Research Report

Effect of Intensive Outpatient Physical Training on Gait Performance and Cardiovascular Health in People With Hemiparesis After Stroke

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Background. Stroke can result in severe motor deficits, and many people who have survived a stroke have poor cardiovascular fitness, with potentially disabling effects on daily life.

Objective. The objective of this study was to evaluate the impact of intensive physical training on gait performance and cardiovascular health parameters in people with stroke in the chronic stage.

Design. This was a single-group, pretest-posttest experimental study.

Methods. Fourteen people with hemiparesis after cerebrovascular injury (mean age=58.4 years, mean time since injury=25 months) participated in a 12-week training intervention, 5 times per week for 1.5 hours per session. The intervention consisted of high-intensity, body-weight–supported treadmill training; progressive resistance strength training; and aerobic exercise. The main outcome measures were gait performance (Six-Minute Walk Test, 10-Meter Walk Test, and aerobic capacity) and parameters of cardiovascular health (systolic and diastolic blood pressures, body mass index, and resting heart rate).

Results. Significant improvements in all main outcome parameters were observed in response to the intervention. Gait speed during the Six-Minute Walk Test increased 62%, and systolic and diastolic blood pressures decreased 10% and 11%, respectively. Weekly testing of walking speed showed that most of the increase in the walking speed occurred in the first 8 weeks of training. Correlation analyses showed that improvements were unrelated to age, chronicity, or level of functioning.

Conclusions. High-intensity physical training for people with stroke in the chronic stage increased walking speed regardless of chronicity, age, or level of functioning. Further studies should investigate the intervention duration needed to reach the full potential of gait recovery.

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Stroke is the most common form of acquired brain injury and is one of the leading causes of death and disability worldwide.[1] In Denmark alone, 11,000 people in a total population of 5.4 million have a stroke annually. A slightly higher relative number of people have a stroke each year in the United States.[2] It has been estimated that at any given time, 30,000 to 40,000 people who have survived a stroke reside in Denmark, incurring high expenses for primary health care, social services, and disability pensions.[3] Hemiparesis is a common consequence of stroke and often leads to problems across multiple systems, including loss of strength (force-generating capacity) and dexterity and poor motor control. Upper-extremity (UE) and lower-extremity (LE) pareses, frequently combined with significantly reduced overground walking speed and walking distance, constitute severe impediments to the ability to perform activities of daily living, participate in normal social life, and manage gainful employment. In addition to persistent motor deficits, concomitant poor endurance and increased fatigability can constitute a psychological burden to people with stroke, as well as their significant others.

At 6 months after the onset of stroke, people are in the chronic stage, and the physical therapy goal often shifts from rehabilitation to maintenance training.[4] Although persistent hemiparesis and concomitant low levels of physical activity are independent risk factors for new cerebrovascular and cardiovascular events,[5] rehabilitation and maintenance training time allocated by private and public physical therapy clinics in Denmark to people with chronic stroke amounts to no more than 1 hour once or twice per week. The lack of available equipment constitutes a further hindrance to training efficacy. These factors may explain why the intensity of conventional physical therapy delivered to people with hemiparesis tends to be low to moderate. Despite rehabilitative interventions, motor sequelae remaining after discharge often are considerable.[6] The comprehensive Copenhagen Stroke Study showed that functional and neural recovery reached a plateau within 6 to 20 weeks after the lesion.[7] The absence of further recovery over time may be ascribed partly to the facts that the above-mentioned parameters are assigned the lowest priority in neurorehabilitation, that the intensity of physical rehabilitation is inadequate, or both.[8]

Body-weight–supported treadmill training (BWSTT) currently is gaining recognition as an effective way to improve walking ability after stroke. Evidence for this type of intervention has not yet been fully established, and research results are not yet unanimously favorable. On the basis of a review of 15 trials including 622 participants, Moseley et al[9] concluded that there were no statistically significant differences between treadmill training, with or without body-weight support, and other interventions for walking speed or independence. However, they found a non–statistically significant tendency for independent walkers training with BWSTT to show improvements in walking speed. In addition, they noted that the treatment effects might be highly dependent on the intensity of the protocol used. Other researchers have obtained more promising results in favor of BWSTT compared with conventional treatments. Pohl et al[10] found significantly higher overground walking speed, cadence, stride length, and Functional Ambulation Category scores in a study comparing the effects of high-intensity, speed-dependent treadmill training with the effects of limited progressive treadmill training and conventional gait training for people with hemiparesis. These data support the use of a high-intensity training protocol, an observation supported by other research groups.[11,12] However, more research is warranted in this area.

