Step Training With Body Weight Support: Effect of Treadmill Speed and Practice Paradigms on Poststroke Locomotor Recovery

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ABSTRACT. Sullivan KJ, Knowlton BJ, Dobkin BH. Step training with body weight support: effect of treadmill speed and practice paradigms on poststroke locomotor recovery. Arch Phys Med Rehabil 2002;83:683-91.

Objective: To investigate the effect of practice paradigms that varied treadmill speed during step training with body weight support in subjects with chronic hemiparesis after stroke.

Design: Randomized, repeated-measures pilot study with 1- and 3-month follow-ups.

Setting: Outpatient locomotor laboratory.

Participants: Twenty-four individuals with hemiparetic gait deficits whose walking speeds were at least 50% below normal.

Intervention: Participants were stratified by locomotor severity based on initial walking velocity and randomly assigned to treadmill training at slow (0.5mph), fast (2.0mph), or variable (0.5, 1.0, 1.5, 2.0mph) speeds. Participants received 20 minutes of training per session for 12 sessions over 4 weeks.

Main Outcome Measure: Self-selected overground walking velocity (SSV) was assessed at the onset, middle, and end of training, and 1 and 3 months later.

Results: SSV improved in all groups compared with baseline ($P<.001$). All groups increased SSV in the 1-month follow-up ($P<.01$) and maintained these gains at the 3-month follow-up ($P=.77$). The greatest improvement in SSV across training occurred with fast training speeds compared with the slow and variable groups combined ($P=.04$). Effect size (ES) was large between fast compared with slow (ES=.75) and variable groups (ES=.73).

Conclusions: Training at speeds comparable with normal walking velocity was more effective in improving SSV than training at speeds at or below the patient's typical overground walking velocity.

Key Words: Locomotion skills; Recovery of function; Rehabilitation.

THE RECOVERY OF independent walking is among the most important goals for patients with hemiparetic stroke and for their rehabilitation therapists. Step training on a treadmill (TM) with body weight support (BWS) is an example of a neurorehabilitation approach that incorporates recent findings from basic science to promote functional locomotor recovery after stroke or spinal cord injury (SCI). This technique, termed body weight–supported treadmill training (BWSTT), is derived from studies of adult cats with a low thoracic spinal transection who recovered the ability to step on a moving TM belt after they were given truncal support, stimulated to recover extensor tone, and assisted in paw placement.[1-3] Investigators have found that the spinal locomotor pools, which include a central pattern generator for activity of automatic, alternating flexor, and extensor leg muscles, are highly responsive to phasic segmental sensory inputs and show evidence of learning during step training.[4] The idea of suspending patients with stroke and SCI from an overhead lift and assisting the legs to step was proposed by Finch et al[5] and Barbeau and Blunt.[6] The face validity of the intervention also derives from animal and human studies that point to the benefit of repetitive practice in a task-oriented fashion to lessen disability in upper-extremity function,[7,8] improve walking,[9,10] and alter cortical sensorimotor representations.[11,12]

The task-specific nature of step training on a treadmill is 1 mechanism that may account for improvements in poststroke locomotor recovery observed with this type of neurorehabilitation intervention. Several studies have specifically examined the effectiveness of TM training in poststroke locomotor recovery. Collectively, these studies reveal a few common threads. First, TM training or therapies that focus on gait-specific activities appear to be more effective than conventional therapy alone in locomotor recovery after stroke.[9,10,13] In addition, BWSTT appears to be more effective than TM training performed without any weight support.[14] These studies investigated treatment effects in individuals from 2 to 12 months poststroke when the hemiparesis most limits ambulation. Despite the relatively positive effects of BWSTT in these populations, it is unclear if the benefits of this type of training could be enhanced with variations in practice schedules.

Studies of BWSTT reported to date have not clearly established that 1 technique of assistance and style of using BWS and TM speed is better than another. An important aspect may be that clinical trials of BWSTT have not increased TM speeds during training to levels that consistently approach those of normal walking velocities. Before BWSTT can be put to a definitive test as an alternative to conventional locomotor therapies, training parameters for optimal outcomes must be addressed in both acute and chronic subjects with stroke who are either less than independent walkers or who walk well below normal overground velocities. If an intensive, task-oriented intervention for walking such as BWSTT is more likely to encourage experience-dependent plasticity in the central nervous system than a conventional physical therapy approach, then BWSTT ought to be built on principles of motor learning

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and performed at speeds, lower-extremity loads, and with limb kinematics that optimize what the spinal and supraspinal locomotor networks can interpret as normal walking inputs.[15] For example, better locomotor outcomes might be achieved by aiming to have subjects practice stepping at walking speeds that are within the normal range of 2 to 3mph, as opposed to step training at one third to one half of normal, similar to that used in other studies.

