Speed-Dependent Treadmill Training in Ambulatory Hemiparetic Stroke Patients

A Randomized Controlled Trial

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Background and Purpose—A new gait training strategy for patients with stroke seeks to increase walking speed through treadmill training. This study compares the effects of structured speed-dependent treadmill training (STT) (with the use of an interval paradigm to increase the treadmill speed stepwise according to principles of sport physiology) with limited progressive treadmill training (LTT) and conventional gait training (CGT) on clinical outcome measures for patients with hemiparesis.

Methods—Sixty ambulatory poststroke patients were each randomly selected to receive 1 of the 3 different gait therapies: 20 subjects were treated with STT, 20 subjects were trained to walk on a treadmill with a 20% increase of belt speed over the treatment period (LTT), and 20 subjects were treated with CGT. Treatment outcomes were assessed on the basis of overground walking speed, cadence, stride length, and Functional Ambulation Category scores.

Results—After a 4-week training period, the STT group scored significantly higher than the LTT and CGT groups for overground walking speed (STT versus LTT, $P<0.001$; STT versus CGT, $P<0.001$), cadence (STT versus LTT, $P=0.007$; STT versus CGT, $P<0.001$), stride length (STT versus LTT, $P<0.001$; STT versus CGT, $P<0.001$), and Functional Ambulation Category scores (STT versus LTT, $P=0.007$; STT versus CGT, $P<0.001$).

Conclusions—Structured STT in poststroke patients resulted in better walking abilities than LTT or CGT. This gait training strategy provides a dynamic and integrative approach for the treatment of gait dysfunction after stroke. (*Stroke*. 2002; 33:553-558.)

Key Words: exercise therapy ■ gait ■ hemiplegia ■ rehabilitation

For many years, the use of treadmill training has been a promising investigational therapy in the rehabilitation of patients with hemiparesis and impaired gait.[1–3] As a supplement to conventional therapies, treadmill training can significantly improve the results of gait training.[1,4] Whether treadmill training is actually superior to other gait therapies is disputed.[4,5] With seriously afflicted patients, who cannot walk under their own power, treadmill training with body weight support is recommended.[1,2] However, the most effective combination of training parameters (eg, amount and timing of body weight support during the gait cycle, belt speed, and acceleration) is still unknown.[1,4]

Recent training techniques in ambulatory hemiparetic patients after stroke have begun to include sport physiological approaches such as aerobic exercises and circuit training.[6,7] Sport physiological research has indicated that training at speeds below the trainee's maximum speed does not provide optimal improvements in gait speed. Only sprint training at maximum speed brings about optimum gait speed improvement.[8,9]

Furthermore, variations in electromyographic activity, angular displacement profiles, and temporal distance parameters as a function of walking speed in healthy subjects have been extensively reported in the literature.[10,11] This is in contrast to a lack of objective information quantifying the effectiveness of speed-dependent training on gait parameters in hemiparetic patients.[1,4] Until now, no controlled studies have compared the effect of normal and fast belt speeds in treadmill training.

Drawing on principles of sport physiology, we have developed a gait training program suitable for ambulatory hemiparetic patients using structured speed-dependent treadmill training (STT), namely, sprint training at maximum speed, while taking care not to overexert the patients, who often have multiple morbidities.

The objective of the present study is to compare the effectiveness of STT against limited progressive (LTT) treadmill training and also against conventional gait training (CGT). A prospective, randomized clinical trial was performed in which 1 group of stroke patients received STT, 1 group received treadmill training with a slow increase of training velocity (LTT), and 1 group received CGT. Clinical outcome measures on overground walking speed, cadence, stride length, and the Functional Ambulation Category (FAC) were compared at the end of a 4-week training period.