Weakness after stroke is a common phenomenon, and emerging evidence suggests that it may be responsible for compromised motor function[5] and that it is related to functional activity performance.[13] Notably, gait ability is closely related to muscle strength.[14,15] Consequently, the restoration of muscle strength should be a cornerstone of rehabilitation. A systematic review of the effects of progressive resistance strength training (PRST) revealed preliminary evidence that PRST programs reduce musculoskeletal impairment, but whether they enhance the performance of functional activities and participation in societal roles remains unknown.[16] The failure to demonstrate consistent benefits of PRST may be due to the heterogeneity of symptoms typically found in people with hemiparesis.[17]

Along with impaired muscle strength and gait in people with hemiparesis, cardiovascular fitness after a stroke has been found to be as low as 50% to 70% of that of sedentary age- and sex-matched individuals.[18] The level of physical activity is related to the aerobic capacity, and a critical level of aerobic capacity must be met to function independently.[13] The energy level required to perform routine ambulation is 1.5- to 2-fold higher in people who have had a stroke than in people who are healthy, and this level can represent 76% of physiological capacity.[13]

On the basis of a recent Cochrane review,[19] including 12 studies, the Danish National Board of Health concluded that aerobic exercise improves ambulation after stroke. The board consequently recommended that aerobic exercise be included in rehabilitation after stroke.[3]

Because weakness after stroke and a low level of fitness appear to be related to functional activity performance, it seems advisable to emphasize the importance of allocating rehabilitation time to the enhancement of strength training and aerobic exercise (AE) through high-intensity training. Numerous studies have provided evidence that PRST increases strength and that AE increases peak oxygen consumption ($\dot{V}O_2$),[14,20] but there is limited evidence for the generalizability of such increases to increased functional activities in people with stroke. The paucity of evidence may be ascribed to the heterogeneity of study participants and to the fact that the relatively low levels of intensity and allocation of many interventions cannot elicit the desired generalizations. The combined effects of PRST, AE, and BWSTT have scarcely been investigated, although promising results have been demonstrated in a single study.[21] It is clear that more research is needed in this area. At present, conventional stroke rehabilitation in Denmark does not comprise intensive strength training or BWSTT.

The aim of this study was to investigate the effects of high-intensity BWSTT, PRST, and AE on gait performance and cardiovascular health parameters in people with post-stroke hemiparesis in the chronic stage. We hypothesized that the training intervention would lead to significant improvements in participants' gait performance and cardiovascular health, regardless of age, time interval between the injury and the start of the intervention, and amount of physical training received before the intervention.

Method

Design

We used a single-group, pretreatment-posttreatment design, with measurement of participants' aerobic capacity before and after the 12-week training intervention. Additionally, participants' performance during physical training was monitored each week (ie, 12 measurements).

Participants

The participants were people with cerebrovascular injuries (3 left-hemisphere lesions and 11 right-hemisphere lesions) in the chronic stage and with hemiparesis resulting in moderate to severe UE and LE motor impairments. Ten of the participants had no volitional function of the affected UE; the remaining 4 participants were able to use the affected UE for support but not for any activities requiring dexterity. All 14 participants were unable to stand on the affected LE without support. None of the participants was able to perform volitional dorsiflexion or eversion of the affected ankle or isolated flexion of the hip or knee on the affected side while standing.

Inclusion criteria were a chronicity of more than 3 months; moderate to severe hemiparesis, with pronounced spasticity (hypertonicity) and synergistic movements of both the UE and the LE and with no volitional dorsiflexion and eversion of the affected ankle joint and no volitional flexion of the hip and knee joints on the affected side while standing; and an age of at least 50 years. Gait function had to be moderately to severely impaired, so that the maximum walking speed would be less than 50% of the normal walking speed for age-, height-, weight-, and sex-matched people.[22] Participants had to be able to perform the Six-Minute Walk Test (6MWT).

All referrals to the program were made by physicians or general practitioners who, having received detailed information about the intervention, had not found the strenuous nature of the intervention to constitute a contraindication to participation. Although exclusion criteria did not comprise atrial fibrillation and previous strokes or heart attacks, all participants s in the present study had experienced only a first-ever stroke, and none had a medical history of atrial fibrillation or heart attacks. All participants were medically stable, independent with regard to basic activities of daily living, and motivated for strenuous physical exercise. Alcohol or substance abuse, psychiatric disorders, and any progressive diseases were exclusion criteria. Medications used by the participants were statins (n=8), antihypertensives (n=8), blood thinners (n=7), anticoagulants (n=6), diuretics (n=3), antispasmodics (n=3), anticonvulsants (n=3), β_1-receptor blockers (n=2), antidepressants (n=4), and nonprescription analgesics (n=3). Of those medications, only the β_1-receptor blockers affect exercise tolerance by lowering the maximum heart rate. There were no changes in medications over the study period, except that one individual began taking nonprescription analgesics and antidepressants during the study.