One neurorehabilitation challenge is to determine how to structure practice to maximize treatment effectiveness and promote motor learning. This is especially true for an intervention such as BWSTT that is labor intensive and requires specialized training by therapists.[15,16] Variable practice is 1 method that typically results in greater learning and generalizability (ie, the ability to transfer what is learned during practice to a novel variation of the task or to a new environment).[17] Variable practice involves practice of a motor task that is varied along some task dimension, such as distance or speed. Locomotor training that uses BWSTT may be enhanced by a variable practice schedule, because this intervention involves a specific motor task (ie, walking) that can be readily varied along a dimension, such as speed. Additionally, it is likely that BWSTT will transfer to a functional outcome such as increased overground walking velocity because task practice is well-matched to the sensorimotor experiences of overground walking. Overground walking velocity is an important functional outcome for measuring poststroke locomotor recovery because higher velocities correlate with an improved gait pattern[18] and a greater likelihood of being an independent community ambulator.[19]

Because previous work has suggested that TM training is more effective than conventional overground gait training[20] and TM training with BWS is more effective than TM training without BWS,[14] the intent of the present study was not to compare conventional gait training with BWSTT. Rather, we were interested in whether stepping practice at faster speeds, such as those that approach normal walking velocities, would result in better transfer to overground walking than training at slow or variable speeds. We also assessed short- and long-term retention of gains in walking velocity to determine functional carryover after training had ceased. Although the present study had a small sample size (yet larger than all but 2 prior trials), we aimed to develop a predictive model based on clinical measures of stroke impairment severity and training strategy to determine factors that might predict whether a particular group of chronic hemiparetic subjects would benefit more from BWSTT. This information could aid in the design of future randomized clinical trials of BWSTT.

METHODS

Participants

Twenty-four individuals with chronic hemiparetic stroke voluntarily consented to participate in the study. The inclusion criteria were the following: unilateral stroke within the middle cerebral artery or basilar artery distribution resulting in unilateral hemiparesis, time since stroke onset greater than 6 months, living within the community, able to ambulate 10m with or without an assistive device and no more than standby physical assistance, and walking speed reported to be slower than before the stroke. Subjects were excluded if they were receiving any physical therapy, had musculoskeletal impairments that limited full knee extension or ankle plantarflexion to neutral, and any other neurologic condition other than unilateral stroke. All subjects were required to sign an informed consent document approved by the institutional review board at the University of California, Los Angles. Subjects were recruited from the greater Los Angeles area.

Each subject was stratified into a category by locomotor severity based on his/her initial self-selected overground walking velocity. If velocity was ≥0.5m/s, the subject was placed in the mild to moderate category. If velocity was less than 0.5m/s, the subject was placed in the severe category. After stratification, the subject was randomly assigned to a BWSTT training group at slow (0.5mph), fast (2.0mph), or variable (0.5, 1.0, 1.5, 2.0mph) TM belt speeds. (According to the International Standards of Measurement, walking velocity is customarily expressed as meters per second. However, US TM belt speeds are indicated as miles per hour. The conversion of mph to m/s for the TM belt speeds used in this study are: 0.5mph=.22m/s; 1.0mph=.45m/s; 1.5mph=.67m/s; 2.0mph=.89m/s.) On average, the slow group trained below, the fast group trained above, and the variable group trained at speeds both below and above their usual overground walking speeds.

All subjects received 12 sessions of BWSTT over a 4-to-5-week training phase and returned for 1- and 3-month follow-ups. The frequency and duration of training was designed to best represent the standard of care for outpatient visits that may be available to individuals with chronic stroke. Each session included four 5-minute walking bouts for a total of 20 minutes of TM walking per session. Heart rate was monitored to assess the subject's exercise tolerance. During the training phase, the only therapeutic intervention a subject received was the 20 minutes per session of BWSTT. Subjects did not receive any other physical training such as overground ambulation or strengthening and endurance exercise. Throughout the training phase and until the completion of the 3-month follow-up, subjects were required to refrain from any TM walking other than what was part of the experimental protocol.

Training Protocol

Participants were fitted in a harness (Medical Harness[a]), which was then connected to an overhead suspension system positioned over a treadmill (fig 1). The suspension system was an overhead-motorized pneumatic lift with a digital readout displaying the amount of BWS (Neuro II[b]). By using the BWS guidelines described by Visintin et al,[14] up to 40% BWS was provided initially and progressively decreased as the subject increased activity tolerance and could maintain proper limb kinematics throughout stance and swing with the therapist's assistance. Subjects were trained with the assistance of 1 physical therapist and 1 aide (fig 1). One person was positioned behind the subject and provided proximal stability at the hips. This person was responsible for monitoring upright posture, pelvic position, and weight shift. The second person was positioned at the hemiparetic lower limb and provided assistance with stepping and limb control during stance and swing. This person also monitored stride characteristics and cadence.

The training strategy focused on the following key components that were normalized for each subject as much as possible: upright trunk alignment, weight shift, and weight bearing through the lower limbs, limb kinematics for stance and swing, coordinated stride characteristics between the limbs, and reciprocal arm swing (see fig 1).[16] Subjects were not allowed to wear a lower-extremity orthosis during training. They were encouraged to use reciprocal arm swing as much as possible. For safety, subjects were positioned within parallel bars but were discouraged from using the bars for upper-extremity support. Initially, subjects were given the option to use the bar until they gained confidence but were quickly transitioned to either a bungee cord positioned in front of the subject and