TABLE 1. Baseline Characteristics

Variable	CGT Group (n=20)	LTT Group (n=20)	STT Group (n=20)
Age, mean±SD, y*	61.6±10.6	57.1±13.9	58.2±10.5
Sex†			
Male/female	13/7	14/6	16/4
Diagnosis†			
Ischemic stroke/intracerebral hemorrhage	15/5	13/7	12/8
Side of lesion†			
Right/left	16/4	16/4	15/5
Body weight support (first 3 settings)†			
Yes/no	...	9/11	10/10
Ashworth score[12]†			
0/1	18/2	18/2	14/6
Duration of hemiparesis, mean±SD, wk*	16.10±18.5	16.8±20.5	16.2±16.4
First/second inpatient rehabilitation†	18/2	17/3	18/2
Need for walking aids during 10-m test†			
Orthosis/cane	2/4	5/3	4/3
Baseline fastest comfortable overground walking speed, mean±SD, m/s*	0.66±0.42	0.66±0.39	0.61±0.32

*$P>0.05$ (NS) by ANOVA with Newman-Keuls multiple comparisons test (for means).
†$P>0.05$ (NS) by χ^2 test (for frequencies).

Subjects and Methods

Subjects

Inclusion criteria for the study were hemiparesis caused by right or left supratentorial ischemic stroke or intracerebral hemorrhage, impaired gait, duration of hemiparesis >4 weeks, no or slight spasticity (Ashworth score 0 and 1),[12] ability to walk without personal assistance (FAC=3), and time required to walk 10 m >5 and <60 seconds. All patients were determined to be in stable cardiovascular condition with a low although slightly greater risk for vigorous exercise than for apparently healthy persons (class B according to the American College of Sports Medicine [ACSM]).[13] The clinical characteristics of the study patients were the absence of known heart disease or a known heart disease classified as class I or II in the New York Heart Association Classification system,[13] no evidence of heart failure, absence of ischemia or angina at rest or during exercise, appropriate rise in systolic blood pressure during exercise, and the absence of nonsustained or sustained ventricular tachycardia. Exclusion criteria were previous treadmill training and class C or D exercise risk by the ACSM criteria,[13] cognitive deficits (defined as score of <26 of 30 on the Mini-Mental State Examination),[14] movement disorders, and orthopedic and other gait-influencing diseases such as arthrosis or total hip joint replacement.

A total of 81 subjects, admitted to the Department of Neurological Rehabilitation Kreischa for poststroke inpatient rehabilitation between September 2000 and May 2001, were eligible and fulfilled the inclusion and exclusion criteria. Twelve of these 81 patients refused to participate, and 69 subjects provided informed consent to participate in this study. Nine of the 69 subjects discontinued treatment in the first 2 weeks of the study period, with resulting interruption of the inpatient rehabilitation program, for the following reasons: pneumonia in 4 subjects, bladder infection with fever in 2 subjects, and viral infections with fever in 3 subjects. The data from these patients were not included in the analysis. Thus, data from 60 patients were analyzed.

Experimental and Control Groups

The randomization of the groups was intended to provide the complete data of 20 patients for analysis in each group. Patients were assigned to groups by block randomization on the basis of the initial time required to walk 10 m without assistance. The 60 subjects were randomized into 1 of 3 groups: the STT (n=20), LTT (n=20), and control (CGT; n=20) groups. All subjects were evaluated before commencement of training, after 2 weeks, and at the end of the 4-week training period. Table 1 shows the characteristics and the pretraining scores of the study participants. To minimize the proven effect of body weight support on the results,[2] body weight support was allowed only in the first 3 training sessions of the treadmill-trained groups (STT and LTT). Body weight was supported with an overhead harness bearing no more than 10% of the patient's weight during treadmill training.[2]

Training Programs and Strategies

All patients participated in 12 training sessions during the study period. Training programs are shown in Table 2. The per-session duration of actual treadmill training was shorter than that of CGT for logistical reasons (eg, preparation time, time for moving the patient). The special training strategies are described below.