A total of 31 people were referred to the program. Seven individuals were excluded from participation for the following reasons: gait function was too severely impaired for 2 people to adhere to the initial test requirements, 2 people had an impairment other than hemiparesis, 2 people had to interrupt their participation because of illness, and 1 individual did not participate on a regular basis. Twenty-four people participated in the intervention, but 10 of these participants were excluded from the present study—not because of significantly different outcomes but to obtain group homogeneity with regard

Table 1.
Demographic and Medical Characteristics of Participants[a]

Characteristic	Minimum	Maximum	Percentiles			$\overline{X}$ (SD)
			25%	50%	75%	
Age at injury (y)	51.3	70.1	53.3	57.7	61.3	58.4 (6.1)
Age at program entry (y)	52.4	71.4	55.9	58.9	63.6	60.4 (5.7)
Time between injury and beginning of training (mo)	2.7	84.7	6.5	18.1	31.3	24.6 (23.1)
Amount of training before intervention (h/wk)	0.0	6.0	1.9	2.8	4.2	3.0 (1.7)

[a] Thirteen participants (93%) were men, and 1 participant (7%) was a woman.

to age and etiology. Among the participants excluded were people with traumatic brain injuries, space-occupying lesions, and tumors. Consequently, the present study included only 14 of the 24 participants who completed the full 12-week intervention. All but 1 participant required some type of walking aid on admission; 11 used a cane or crutch, and 12 used an ankle-foot orthosis. Finally, 2 of the participants used wheelchairs, 2 participants used an electric scooter, and 1 participant used a wheeled walker.

Table 1 shows the demographic and medical characteristics of the 14 participants. Time since injury varied from 3 months to 7 years. The distribution of time since injury was heavily skewed; 50% of the participants began the intervention within the first 16 months after the injury, and 86% began within the first 40 months. Preintervention training time with a physical therapist varied considerably. Although only 1 participant had received no training at all and 2 participants had received more than 5 hours of training, 79% of the participants had received between 1.5 and 5 hours of training per week. Although the majority of the participants were men (only 1 woman was included in the study), this skewed sex distribution was coincidental and did not reflect the general referral pattern. All participants provided written informed consent before participation in the study.

Intervention

The intervention took place at the gait rehabilitation facility of the Center for Rehabilitation of Brain Injury (see video, available at ptjournal.apta.org). The facility had been especially equipped for the project, which comprised 12 weeks of training, 5 times per week for 1.5 hours per session. The intervention consisted of 4 key elements: BWSTT, AE, PRST, and functional training. The chief objective was to improve gait function (ie, ambulatory safety), walking speed, and walking distance. Moreover, the intervention aimed at improving maximum muscle strength and cardiorespiratory fitness.

Each intervention week comprised 3 days with the main emphasis on strength training activities and 2 days with an emphasis on cardiorespiratory endurance training and functional training. Training sessions on all training days invariably began with BWSTT. To ensure safety and maximum training intensity, a personal physical therapist was assigned to each participant. All output data were collected on individual preprogrammed USB memory sticks (TGS*) and stored on the central computer together with heart rate data from all AE sessions. The participants' personal physical therapists evaluated and revised training output daily to ensure continuous improvement. Decisions about progression and daily reprogramming of the USB memory sticks were made jointly by the physical therapists but often required *ad hoc* adjustments because of overestimation or underestimation of participants' energy, strength, and endurance, which fluctuated not only from day to day but also during the course of the training sessions. Maximum walking speed was assessed every Monday with the 6MWT, the 10-Meter Walk Test (10MWT), or both to ensure continuous walking speed progress and to boost participants' motivation and adherence.

To promote the transfer of training progress to daily life and to secure optimum restitution after the intensive strength training, we modified the training schedule for weeks 4 and 10. In these weeks, the tasks consisted of treadmill training and functional training but not PRST.

BWSTT. The BWSTT system used was a prototype developed by the Center for Rehabilitation of Brain Injury in collaboration with Ergolet A/S,† which specializes in track lift

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† Ergolet A/S, Taarnborgvej 12C, DK-4220 Korsoer, Denmark.

systems. Mounted on a 10-m ceiling track, the track lift either can be used in a locked position or can ride freely along the rail, thus making it possible to put the harness on before stepping onto the treadmill. The lift system is an open-loop, force-controlled mechanism, operating with a pneumatic cylinder. Attached at one end to the lift and at the other end to the weight relief spreader bar, the lift cable travels over a 55-cm lever with a floating range from top to bottom of 50 cm; therefore, a constant amount of body-weight support is delivered when the center of mass fluctuates along a sinusoidal wave, which often is exacerbated by a pronounced limp. The weight relief can be adjusted from 0 to 80 kg; the maximum lifting capacity is 200 kg. The harnesses were Guldmann Active Trainer harnesses,[‡] and the treadmill was a standard Technogym Runrace treadmill* with TGS USB memory sticks.