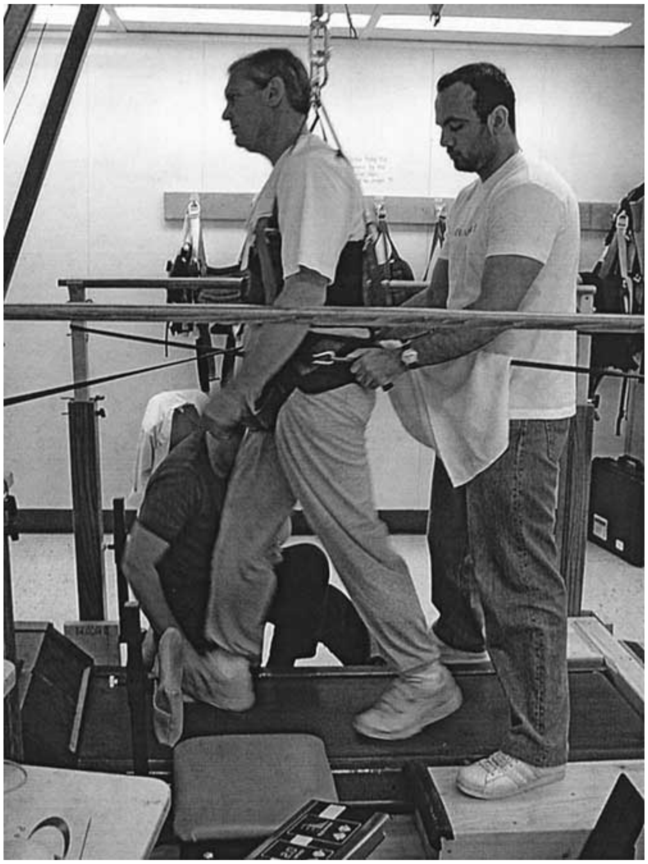

Fig 1. Setup for step training with BWS. Photograph depicts the apparatus, treadmill, and trainer positions.

suspended across the parallel bars or no upper-extremity support at all.

The training protocol required that the subject complete training at the speed assigned by group membership. Subjects in the slow or fast group walked at 1 speed (0.5 or 2.0mph, respectively) and the variable group walked at 4 different speeds. A subject was allowed to take as many rests as needed throughout each session in addition to the regularly scheduled rest at the 5-minute interval. The loading on the lower extremities was progressively decreased if the subject maintained proper limb kinematics. However, we continued BWS as needed to aid the subject in effective stepping at their assigned speed.

Clinical Assessments

Clinical characteristics. Before training, we made representative assessments of motor and cognitive impairment, functional ability, and disability level to determine the homogeneity between experimental groups and to determine if clinical characteristics contributed to locomotor outcomes. The Mini-Mental State Examination (MMSE) was used to assess overall cognitive function. The severity of motor impairment for the hemiparetic limb was assessed by the motor component of the Fugl-Meyer assessment. The total Fugl-Meyer motor score (TFM) and the lower-extremity Fugl-Meyer score (LEFM) were calculated. The Fugl-Meyer assessment is a valid and reliable measure of poststroke motor control severity.[21,22] The motor subscale of the FIM™ instrument was used to determine the level of functional limitation and physical assistance required to complete activities of daily living (ADLs).[23] The physical functioning subscale of the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36) was used as a measure of health status and relates to the subject's perception of physical disability.[24]

Self-selected overground walking speed. The primary outcome variable was self-selected overground walking velocity (SSV). Gait velocity is a clinically relevant outcome measure[19] that is sensitive to change in locomotor recovery especially in chronic stroke populations.[18] Subjects were timed with a stopwatch as they walked a 10-m walkway at their self-selected, comfortable walking speed. For safety, standby supervision but no physical assistance was provided. Overground walking speed was assessed in a pretest before BWSTT, after the sixth and twelfth BWSTT session, and at the 1- and 3-month follow-ups. All data collection events were videotaped. If applicable, subjects were allowed to use their assistive device and/or lower-extremity orthosis. If a subject used an assistive device or orthosis in the pretest, the subject was required to use these devices in all subsequent retests.

Statistical Analyses

Descriptive statistics were calculated for the clinical characteristics of each experimental group. One-way factorial analysis of variance (ANOVA) was used to assess group differences. To determine the effect of TM training speed and locomotor severity on SSV for training and follow-up phases, separate analyses were completed. A 3-group (slow, variable, fast) × 2–locomotor severity (mild/moderate, severe) × 3-session (pre, session 6, session 12) ANOVA with repeated measures on the last factor was used for the training phase. Follow-up performance was assessed in 2 ways. First, shorter term retention that compared SSV at the end of training with the 1-month follow-up was assessed using a 3-group (slow, variable, fast) × 2-severity (mild/moderate, severe) × 2-session (session 12, 1-mo follow-up) ANOVA with repeated measures on the last factor. Second, longer term retention that compared SSV at the 1-month with the 3-month follow-up was assessed using a 3-group (slow, variable, fast) × 2–locomotor severity (mild/moderate, severe) × 2-session (1-mo, 3-mo follow-up) ANOVA with repeated measures on the last factor.

To elucidate the effect of training speeds, the absolute change in velocity between the pre- and posttraining phases between groups was analyzed. A 1-way ANOVA was used to determine the effect of training group on the absolute change in velocity across training. To explore the practical significance of group differences, an estimate of the magnitude of the differences between groups was calculated that used effect size (ES) ($ES = Mean_{Group1} - Mean_{Group2}/SD_{pooled}$). The ES is a value that reflects the impact of a treatment within a population of interest and is reported according to established criteria as small ($<.41$), medium (.41–.70), or large ($>.70$).[25]

Finally, a multivariate analysis that used stepwise linear regression analysis was completed to determine if clinical and/or training characteristics were predictive of improvement in SSV across training. For this analysis, the change in SSV across the training phase was used as the dependent measure.