Structured Speed-Dependent Treadmill Training

The goal of STT was to achieve an increase in walking speed with each training session. All patients wore an unweighted

TABLE 2.   Training Programs

	CGT Group (n=20)	LTT Group (n=20)	STT Group (n=20)
Component 1	12×45 minutes of CGT	12×30 minutes of LTT	12×30 minutes of STT
Component 2	8×45 minutes of conventional physiotherapy, gait training allowed	8×45 minutes of conventional physiotherapy, gait training allowed	8×45 minutes of conventional physiotherapy, gait training allowed
Total	15 hours of treatment	12 hours of treatment	12 hours of treatment

safety belt. The patients were assisted during the treadmill training by a physical therapist, but the therapist gave no assistance in the actual performance of the movements. Because of the high belt speeds, the therapist was unable to provide any direct facilitation of the walking cycle. The maximum overground walking speed (V0max) was determined before the first training session. This speed was then halved and used for a 5-minute warm-up on the treadmill. After the warm-up, the first speed-dependent training phase (Vt1) began. During a period of 1 to 2 minutes, the belt speed was increased, in communication with the patient, to the highest speed at which the patient could walk safely and without stumbling. This maximum-achieved belt speed (Vt1) was held for 10 seconds, followed by a recovery period during which the patient's pulse was allowed to return to its resting level. If the patient maintained the speed and felt safe during the 10 seconds at Vt1, the speed would then be increased by 10% during the next attempt. This speed (Vt2) was again held for 10 seconds, followed by another recovery period. If the patient, during any phase, was unable to maintain the speed, felt unsafe, or stumbled on the belt, the speed was reduced by 10% in the next phase (V0max−10%, Vt1−10%, Vt2−10%, . . .). Each time the patient successfully completed 10 seconds of walking at the set speed, the speed was increased during the next phase by 10%. Over the course of each training session, the speed was increased at least by a factor of 3 and at most by a factor of 5 (Vt1 to Vt5). The total walking distance varied from session to session. At the next training session, the treadmill would be set (after a short warm-up) to the last-achieved maximum speed from the previous session. The treadmills were run at 0% incline.

Limited Progressive Treadmill Training

For the LTT group, the training speed was increased by no more than 5% of the maximum initial walking speed each week (20% over 4 weeks). The total walking distance was also allowed to vary in this group. During training, the therapist directly assisted the patients in executing the walking cycle. The treadmills were run at 0% incline.

Conventional Gait Therapy

Physiotherapeutic gait therapy based on the latest description of the principles of the proprioceptive neuromuscular facilitation (PNF) and Bobath concepts[15,16] was performed by experienced and skilled therapists with additional qualification in the PNF and Bobath techniques.

Cardiovascular Monitoring

Blood pressure and pulse were monitored manually during every training phase and during measurement of overground walking speed in all groups. Additionally, every treadmill training session was supervised by a nurse (S.R.). If blood

pressure rose to >200 mm Hg systolic or >110 mm Hg diastolic or pulse rose to >160/min, training was discontinued.

For the STT group, an entry screening test was performed to evaluate cardiovascular tolerance. Exercise tests were performed on a treadmill, with continuous monitoring of ECG and vital signs. The test was initiated with a belt speed of 0.2 m/s. The belt speed was increased by a maximum of five 0.1-m/s increments, according to the patient's tolerance. Testing was discontinued according to the guidelines of the ACSM.[13]

Clinical Outcome Measures

Clinical outcome measures of overground walking speed, cadence, stride length, and FAC scores were compared at the end of the training period. All clinical outcome measures were obtained as blinded tests by individuals who were unfamiliar with the group assignment.

The fastest comfortable overground walking speed was measured in meters per second as the subject walked across a 10-m walkway.[17] The walking speed was recorded with the use of a stopwatch. When overground walking speed was measured, the subjects were allowed to use walking aids such as foot ankle orthoses or walking canes. For better comparability, the same walking aids were used during each measurement of overground walking speed.