The chief goal of each treadmill session was for participants to walk as far and as fast as possible without breaking up the gait pattern or risking safety, while increasing the maximum walking speed whenever possible and constantly focusing on movement quality. Training sessions on the treadmill lasted up to 25 minutes and normally consisted of 3 walking periods of 6 to 8 minutes each, interspersed with breaks. Some participants walked less and needed more breaks because of fatigue. Ideally, the 3 walking periods were designed to focus on 3 components of gait: symmetry and balance, fluctuating speed, and cardiorespiratory endurance. For all components of gait, the highest safely attainable speed was encouraged. However, given the heterogeneity of the participants, we made allowances for individual gait patterns, muscle strength, and endurance. Although it was impossible to adhere strictly to a subdivision into separate and distinguishable walking periods, physical therapists attempted to observe the following basic principles:

- All participants were encouraged to maintain a treadmill speed that was significantly higher than the average speed of the most recent 6MWT.
- Holding on to the bar of the treadmill was permitted only when absolutely necessary.
- The cardiorespiratory system was challenged by increasing speed and by increasing the treadmill gradient up to 10% to approach, as closely as possible, 80% of the maximum heart rate.
- To promote movement quality at higher walking speeds and higher levels of cardiovascular intensity, some participants were fitted with an Activister,[§] an elastic band that was twisted around the LE to correct excess lateral (external) or medial (internal) rotation, depending on the direction of the band.
- Some participants required manual guidance from therapists during various parts of the gait cycle to enhance gait quality and walking speed.
- Body-weight support, which was determined as the amount of support that would enhance gait quality, varied from 10 to 25 kg.
- Treadmill speeds, intervals, gradient, and dosage were evaluated daily and increased whenever possible.

Aerobic exercise. Aerobic exercise comprised 5 separate training stations with TGS USB memory sticks: BWSTT (Technogym Runrace), stationary bipedal and unipedal paretic leg cycling (Technogym Bikerace HC600*), unipedal paretic arm cycling (Technogym XT PRO Top600*), and body-weight–supported stair climbing (Technogym Steprace HC300*). Training intensity was monitored with a heart rate monitor transmitting continuously to the TGS key of the training station to ensure an adequate aerobic challenge. At the beginning of the intervention, some participants could not reach the heart rate target zone; in 2 cases, the explanation was the heart rate–lowering effect of β_1-receptor blockers. The goal for these individuals was to gradually maximize the heart rate attained in each activity. Except for weeks 4 and 10, Mondays and Wednesdays were AE days, with approximately 1 hour of aerobic exercise after the initial 25 to 30 minutes of BWSTT. The actual amount of cardiorespiratory training achieved during the 2 weekly AE sessions depended on each participant's endurance. At the beginning of the 12-week program, most participants were so deconditioned and unaccustomed to cardiorespiratory challenges that their endurance permitted only short bursts of 5 to 6 minutes of any given activity at an intensity of 80% of the maximum heart rate before they required a break and a drink of water. As fitness levels improved, so did endurance and acceptance of more time spent on each activity. Toward the end of the training program, most participants were able to tolerate 12 to 15 minutes of each cardiorespiratory activity at a heart rate of at least 80% of their estimated maximum heart rate (220 bpm minus age [in years]).

The principal goal of AE was to increase power output (ability to perform work over time), measured in watts, on the display of the machine; consequently, the goal of each training session was to exceed the highest previous power output achieved. This goal was emphasized before each activity, and feedback about performance and goal attainment was given continuously. Power output was measured in watts by the computer of each machine and

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[‡] V Guldmann A/S, Graham Bells Vej 21–23A, DK-8200 Århus N, Denmark.

[§] Ortopaedingenioerene, Gl. Darupvej 5C, DK-4000 Roskilde, Denmark.

Table 2.
Progression of Number of Repetitions in Progressive Resistance Strength Training

Week	Repetition Maximum	Week	Repetition Maximum
1	12, 12, 12	7	12, 10, 10, 8
2	10, 10, 10	8	10, 8, 8, 8, 6
3	8, 8, 8, 8	9	8, 6, 6, 6, 4
4	Functional training	10	Functional training
5	8, 8, 8, 8	11	10, 8, 8, 6
6	8, 8, 8, 8	12	8, 6, 6, 4

saved on TGS keys. In addition to increasing power output, there could be other goals, such as improving cadence or symmetry. Furthermore, during training for overground walking and stair climbing, participants wore a heart rate monitor to ensure an adequate aerobic challenge. Cardiorespiratory training was evaluated daily and, when possible, adjusted and increased.