The Greenhouse-Geisser degrees of freedom adjustment was used to compute the probability level for the repeated-measures factor. For all statistical tests, significance was set at *P* less than .05. All data analysis was performed by using SPSS Professional Statistics 9.0 software.[c]

Table 1: Group Comparisons

Variables	Training Groups: Slow	Variable	Fast	P
Age (y)	70.9±9.8 (56–81)	66.5±13.9 (43–79)	64.4±13.4 (34–74)	.59
Gender (M/F)	5/3	7/1	7/1	
Side of stroke (R/L)	5/3	5/3	6/2	
Stroke onset (mo)	22.51±3.6 (8–45)	27.6±21.5 (7–62)	27.2±13.7 (6–44)	.79
MMSE (30 max)	27.1±3.4 (20–30)	28.7±2.7 (22–30)	27.0±3.3 (21–30)	.53
Total motor Fugl-Meyer (100 max)	72.4±23.7 (34–95)	58.1±22.1 (37–87)	57.41±4.8 (43–81)	.28
Lower-extremity Fugl-Meyer (34 max)	25.9±4.4 (22–32)	25.3±4.3 (22–33)	26.9±2.8 (25–33)	.71
FIM motor subscale (7–91)	81.19±0.9 (60–91)	79.5±7.6 (70–91)	80.5±6.2 (69–90)	.92
SF-36 physical function (0–100)	38.12±7.8 (0–70)	41.9±26.4 (5–95)	34.4±20.1 (10–75)	.84

NOTE. Values are mean ± SD (range).
Abbreviations: M, male; F, female; R, right; L, left.

RESULTS

Of the 24 participants, 8 subjects were randomized to each training group (slow, variable, fast). There was an equal number of participants from the mild/moderate and severe categories in each group. All subjects completed the 12 training sessions and returned for the 1-month follow-up. Four subjects, 2 from the slow and 2 from the variable groups, did not complete the 3-month follow-up (because of second stroke, medical complications, relocated from area, refused).

Nineteen men and 5 women participated in the study. The mean age was 67±12 years (range, 34–81y). Time since stroke onset averaged 25.8±16 months with a median of 24 months (range, 6–62mo). Sixteen subjects had a right and 8 had a left unilateral cortical or subcortical stroke. Table 1 indicates the frequency counts for gender and side of stroke and the group means, standard deviations (SDs), and ranges for the clinical characteristics. There were no statistically significant differences between the groups for age ($P=.59$), stroke onset ($P=.79$), cognitive status (MMSE, $P=.53$), severity of hemiparesis (TFM, $P=.28$), lower extremity paresis (LEFM, $P=.71$), physical assistance in ADLs (FIM motor subscale, $P=.92$), and physical disability (SF-36 physical function component, $P=.84$).

Training Tolerance

Figure 2A shows the percentage of body weight used for sessions 1, 6, and 12 for the slow, variable, and fast groups. The percentage of BWS progressively decreased for all groups from session 1 (mean ± SD: slow, 34%±9%; variable, 34%±6%; fast, 33%±6%) to session 12 (slow, 11%±10%; variable, 14%±6%; fast, 14%±7%). This resulted in a significant effect for session ($P<.001$). No differences were found in the percentage of BWS used between groups (group effect, $P=.68$). The percentage of BWS decreased proportionately and to a comparable degree for each group across the training phase (group × session, $P=.74$).

In addition to the rests provided at each 5-minute interval, subjects were provided with additional rests as needed. Figure 2B shows the mean number of additional rests provided for sessions 1, 6, and 12 by group. All groups were able to decrease the number of additional rests across training (session effect, $P<.001$). The number of rests provided differed by group (group effect: $P=.02$). Post hoc analysis revealed that the slow group needed significantly fewer rests than either the variable ($P=.01$) or fast ($P=.01$) groups. However, despite the higher number of rests needed in session 1, both the variable and fast groups were able to decrease the number of additional rests from session 1 (variable, M=4.4; fast, M=4.6) to session 12 (variable, 0 rests; fast, 0 rests), which resulted in a significant group × session interaction ($P=.01$).

To reinforce normal limb kinematics including reciprocal arm swing during gait, subjects were encouraged to walk on the treadmill without any upper-extremity support. Figure 2C shows the changes in the type of upper-extremity support used (parallel bar, bungee, no upper-extremity support) for sessions 1, 6, and 12. In session 1, the majority of subjects used the parallel bar for support; however, by session 12, most were walking on the treadmill without upper-extremity support, regardless of TM training speed.

Training Effects

Figure 3 shows the SSV group means for the pretest, after training session 6, and after training session 12. The slow, variable, and fast groups showed improvements in overground walking velocity indicated by group mean increases in SSV from the pretest (slow, .53±.29m/s; variable, .52±.31m/s; fast, .57±.26m/s) compared with session 12 (slow, .59±.36m/s; variable, .59±.34m/s; fast, .72±.34m/s). All groups improved overground walking speed with BWSTT as indicated by a main effect for session ($P<.001$).

The performance from the last training session to the 1-month follow-up is shown in figure 3. Interestingly, all groups continued to make approximately a 9.5% improvement in walking speed across the 1-month follow-up (1-month SSV: slow, .67±.42m/s; variable, .64±.36m/s; fast, .78±.41m/s; session effect, $P<.01$). This finding suggests that subjects were able to build on the training experience to make continued gains in overground walking velocity even after training had stopped.