Cadence is defined as steps per minute. Stride length (meters) was determined by dividing the walking speed (meters per second) by cadence (steps per minute).[18]

The FAC distinguishes 6 levels of walking ability on the basis of the amount of physical support required, although it does not take into account walking aids such as canes.[19]

Statistical Analyses

To compare the baseline characteristics and the pretraining gait scores of the 3 study groups, ANOVA with post hoc Newman-Keuls multiple comparisons test was used for means, and χ^2 test was used for frequencies.

Differences in the clinical outcome measures overground walking speed, cadence, and stride length were evaluated by use of an ANCOVA for repeated measurements with a group factor *order* (STT, LTT, CGT) and a factor of repeated measurements *treatment* (after 2 weeks and at the end of the training program). Differences in the measure FAC scores were evaluated by use of an ANCOVA with only a group factor *order* (STT, LTT, CGT). The covariate used for all ANCOVA analysis was the level of ambulatory status (initial FAC scores). Post hoc Newman-Keuls multiple comparisons test (post hoc analysis) was used to determine differences of means between each group.[20]

TABLE 3.   Gait Parameters

Variable	CGT Group (n=20)	LTT Group (n=20)	STT Group (n=20)	Overall Significance*
Fastest comfortable overground walking speed, m/s				
At baseline	0.66±0.42	0.66±0.39	0.61±0.32	
After 2 weeks	0.84±0.60	0.86±0.57	1.13±0.59	P<0.001
At end of study	0.97±0.64	1.22±0.74	1.63±0.80	
Cadence, steps/min				
At baseline	79.9±29.7	82.8±33.2	81.6±22.8	
After 2 weeks	91.4±40.3	89.0±35.5	113.5±28.4	P<0.001
At end of study	96.8±39.0	115.4±51.9	128.8±30.1	
Stride length, m				
At baseline	0.46±0.15	0.45±0.13	0.42±0.13	
After 2 weeks	0.51±0.18	0.52±0.17	0.57±0.16	P<0.001
At end of study	0.56±0.17	0.60±0.16	0.72±0.21	
FAC score				
At baseline	3.9±0.7	3.7±0.8	3.7±0.8	P<0.001
At end of study	4.3±0.7	4.6±0.6	5.0±0	

Values are mean±SD.

*Interaction between factors *order* (STT, LTT, and CGT) and *treatment* (values at baseline, after 2 weeks, and at end of study) revealed by ANCOVA.

Results

In all groups, no cardiac symptoms (eg, angina pectoris) or other side effects (eg, dizziness, muscle or joint trouble) were reported by the patients during the training sessions. Additionally, no significant arrhythmia, fall in systolic blood pressure from baseline, or rise in systolic blood pressure or pulse rates over cutoffs was observed by the supervising staff. One patient in the LTT group felt vertiginous at the beginning of the third training session, but this did not lead to a termination of this training phase.

The means (±SD) of the outcome measures are shown in Table 3. ANCOVA revealed significant effects of the factor *order* (F=4.5, P=0.02), the factor *treatment* (F=8.9, P=0.03), and the interaction between factors *order* and *treatment* (F=7.3, P<0.001) for overground walking speed. For cadence, ANCOVA also revealed significant effects of the factor *order* (F=4.9, P=0.01), the factor *treatment* (F=8.9, P=0.03), and the interaction between factors *order* and *treatment* (F=8.5, P<0.001). Although there was no effect of the factor *order* (F=2.7, P=0.08), ANCOVA revealed significant effects of the factor *treatment* (F=8.9, P=0.03) and the interaction between factors *order* and *treatment* (F=8.5, P<0.001) for stride length. The influence of the different gait training strategies on outcome measures (defined as interactions between factors *order* and *treatment* across the 3 groups) is shown in Table 3.

In a comparison of the single groups with each other, post hoc analysis revealed significant differences in all gait parameters between STT and CGT (overground walking speed [P<0.001], cadence [P<0.001], and stride length [P<0.001]) and between STT and LTT (overground walking speed [P<0.001], cadence [P=0.007], and stride length [P<0.001]). In a comparison of LTT with CGT, post hoc

analysis revealed significant differences in overground walking speed (P=0.004) and cadence (P<0.001). No differences were found for stride length (P=0.12).