Progressive resistance strength training. Progressive resistance strength training comprised 4 activities with TGS USB memory sticks: semiseated leg press, leg curl, leg extension, and seated leg press with a Technogym Isotonic Line with Power Control[§]; the equipment offered visual feedback with regard to range of motion and power output in watts for each repetition and average power output for each set of repetitions. Except for weeks 4 and 10, Tuesdays, Thursdays, and Fridays were PRST days, with approximately 1 hour of resistance training after the initial 25 to 30 minutes of BWSTT. Although only 3 to 5 sets were performed unilaterally for 4 resistance activities, the total time spent on resistance training usually amounted to 1 hour per session because transferring from one training station to another as well as resting between sets was very time-consuming. Progressive resistance strength training was performed unilaterally with the paretic leg to ensure the highest possible training intensity for the affected extremity. Sets, repetitions, and a 90-second resting pause between sets were identical for all participants. The weight load of each set was adjusted so that participants could only just perform the number of repetitions required in the set, that is, to volitional failure. All repetitions had to be performed with as much burst as possible to promote maximum movement speed and range of motion. The progression of the number of repetitions during the course of the PRST program is shown in Table 2.

Functional training. In weeks 4 and 10, the training program was changed to ensure the effectiveness of the intensive BWSTT, PRST, and AE. In week 4, functional training replaced all PRST and AE; 0.5 hour of BWSTT per day was retained. In week 10, functional training also replaced all PRST and AE, except on the middle day of the week (Wednesday), when PRST was retained. On Fridays of weeks 4 and 10, the functional training concluded with a "walkathon," a self-paced 30-minute walking test in which the participants covered as much distance as possible, thus proving the effects of their efforts. The components of functional training depended on the functional level of each participant, the goal being to ensure optimum carryover from functional improvements to activities of daily living. Functional training comprised training for specific details of the gait pattern, gait training in a nonclinical setting, stair climbing, and transfers. For participants with the potential ability to learn to ride a tricycle, outdoor cycling also was introduced in weeks 4 and 10.

Measures

The following measures were used at the beginning and end of the program. Systolic and diastolic blood pressures and resting heart rate were measured on the nonparetic arm with an Omron M4 device[‖] after the participant had been seated for 10 minutes; the average of 3 consecutive measurements was calculated. Body weight was measured with a Tanita BWB-600 scale[#] (we subtracted 2 kg for clothing and shoes), height was measured, and the body mass index was calculated.

Walking speed was tested with the 6MWT[23] on an indoor 50-m track without disturbances. No encouragement was offered during the test, except for information provided once per minute about time elapsed. Participants used their customary assistive devices during the test; however they were requested to walk without support from an elbow crutch or cane when possible.

[‖] Omron Corp, Shiokoji Horikawa, Shimagyo-ku, Kyoto 600-8530, Japan.
[#] Tanita Europe BV, Kruisweg 813-A, 2132NG Hoofddorp, the Netherlands.

Table 3.
Test Results Obtained Before and After Program

Test	No. of Participants	Before Program		After Program		Mean Difference (95% Confidence Interval)	P^a
		$\bar{X}$ (SD)	Median	$\bar{X}$ (SD)	Median		
Systolic blood pressure (mm Hg)	12	142.3 (17.7)	144.5	127.6 (14.2)	126.0	14.7 (6.2–23.2)	.005
Diastolic blood pressure (mm Hg)	12	88.0 (10.2)	87.0	78.3 (10.3)	78.5	9.7 (3.2–16.1)	.017
Resting heart rate (bpm)	12	70.3 (10.6)	73.0	66.9 (11.0)	63.5	3.4 (−2.2–9.1)	.27
Body mass index (kg/m^2)	11	28.9 (4.3)	28.5	28.1 (4.3)	27.5	0.8 (0.2–1.4)	.005
Six-Minute Walk Test (km/h)	14	2.1 (1.1)	2.1	3.4 (1.3)	3.8	1.3 (1.0–1.6)	<.001
10-Meter Walk Test (s)	14	18.9 (12.2)	14.5	11.5 (9.1)	8.4	7.4 (4.4–10.4)	.001
Estimated aerobic capacity (mL O_2/min/kg)	5	22.4 (3.8)	21.7	26.5 (2.7)	26.0	4.1 (−0.7–8.9)	.08
Self-rated maximum walking distance (m)	11	1,570.5 (1,546.0)	1,500.0	3,171.4 (2,041.4)	3,000.0	1,601 (679–2,523)	.003

[a] As determined with the Wilcoxon matched-pairs signed rank test (1-tailed).

The 10MWT was used to assess participants' maximum walking speed over a short distance.[24] A 10-m portion of the 50-m track was used. The fastest of 3 attempts was used. They were requested to walk without support from an elbow crutch or cane when possible.

Participants' cardiorespiratory endurance was estimated by use of the submaximal stationary ergometer test from the Åstrand and Rhyming calculation of aerobic capacity from heart rate during submaximal work[25,26] in combination with the Borg Rating of Perceived Exertion.[27] Only 5 participants were able to complete the initial cardiorespiratory test. An additional 3 participants were able to complete the final test. The reason why 3 more participants were able to complete the postintervention test was that their aerobic capacity had improved sufficiently.