To assess longer term follow-up, group comparisons of the 1- and 3-month follow-ups were calculated. There was no change in SSV between the 1- and 3-month follow-up intervals

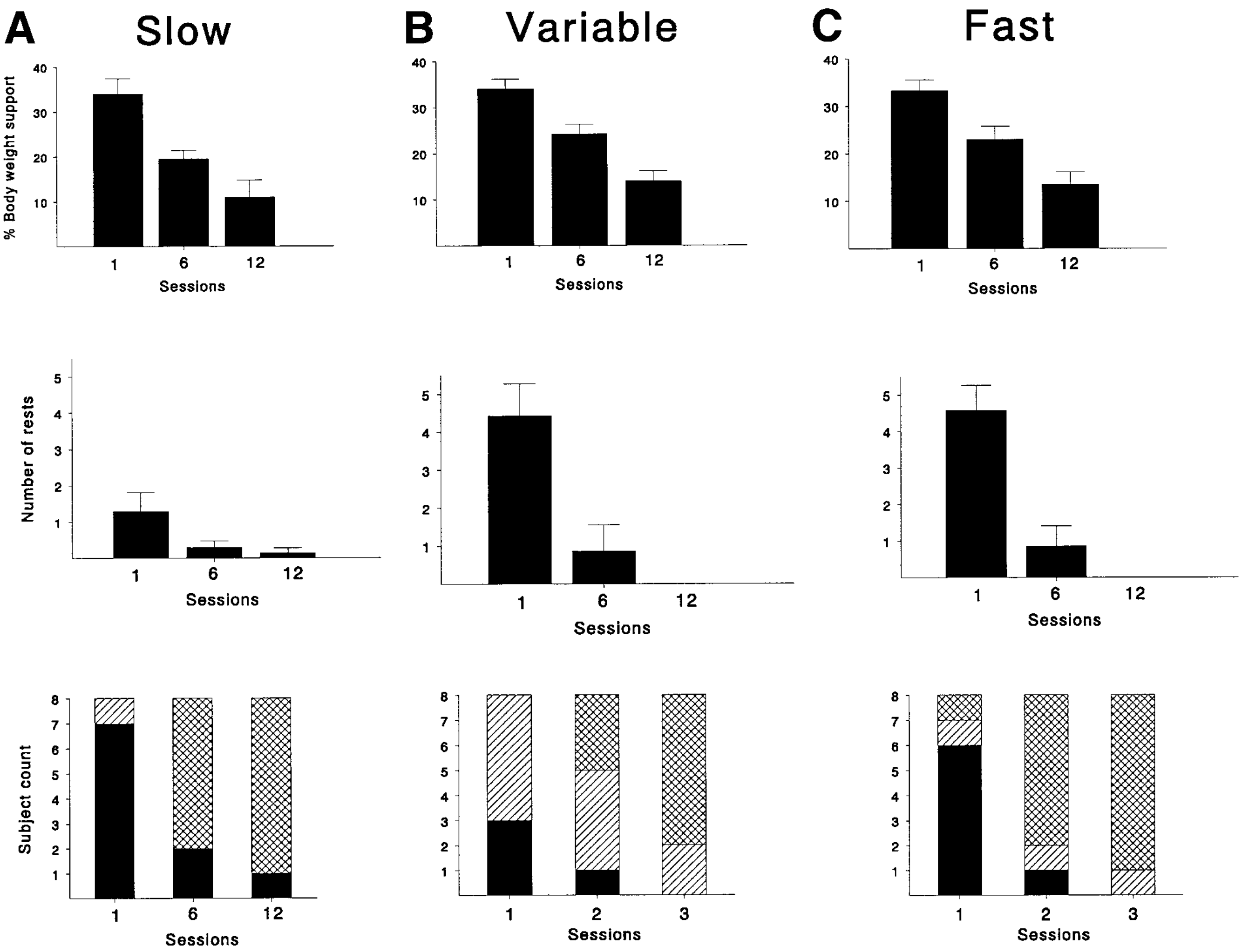

Fig 2. Training tolerance indicators for the slow, variable, and fast groups (in columns) for (A) mean percentage BWS ± standard error of the mean (SEM); (B) mean number of rests for sessions 1, 6, and 12 ± SEM; and (C) frequency count type of upper-extremity support for sessions 1, 6, and 12. ■, bar; ▨, bungee; ▩, no upper extremity.

(3-month SSV: slow, .69±.45m/s; variable, .63±.40m/s; fast, .78±.42m/s; session effect, *P*=.77). Therefore, the gains in walking speed achieved over training and in the 1-month posttraining period were maintained at 3 months.

Effect of Training Speed

A 1-way ANOVA revealed that the group effect was not significant (*P*=.18). However, the greatest trend for improvement in overground velocity was seen in the fast training group (velocity change: slow, .06±.09m/s; variable, .07±.08m/s; fast, .15±.14m/s). ES calculations revealed a large strength difference between the fast and slow groups (ES=.75) and fast and variable groups (ES=.73). In contrast, the ES difference between the slow and variable groups was negligible (ES=.13). The ES differences suggest that, in all likelihood, a larger sample size would have produced a statistically significant effect.[25,26] To verify this possibility, the groups that trained at the slow or variable speeds were combined and compared with the group trained at exclusively fast speeds. A group (fast, slow-variable) × session repeated-measures ANOVA revealed a significant group × session interaction (*P*=.04), which shows that the change across training was

