities-specific Balance Confidence Scale among individuals with stroke. Disabil Rehabil 2005;27:156-63.
40. Hoyer E, Jahnsen R, Stanghelle JK, Strand LI. Body weight supported treadmill training versus traditional training in patients dependent on walking assistance after stroke: a randomized controlled trial. Disabil Rehabil 2012;34:210-9.
41. Mulroy SJ, Klassen T, Gronley JK, Eberly VJ, Brown DA, Sullivan KJ. Gait parameters associated with responsiveness to treadmill training with body-weight support after stroke: an exploratory study. Phys Ther 2010;90:209-23.
42. Levin MF, Kleim JA, Wolf SL. What do motor "recovery" and "compensation" mean in patients following stroke? Neurorehabil Neural Repair 2009;23:313-9.
43. Fritz S, Lusardi M. White paper: "walking speed: the sixth vital sign." J Geriatr Phys Ther 2009;32:46-9.
44. Bowden MG, Behrman AL, Woodbury M, Gregory CM, Velozo CA, Kautz SA. Advancing measurement of locomotor rehabilitation outcomes to optimize interventions and differentiate between recovery versus compensation. J Neurol Phys Ther 2012;36:38-44.
45. Bowden MG, Embry AE, Gregory CM. Physical therapy adjuvants to promote optimization of walking recovery after stroke. Stroke Res Treat 2011;2011:601416.
46. Eng JJ, Tang P. Gait training to optimize walking ability in people with stroke: a synthesis of the evidence. Expert Rev Neurother 2007;7: 1417-20.