During the initial interview, participants were requested to estimate their maximum walking distance in meters when walking without any interruptions or breaks and when using their customary assistive devices. Three participants were unable to provide an estimate of their maximum walking distance. Participants also were asked about the amount and nature of training that they were receiving at the time of the interview.

Participants' performance was monitored once per week throughout the intervention by administering the 6MWT on Mondays and calculating their average walking speed during the fastest treadmill training interval on the Monday training sessions each week.

Data Analysis

For inferential statistics, we used nonparametric procedures (Spearman correlations, Friedman test, and Wilcoxon signed rank test with α set at .05). For the examination of improvements in test performance, 1-tailed tests were used. For investigation of the relationship between improvements in test performance and participants' age, time since injury, and amount of training before the intervention, 2-tailed tests were used. Statistical analyses were performed with SPSS 13.0** and GPOWER.[28]

Role of the Funding Source

Subjects' participation in the intervention was funded by public health care. Equipment and research expenses were funded by the Center for Rehabilitation of Brain Injury, which is a nonprofit rehabilitation facility.

Results

Gait Performance and Aerobic Capacity

The group of participants as a whole improved on almost all measures of gait performance and aerobic capacity (Tab. 3). The improvements were consistent across participants. On the 6MWT and the 10MWT, all participants showed improved performance. On the submaximal stationary ergometer test, 4 of 5 participants showed improvements, and 3 participants who were unable to complete the initial test were able to complete the final test. These objective findings were reflected by the participants' own experiences. All participants experienced improvements in maximum walking distance. Their self-rated improvement of 102% was considerably higher than the objective improvements (62%, 39%, and 19% on the 6MWT, on the 10MWT, and in aerobic capacity, respectively). Finally, systolic

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** SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

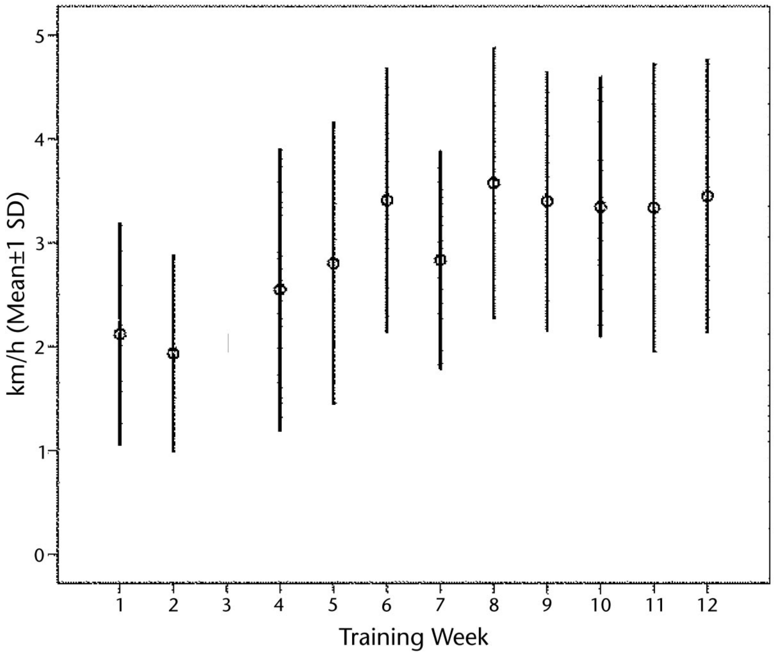

Figure 1.
Improvement in participants' walking speed on the Six-Minute Walk Test during the training period. Data are means (circles) and standard deviations (error bars).

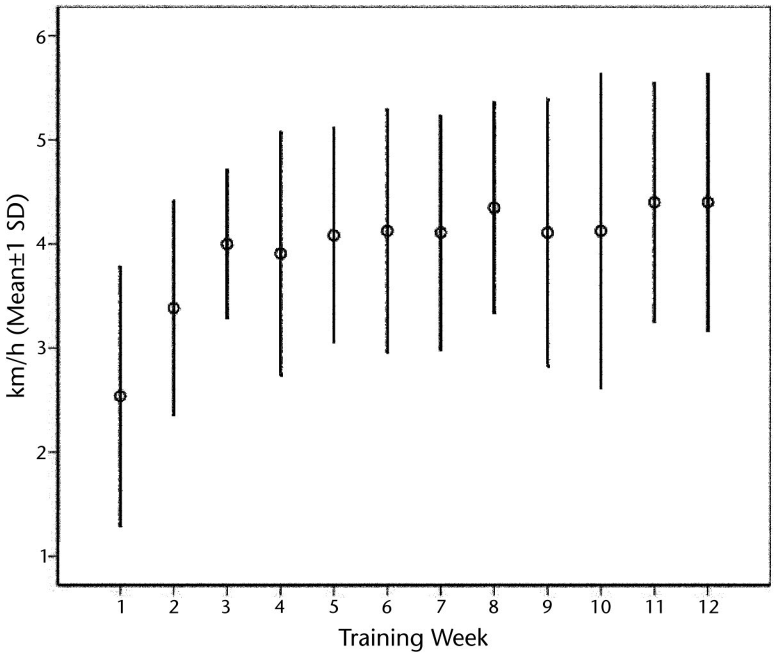

Figure 2.
Improvement in participants' walking speed during the fastest treadmill training interval. Data are means (circles) and standard deviations (error bars).

and diastolic blood pressures decreased by 10% (P=.005) and 11% (P=.017), respectively.