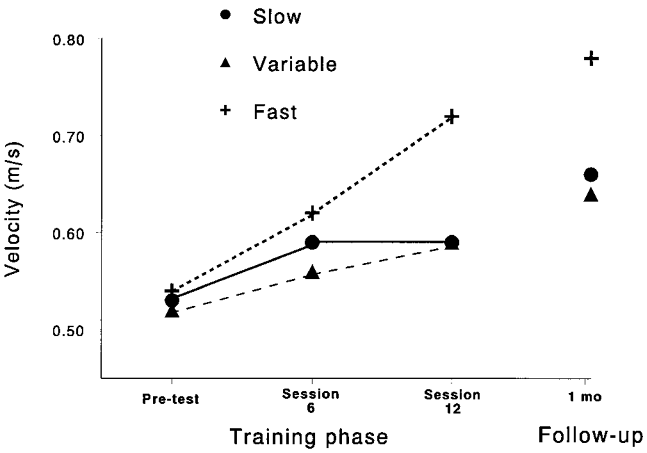

Fig 3. Self-selected velocity for each training group (group means) for the training phase and 1-month follow-up (N=24). All groups improved performance over training ($P<.001$) and continued to make improvement between the end of training and the 1-month follow-up ($P<.01$).

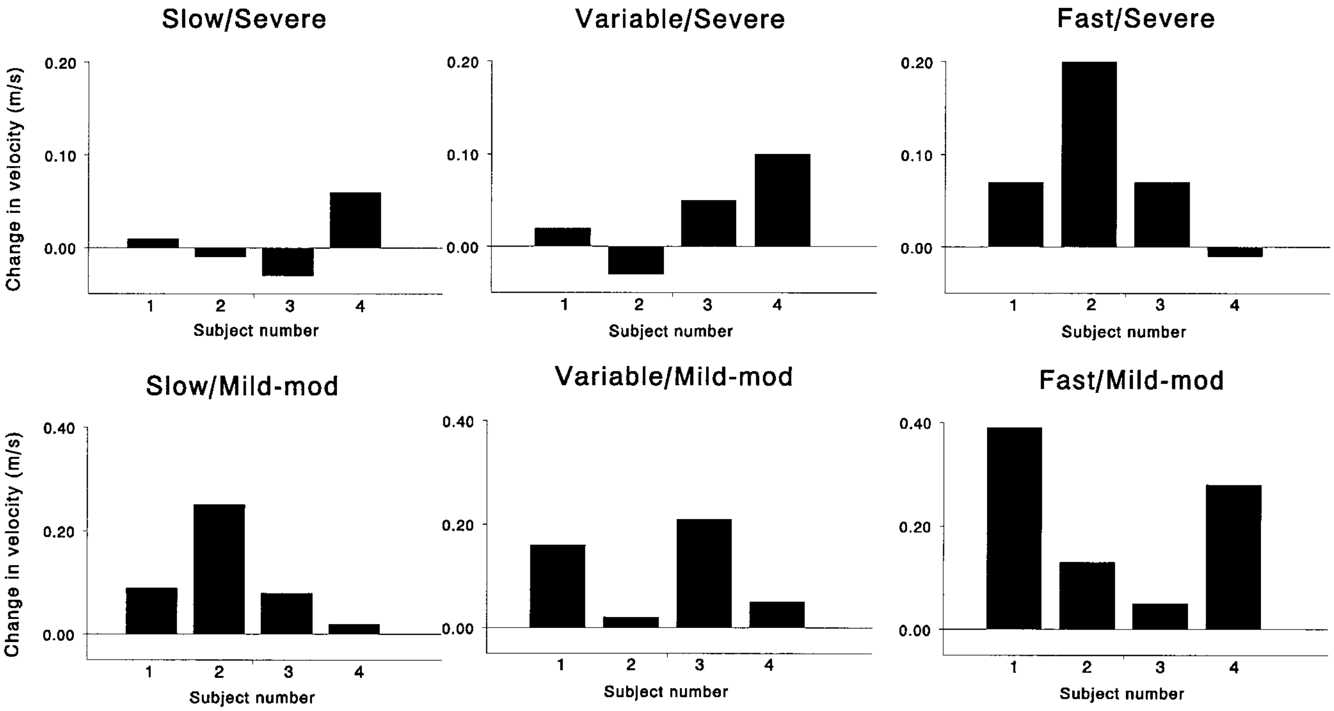

Fig 4. Individual data of all subjects. Bars depict the change in velocity across training for each subject grouped by training speed and stroke locomotor severity.

greater for the fast group (see fig 4). In addition, the large ES between the slow and variable groups compared with the fast group and the statistically significant difference between the fast and slower trained groups combined suggests that the greatest change in overground velocity was most likely related to BWSTT at fast speeds.

Effect of Stroke Locomotor Severity

Stroke locomotor severity influenced the increase in SSV as a result of BWSTT. The mild/moderate and severe groups showed improvements in overground walking velocity, indicated by group mean increases in SSV from the pretest (mild/moderate, .78±.15m/s; severe, .29±.10m/s) compared with session 12 (mild/moderate, .93±.19m/s; severe, .34±.13m/s). However, the greatest gain in SSV across training was in the mild/moderate compared with the severe group (locomotor severity × session: $P=.02$).

Predictive Factors

Stepwise linear regression analysis was used to determine the independently significant correlates of clinical characteristics and training group on the absolute change in SSV across the training phase. This analysis was used to determine the clinical and training factors that might predict the best functional outcomes (ie, improvement in overground walking velocity) as a result of BWSTT. The absolute change in SSV correlated significantly with LEFM ($r=.46$, $P=.02$), training group ($r=.39$, $P=.03$), and locomotor severity ($r=-.47$, $P=.01$).