Differences in final FAC scores across the 3 groups were calculated with the use of ANCOVA with initial FAC score used as covariate. ANCOVA revealed a significant effect of the group factor *order* (STT, LTT, and CGT; F=16.9, P<0.001). In a comparison of the single groups with each other, post hoc analysis revealed significant differences in FAC scores between STT and CGT (P<0.001), between STT and LTT (P=0.007), and between LTT and CGT (P=0.02).

In the LTT group, the treadmill speed at the end of the program had been increased by 20% of the initial speed. In the STT group, the treadmill speed at the end of the program had been increased by an average factor of 3.7±1.9 of the original speed. The average treadmill speed at the last STT therapy session was 2.1±0.7 m/s. The average belt speed and average fastest comfortable overground walking speed at the end of therapy tended to be comparable in the STT group (P=0.1; for mean overground walking speeds of STT group, see Table 3).

Discussion

The results of this randomized trial suggest that structured speed-dependent training is more effective in improving gait parameters than training without significant speed increases. In addition, the study shows that treadmill training, with or without structured speed variation, is more effective than CGT in improving gait parameters. Although STT is a vigorous exercise for many patients, the patients' tolerance was excellent and was comparable with the other treatment strategies. In addition to the significant improvement of patients in the STT group, the authors observed an acceptance

of this form of therapy, although this was not a goal of the study.

Treadmill Training and Speed

The gait of a patient with hemiparesis is markedly slower than that of a normal person.[21,22] For patients with reduced walking ability, increasing walking speed results in giving that patient a greater behavioral repertoire in everyday life.[1,23] The literature suggests that an average walking velocity of 1.1 to 1.5 m/s is probably fast enough to be functional as a pedestrian in different environmental and social contexts (eg, crossing a street safely).[23] These speeds were generally achieved for the treadmill groups (STT and LTT) by the end of the study, representing safe and quick walking for these patients in everyday life.

In performance sports, it is known that speed training gives greater results when maximal, as opposed to submaximal, speeds are used.[8,9] This study has shown for the first time that this also carries over to patients with hemiparesis. Furthermore, modern concepts of motor learning favor task-specific repetitive training.[23] A guiding principle in the rehabilitation of neurological patients is that, in general, a skill will improve if it is practiced.[5,7,24] If this concept is applied to questions of gait speed, a person who wants to walk faster has to train his or her walking speed.[23]

In this respect, it is not surprising that speed training (on a treadmill) can improve walking speed (on the floor). In addition to speed gains, other gait parameters, such as cadence and stride length, were more greatly improved in the STT group than in the LTT and CGT groups. There was also a greater gain in independent walking ability in the STT group at the end of the program, as measured on the FAC scale.

Some researchers oppose speed-oriented treadmill training for patients with hemiparesis. It is feared by some that gait symmetry might worsen and that "unphysiological" walking patterns might become established, which would persist and be difficult to correct later.[5] In contrast, other investigators report that treadmill training can improve selected components of gait biomechanics and reduce the energy cost of floor walking in stroke patients.[6,25,26] Furthermore, many sources note that improvements in walking ability are strongly correlated with improvements in walking speed in patients with hemiparesis.[18,22] However, the results of this study can point to no conclusions in this regard because the walking safety and symmetry of the patients were not studied. Further research is required to address these concerns.

Velocity is not the only factor that is influenced when gait speed is changed. Muscular strength training, for athletes as well as poststroke patients, leads to improvement in both strength and gait velocity.[27,28] Furthermore, there is a direct correlation between muscle strength and maximum gait speed.[29] From this it may be supposed that training for gait velocity strengthens the lower limbs, which in return results in an improvement in walking speed.