Relationships Among Main Parameters

We examined whether the improvement in aerobic capacity was related to the participants' age and the time interval between the brain injury and the initiation of the intervention. Age and time from injury to the initiation of the intervention were not related to aerobic capacity at the initiation of the intervention or to the improvement in aerobic capacity. No significant relationship between the amount of standard physical therapy training received before the intervention and the physical improvements experienced during the intervention was observed.

Time-Wise Progression of Improvements

We examined the time course of improvements in the participants' walking speed on the 6MWT during the training period. The number of participants for whom walking speed data were available varied from week to week, from 8 to 14. As shown in Figure 1, participants showed approximately linear improvements in walking speed until week 8, when a plateau was reached (Friedman test, P<.001). The 6MWT results from week 1 and week 12 resembled the test results from before the intervention and after the intervention, respectively.

We next examined the time course of improvements in the participants' walking speed during the fastest treadmill training interval. In most weeks, 1 to 3 participants were not able to attend the test; in week 10, 6 participants could not attend for logistical reasons. The dramatic increase in performance occurring in the first 3 weeks of training was followed by more gradual, but still continuous, improvements in speed

(Friedman test, $P<.001$) (Fig. 2). At all time points, the participants' walking speed during the fastest treadmill training interval was above the speed on the 6MWT. This finding was statistically significant at all time points except weeks 1, 8, and 10 (Wilcoxon matched-pairs signed rank test, 2-tailed).

Discussion

The principal findings of the present study are that people with stroke in the chronic stage can achieve clinically relevant improvements in gait performance and cardiovascular health parameters through high-intensity physical training consisting of a combination of BWSTT, PRST, AE, and functional training.

Gait Performance and Aerobic Capacity

Common physical impairments after stroke are poor strength, a low level of fitness, and slow ambulation. These impairments, in combination with cognitive deficits, lead to decreased levels of activity and participation. Interventions for people in comparable age groups, for whom improvements in gait function had a priority similar to that in the present study, included just one element of physical training to determine its effect. Isolated BWSTT gait interventions resulted in improvements on the 6MWT, albeit of a magnitude more modest than that in the present study.[29,30] Likewise, an examination of the effects of isolated PRST on gait, various functional parameters, and strength in people with post-stroke hemiparesis and similar in age and chronicity to the participants in the present study revealed that although significant strength improvements could be elicited through PRST, no significant difference between intervention and control groups could be found for any performance-based measure of function. However, a nonsignificant improvement of 10% on the 6MWT was noted.[31] It is likely that the best effects of various elements can be achieved when they are combined. The literature offers little evidence for the generalizability of increased strength to increased functional abilities, but if strength training is combined with goal-oriented exercise, the outcome may be different. Our intervention included various elements of training at the highest possible level of intensity; this design made it more difficult to determine which element was responsible for which portion of the overall effect.

The results of the present study, however, showed that the intervention had large effects on all parameters. The cardiovascular improvements achieved—10% and 11% decreases in systolic and diastolic blood pressures, respectively—were capable of significantly reducing the risk of recurrent stroke.[32] The effects of exercise on blood pressures in the present study, therefore, were consistent with or superior to the findings of a similar study. Rimmer et al[33] found that moderate-intensity, shorter-duration exercise had more favorable effects on systolic and diastolic blood pressures than did lower-intensity exercise but that neither moderate-intensity exercise nor lower-intensity exercise could induce significant changes in peak $\dot{V}O_2$ or submaximal $\dot{V}O_2$. It may be presumed that the intensity of that intervention study was too low to elicit changes in $\dot{V}O_2$. A reduced risk of recurrence is commonly achieved medically, but if risk reduction is induced through an increase in activity, then it will have other beneficial effects as well.

Although the speed of gait increased markedly in the present study, we did not include any objective measures of movement quality during gait. However, our clinical observations indicated that the increase in walking speed was principally attributable to improvements in stance phase and stride length in the affected leg, as well as to an increase in steps per minute. The clinical relevance of increased walking speed is irrefutable. It has been demonstrated that the functional walking speed in a community environment should be between 4.1 and 5.4 k/h[13]; therefore, the participants in the present study attained functionality.