A multivariate stepwise regression analysis with absolute change in SSV as the dependent measure and stroke onset, side of stroke, locomotor severity level (mild/moderate, severe), training group (fast, slow/variable combined), and scores for MMSE, TFM, LEFM, FIM, and SF-36 as the independent variables revealed that locomotor severity and training group correlated independently with the change in velocity across training ($R^2=.37$, $P=.04$). In other words, the greatest change in SSV as a result of BWSTT was associated with individuals with chronic hemiparetic stroke who had initial walking velocity ≥0.5m/s and received BWSTT in the fast training group.

Individual data in figure 4 shows the absolute change in SSV across training for subjects grouped by locomotor severity and training speed. The independent contributions of locomotor severity and training speed are elucidated in this figure. Comparison between columns reveals the effect of speed. The magnitude of change was greatest for the individuals who trained at the faster speeds regardless of locomotor severity. In contrast, comparison between rows reveals the effect of locomotor severity. The magnitude of change was greater for those individuals with initial walking velocity ≥0.5m/s.

DISCUSSION

The results of the present study support and extend findings related to the use of TM training[9,27] and BWSTT[13,14,28] to improve walking abilities in individuals with chronic hemiparetic stroke. The BWSTT protocol we used was a short-duration pulse of modest intensity, task-specific training. Regardless of the variations in TM training speed, all groups benefited from 12 sessions of BWSTT, as shown by increases in their overground walking velocity with training. Furthermore, all groups were able to build on the training experience to make continued gains in walking velocity in the 1-month interval after training had ceased. Longer term follow-up assessment revealed that the improvements in overground velocity made across the training and 1-month posttraining period were maintained at 3 months. These findings support the use of step training on a treadmill with BWS for locomotor recovery after chronic stroke and suggest that this type of task-specific activity results in retention and transfer to an important functional outcome such as overground walking velocity. We also found a strong trend for greater improvement in overground walking speed in the group trained at fast speeds compared with the groups that trained at slower speeds. This suggests that step training on a treadmill with BWS could be most effective when patients with chronic hemiparetic stroke are challenged to walk on the treadmill at speeds closer to normal overground walking velocities.

According to the specificity of learning hypothesis,[17] the best motor learning occurs if performance during practice is well matched to the performance required for retention or transfer conditions. Schmidt and Lee[17] have suggested that motor learning reflects a neural specificity of practice because motor learning involves the integration of motor and sensory information that is available during practice. The specificity of learning hypothesis is consistent with recent advances in neurorecovery and neuroplasticity that have shown that task-dependent activity results in changes in the nervous system that correlate with improvements in motor behavior. Several animal studies[7,29,30] have shown that neurorecovery and functional performance are enhanced after cortical infarction when postinjury training incorporates motor tasks of greater complexity and higher-intensity demands than training conditions that do not. Particularly relevant to a neurophysiologic rationale for step training on a treadmill, the animal and human work in locomotor recovery specifically address how neuroplasticity is induced by repetitive locomotor activity that attempts to optimize the sensorimotor experience of walking at spinal and supraspinal levels.[2,31,32] Step training enables participants to optimize sensory inputs related to load, speed, and limb kinematics associated with more normal gait patterns and stance and swing characteristics.[33] The enhanced performance of the fast training group in the present study suggests that the greatest gains in locomotor recovery after stroke may be associated with training interventions that are task-specific and have high-intensity demands such as step training at speeds faster than an individual's known capability overground.

In the present study, individuals with chronic stroke who trained at faster TM speeds (2.0mph) achieved an average increase in overground walking velocity across the training phase of 28.6%. In contrast, overground walking velocity increased by 11.3% and 13.5% for the groups trained at slow (0.5mph) or variable (0.5, 1.0, 1.5, 2.0mph) speeds, respectively. These findings are, perhaps, contrary to the hypothesis that practice at variable speeds would be more beneficial to retention and transfer than training at constant speeds. In the present study, walking at different speeds is an example of a class of action (ie, walking) that is varied by changing the speed parameter. However, it appears that the improved performance of the fast compared with the variable training group is related less to variable practice and is more related to principles of practice specificity and training intensity. Indeed, the improved performance of the fast compared with the variable training group suggests that practice specificity (ie, walking at near normal speed) and training intensity (ie, constant practice at the highest speed) had a greater impact on the effectiveness of step training than was found with variable practice. It might be possible to demonstrate a variable versus constant practice effect if higher TM speeds are used such as varying speed from 1.0 to 3.0mph.

The faster TM speeds used in the present study are substantially higher than the speeds used in previous studies that have examined the effectiveness of BWSTT[13,14,34]; however, the patients in these studies were more acute and had more severe gait deficits then the present study. Hesse et al,[13] in a single-subject design study with 7 chronic (3mo–1y poststroke), nonambulatory stroke subjects, trained subjects at very slow speeds that ranged from .16 to .49mph during BWSTT.

In a larger randomized clinical trial, Visintin et al[14] specifically investigated the effect of BWS during TM training.

Patients about 2 months poststroke trained during acute rehabilitation at TM speeds that ranged on average from 0.5mph early in training to .95mph by the end of 6 weeks of training. The TM speeds were even slower for the group randomized to TM training without BWS. In both studies, stroke subjects' posttraining velocities had increased to approximately 1 to 1.5mph; yet, training speeds were slower than the patient's overground gait capabilities.