Belt speed in the LTT group was increased by no more than 20% of the maximum initial walking speed over 4 weeks. Despite this, the LTT group experienced an 85% increase in overground walking velocity across the training epoch (Table

3). This implies that the modest increases in the treadmill training speeds used in the LTT group did not keep pace with their rate of gains in floor walking velocity. Therefore, LTT may be characterized as limited progressive in that the increases did not match the gains in gait velocity.

Treadmill and Overground Walking Speed

It must be emphasized that the baseline walking speed in this study (Table 3) was higher than that in other studies.[2,3,7,25] This is a result of the selection of fastest comfortable maximum walking speed as a parameter and also of the preexisting level of walking ability of the patients at the beginning of the study. The average baseline overground fastest comfortable walking speeds in this study were comparable to the maximum walking speeds of ambulatory patients described by Suzuki et al[30] (0.67 m/s at baseline) and Hesse et al[19] (0.84 m/s at baseline).

In comparison with other studies, a surprisingly larger gain in fastest comfortable overground walking speed was found in the CGT group. Hesse et al[19] found in comparable patients a gain in maximum walking speed from 0.84 to 0.9 m/s after a 4-week Bobath training program. Suzuki et al,[30] after 4 weeks of a computer-assisted gait training program, observed an improvement of maximum walking speed from 0.67 to 1.05 m/s. However, despite the high gain of speed in the CGT group in this study, the gain in the STT group was even higher.

Treadmill Versus Conventional Therapy

The study showed significant superiority of the STT and LTT groups compared with the CGT group with reference to the studied parameters. There were also significant differences between the LTT group and the CGT group with reference to walking speed, cadence, and FAC scores. The relative merit of treadmill training, in comparison with other forms of gait rehabilitation for hemiparetic patients, is a controversial topic in the medical literature.[3–5,26] Liston et al[31] found no difference between the effects of conventional physiotherapy and treadmill training on the gait of patients with higher-level gait disorders associated with cerebral multi-infarct states. In contrast, Hesse et al[3,32] observed better results with treadmill training than with physiotherapy based on the Bobath concept or "floor walking." However, in the authors' opinion, treadmill training with structured speed dependence is one of many task-specific training techniques. It cannot, therefore, replace physiotherapy, which addresses a variety of motor tasks, but it may serve as a powerful complementary tool in gait rehabilitation. Therefore, all patients in this study received additional physiotherapy, including gait training without the use of a treadmill, during the 4-week trials to improve such parameters as postural stability.

Study Design

One of the weaknesses of this study is the relatively small group size. However, this may be somewhat compensated for by the homogeneity of the groups. Furthermore, the short duration of the intervention and lack of testing for durability at a later time point are weaknesses of the study design. Richards et al[33] showed that the increased rate of gate recovery disappeared at 3

months after stroke. In contrast, Visintin et al[2] demonstrated that overground walking speed is a very stable parameter and that gains made during therapy were retained at a 3-month follow-up. According to Visintin et al,[2] the deciding factor in the long-term outcome of gait therapy is that the patient achieves the ability to walk without assistance. Worsening of walking speed is then only to be expected if the patient does not continue to walk. The study was designed, however, to investigate only the short-term effects of treadmill training.

Furthermore, it should be emphasized that only some of the possible gait parameters were taken into consideration in this study. The plan of the study did not take into account parameters such as endurance, motor recovery score, gait symmetry, or balance.[1,2]

Conclusions

This study demonstrates that gait therapy with structured STT is an effective approach, resulting in superior walking ability in ambulatory hemiparetic patients in comparison with the Bobath or PNF and LTT strategies. STT may be used in combination with other rehabilitation strategies, such as CGT based on Bobath concepts,[15] and body weight support[2] to improve walking ability in hemiparetic patients. Possible modifications of the STT program might include addition of treadmill incline, increase of the duration of maximum belt speed, and reduction in the use of a handrail to increase the postural training demand. This novel training strategy appears effective in enhancing locomotor recovery and provides a dynamic and integrative approach to treating gait dysfunction after stroke.

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