Strengthening of the affected leg is a key element in a more stable stance phase. Therefore, PRST may have contributed to the increased speed on the 6MWT. During the initial weeks of the intervention, walking speed gradually decreased during the performance of the 6MWT because of fatigue, but by the end of the intervention, most of the participants were able to maintain a constant speed throughout the test. This observation can be ascribed not only to increased muscular endurance and a higher level of fitness but also to a more energy-efficient gait pattern.

Overall, no signs of increased spasticity were observed by therapists or reported by participants. During strenuous exercise, spasticity did increase temporarily in some participants but tended to abate when the exercise was stopped. Some participants felt uncomfortable about this increase in spasticity during exercise, interpreting it as a loss of control.

Relationships Among Main Parameters

Regardless of chronicity, aerobic capacity at the start of the intervention was low and not related to time since injury. The comprehensive Copenhagen Stroke Study reported that neurological recovery and functional recovery reach a plateau within 6 to 20 weeks after the occurrence of the lesion.[7] This report might imply that once motor function has reached a plateau, no further changes can occur unless there is a massive change in the level of activity. This notion is consistent with the fact that all participants in the present study showed the same amounts of improvements in physical parameters irrespective of age or time since injury. Consequently, it seems likely that this kind of intervention will have an effect on most people who have had a stroke.

Because all participants were in the chronic stage at the beginning of the intervention and because there was a substantial difference in the amounts of physical training that they received before the intervention, (ranging from 0 to 7 hours per week), the previous rehabilitative training did not relate to aerobic capacity at the beginning of the intervention or to improvements after the intervention. These findings indicate that an individual's potential for improvement is not related to a prior intervention. Most of the participants reported that training received before the intervention did not involve sweating or being out of breath because it was less intense than the intervention. Training intensity seems to play a crucial role in an individual reaching full potential for functional recovery. Another important aspect is the magnitude of the total training volume over the course of a training week. In addition, the elements of the training protocol are factors that determine outcome.

Time-Wise Progression of Improvements

The time course for treadmill speed improvements revealed a gradual decrease in the rate at which speed increased during the intervention. Therefore, speed was still increasing during the final weeks of the intervention, albeit to a lesser extent than during the initial weeks. These findings indicate that longer training periods of high-intensity BWSTT, PRST, and AE may lead to further improvements in physiological capacity. The other intervention elements also showed this tendency. Most of the initial progression appeared to be attributable to gradual adaptation to the exercises and determination of the appropriate level of intensity. Later, when the rate of progression decreased, further progression likely was attributable to real physiological changes.

The walking speed on the 6MWT increased approximately linearly throughout the intervention, indicating that if the duration of the intervention had been longer, then there might have been further improvement.

Because there is good evidence in the literature for speed-dependent BWSTT, 2 of the 3 sessions in the present study were speed dependent. In one session, the goal was to reach the highest speed possible; in the other session, the goal was quality of movement rather than speed, so the speed was to be slightly above the most recent 6MWT speed. During the entire intervention, participants maintained a treadmill speed that was substantially higher than the 6MWT speed; therefore, the 6MWT speed could serve as a parameter for setting the treadmill speed in BWSTT sessions.

It was possible to combine the interventions and sustain a high level of intensity for a 12-week period without any negative side effects. All participants but 1 were motivated during the entire intervention and were able to endure the intensity.

A limitation of the present study was the lack of a control group. However, as previously shown,[7] functional and neurological performance reaches a steady state within the first 6 months after injury. Because the average time since injury was more than 2 years in the present study, it is highly unlikely that the observed gains in ambulation and cardiovascular health could be ascribed to a natural course of recovery. However, the results of the present study should be tested in a future randomized controlled trial.

Conclusion

A high dose of intensive physical training for participants with stroke in the chronic stage (a combination of BWSTT, PRST, and AE 5 times per week for 1.5 hours per session for 12 weeks) increased walking speed on the 6MWT by 62%, regardless of chronicity, age, or level of functioning. Weekly testing of the walking speed revealed an almost linear progression during the entire intervention, indicating that an undetected and dormant plateau of recovery after stroke was reached for this group of participants. Further studies should investigate the duration of intervention needed to reach the full potential of recovery of gait.

All authors provided concept/idea/research design. Mr Jørgensen, Mr Bech-Pedersen, Mr Zeeman, Dr Andersen, and Dr Schönberger provided writing. Mr Jørgensen, Mr Bech-Pedersen, Mr Zeeman, and Mrs Sørensen provided data collection. Dr Schönberger provided data analysis. Mr Bech-Pedersen and Mrs Sørensen provided fund procurement and participants. Mr Zeeman and Mrs Sørensen provided facilities/equipment. Mrs Sørensen, Dr Andersen, and Dr Schönberger provided consultation (including review of manuscript before submission).

This study was approved by the local ethics committee (De Videnskabsetiske Komitéer for Københavns og Frederiksberg Kommuner, Copenhagen, Denmark; study approval no. KF-01-240/04).

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