These previous studies chose slow TM speeds to enable the trainers to correct gait pattern deviations[14] and to permit longer training sessions without rests.[13] Stroke locomotor severity and level of acuteness may well be important factors in training parameter selection; however, the chronic subjects in the present study who had severe gait disability (see fig 4) were able to tolerate and benefit from training speeds substantially higher than their overground walking velocity. Anecdotally, acute patients in our stroke unit are also able to tolerate BWSTT at speeds substantially higher than their overground walking speeds, suggesting that training intensity may be increased for acute patients with severe gait deficits. Clearly, more study is needed to identify training parameters for various phases of locomotor recovery after stroke.

The present study showed that individuals with chronic hemiparetic stroke who have some level of ambulatory ability were able to tolerate the activity level of faster TM speeds. The study did not include any physiologic measures of exercise tolerance except for monitoring heart rate. Because of the frequent rests and the proportion of BWS, maximum heart rates never increased to age-predicted target heart rates high enough to result in an aerobic training effect (highest heart rates ranged from 100–110 beats/min). Low physiologic load as a result of BWS is consistent with a recent study by Danielsson and Sunnerhagen[35] who showed that heart rate and oxygen consumption were lower when individuals with stroke walked on a treadmill at 30% BWS compared with walking with full body weight load. We examined other indicators of training tolerance. Across training, all groups progressively decreased the proportion of BWS used. Early in training, the fast and variable groups required more rests, but by the end of training, there was no difference in activity tolerance (eg, number of rests) or the need for upper-extremity support, regardless of TM training speed. The results of this study support other work[27] that suggests individuals with chronic stroke are able to tolerate higher activity levels than those that are typically demanded of them in therapy. The proportion of BWS can be gradated across training so that patients can maintain practice parameters such as proper limb kinematics and more normal ranges of walking speed. In addition, BWS can also be used to decrease mechanical work and, hence, physiologic load in patients with cardiovascular deconditioning. More research is needed to understand the physiologic effect of this intervention in individuals with stroke.

We found that individuals with chronic hemiparesis with an initial walking velocity of 0.5m/s or greater experienced the largest change in gait velocity as a result of BWSTT. Barbeau et al[28] reviewed studies that compared initial walking speed and change in walking speed for gait-specific rehabilitation, BWSTT, and gait training with functional electric stimulation. These investigators found that initial walking velocity did not appear to be a factor that predicted change in walking velocity for gait-specific rehabilitation or BWSTT. One of the limitations of their analysis was that few studies to date have included subjects walking at or above 0.5m/s to determine accurately this relationship. However, our present results suggest that the greatest potential for functional recovery may be possible for chronic stroke patients who have reached casual walking velocities above 0.5m/s. Self-selected walking velocity is the best predictor of functional ambulation status after stroke.[19] According to the classification of Perry et al,[19] limited community ambulation requires walking velocities of .58m/s, and unlimited community ambulation is achieved at walking velocities of .80m/s. However, walking velocity at these levels is still substantially below walking velocities of 1.2m/s (2.7mph) expected for age-matched adults who have not had a stroke.[36] And yet, individuals with chronic stroke who walk slowly, at community ambulation levels, would be considered too independent for US Medicare reimbursement of locomotor-related therapy. Results from the present study suggest that further improvements in functionally important locomotor outcomes are possible for individuals with chronic stroke, especially for those who are classified as community ambulators.

To ensure that effects could most readily be related to training, the present study included individuals whose time since onset of stroke was greater than 6 months. In addition, 12 training sessions were selected because this number is within the standard of care for outpatient visits for stroke patients who can ambulate 150ft (45.72m) without assistance. Differences in the training groups were not evident until the interval between sessions 6 and 12. At session 6, we found little difference in SSV between groups, which reinforces that a critical number of sessions is required to produce a substantial training effect that can lead to a functionally significant transfer to the task of overground walking. However, we did not extend the training duration to seek its optimal effect. Because total time in training was controlled to investigate specifically the effect of practice schedule (variable vs constant) and training speed, we did not control for the total number of repetitions (ie, number of steps), which was inherently higher in the fast trained group compared with the variable and slow groups. We believed this approach was justified because we were interested in how BWSTT practice should be structured to maximize functional outcomes, considering that available health care resources limit total therapy time. Finally, we can only anticipate the potential that additional training may have on further improvements in walking velocity. All groups showed the capability for additional gains in functional ambulation speed; improvements were evident in the 1-month follow-up. We do not know what the consequence of longer duration training (eg, 24 sessions), greater intensity (eg, 40-min sessions), or higher speed (eg, training at 2–3mph) would have on continued gains in walking velocity.

CONCLUSION

The present study investigated how practice can be structured to increase the effectiveness of BWSTT. It appears that step training with BWS at TM speeds well below a patient's self-selected overground walking velocity may not be as effective at improving walking velocity or the rate of gain in walking velocity as training at faster speeds. This finding reflects the impact that training speed may have on the effectiveness of BWSTT on the locomotor recovery of individuals with chronic stroke. This pilot study also provides information to determine power and sample size calculations for further randomized clinical trials needed to establish the efficacy of a well-defined intervention that can enhance walking ability after stroke.

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Suppliers

a. Robertson Harness, PO Box 90086, Henderson, NV 89009-0086.
b. Vigor Equipment Inc, 4915 Advance Way, Stevensville, MI 49127.
c. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.