Task-Related Circuit Training Improves Performance of Locomotor Tasks in Chronic Stroke: A Randomized, Controlled Pilot Trial

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ABSTRACT. Dean CM, Richards CL, Malouin F. Task-related circuit training improves performance of locomotor tasks in chronic stroke: a randomized, controlled pilot trial. Arch Phys Med Rehabil 2000;81:409-17.

Objective: To evaluate the immediate and retention effects of a 4-week training program on the performance of locomotor-related tasks in chronic stroke.

Design: Randomized, controlled pilot study with 2-month follow-up.

Setting: Rehabilitation center.

Subjects: A convenience sample consisting of 12 chronic stroke subjects was used. Subjects were randomly assigned to the experimental or the control group. Three subjects withdrew from the study.

Intervention: Both experimental and control groups participated in exercise classes three times a week for 4 weeks. The exercise class for the experimental group focused on strengthening the affected lower limb and practicing functional tasks involving the lower limbs, while the control group practiced upper-limb tasks.

Main Outcome Measures: Lower-limb function was evaluated by measuring walking speed and endurance, peak vertical ground reaction force through the affected foot during sit-to-stand, and the step test.

Results: The experimental group demonstrated significant immediate and retained (2-month follow-up) improvement ($p \leq .05$) compared with the control group in walking speed and endurance, force production through the affected leg during sit-to-stand, and the number of repetitions of the step test.

Conclusion: The pilot study provides evidence for the efficacy of a task-related circuit class at improving locomotor function in chronic stroke.

Key Words: Stroke; Exercise training; Rehabilitation.

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STROKE IS A MAJOR cause of disability and handicap in adults. While rehabilitation aims to reduce disability by optimizing the performance of everyday tasks, on discharge, many individuals are significantly disabled and handicapped.[1-3] For example, many individuals can walk independently; however, only a small proportion can walk with sufficient speed and endurance to enable themselves to function effectively within their community. Hill and colleagues[1] found that only 7% of patients discharged from rehabilitation met four criteria for community ambulation. In addition, individuals after stroke report low levels of physical activity after discharge from rehabilitation.[4] Thus, the persistent disability and handicap experienced by many individuals after stroke arises not only from the impairments resulting from the stroke, but also from the deleterious neural, muscle, psychological, and cardiovascular adaptations that accompany disuse and use of maladaptive behaviors.

The absence of ongoing exercise or activity programs after discharge from rehabilitation may be a major oversight in stroke management, an oversight that exacerbates disability and handicap. Several investigators have reported that stroke patients did not maintain functional gains after the cessation of rehabilitation.[5-7] Moreover, although it has been found that most recovery of function occurs in the first 3 months following stroke,[8-10] there is a growing body of evidence demonstrating that with training, individuals at least 6 months after stroke can improve performance of functional tasks[11-16] and aerobic capacity.[17] Despite this evidence, training programs appear to be available only to participants in research projects and only for the duration of the project. Exercise classes are one way to provide ongoing programs to maintain and/or improve performance after discharge from rehabilitation. Such classes are advantageous because they not only provide the opportunity for exercise and social interaction, but are also cost-effective with several individuals participating at the same time. Exercise classes can also be used to implement the philosophy of rehabilitation described and updated by Carr and Shepherd.[18-22] They advocated that rehabilitation involve training of everyday actions using information from movement sciences, particularly the fields of biomechanics and motor learning, as well as knowledge of the pathology and impairments associated with stroke.[18-22] Moreover, Carr and Shepherd have suggested that training can be organized into a circuit with a series of workstations designed to strengthen affected muscles and provide the opportunity for task practice.[22]

The main objective of this pilot project was to investigate the feasability and efficacy of an exercise class aimed at improving performance of locomotor-related tasks in individuals discharged from rehabilitation following stroke. The class focused on improving the performance and endurance of functional tasks involving the lower extremities (sit-to-stand, walking, reaching in sitting and standing, walking, and stair ascent and descent). Since subjects in the control group also participated in a training program (focused on the upper limb) as a means of reducing effects caused by placebo, the effects of this training program were also evaluated.

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METHODS

A convenience sample consisting of 12 subjects was recruited from the rehabilitation research group database for this pilot study. To participate, subjects had to meet the following inclusion criteria: (1) first stroke resulting in hemiplegia; (2) at least 3 months poststroke, (3) discharged from all rehabilitation services; (4) able to attend the rehabilitation center three times a week for 4 weeks; and (5) able to walk 10 meters independently with or without an assistive device. Subjects were excluded if they had any medical condition that would prevent participation in a training program. All subjects lived at home and agreed to pay their own transportation for getting to and from the rehabilitation center. Individual subject characteristics are outlined in table 1. Subjects signed informed consent documents, and all procedures were performed in accordance with the ethics approval granted by the Institut de réadaptation en déficience physique de Québec.

Design

A randomized group design with pretraining, posttraining, and 2-month follow-up evaluations was used. All subjects completed the pretraining evaluation and were then grouped into matched pairs according to the average walking speed at the pretraining evaluation. Subjects in each pair were then randomly assigned to the experimental or control group. The randomization process involved drawing two cards, one with subjects' names, and the other with the group allocation from two separate boxes. The cards were drawn by a person independent of the study. Six subjects were allocated to each group.

Two subjects (E1 and C3) withdrew from the study before training; one withdrawal was due to transport costs. Another subject in the control group (C5) withdrew after completing all training sessions as a result of a serious medical condition unrelated to the training. Nine subjects, 5 from the experimental group and 4 from the control group, completed the training and pretraining and posttraining evaluations, and 8 subjects completed the follow-up evaluation, because 1 subject (E5) was unavailable.

Intervention

Subjects in both groups participated in 1 hour of task-related training held at the rehabilitation center three times a week for 4 weeks. All training sessions were organized into a group exercise class, conducted by the one of the investigators (C.D.) who was assisted by another physiotherapist.

For the experimental group, the exercise class was designed as a circuit program, with subjects completing practice at a series of work stations as well as participating in walking races and relays with other members of the group. The workstations were designed to strengthen the muscles in the affected leg in a functionally relevant way and provide for practice of locomotor-related tasks.

The 10 workstations incorporated into the circuit were: (1) sitting at a table and reaching in different directions for objects located beyond arm's length to promote loading of the affected leg and activation of affected leg muscles[16,18,22]; (2) sit-to-stand from various chair heights to strengthen the affected leg extensor muscles and practice this task[22]; (3) stepping forward, backward, and sideways onto blocks of various heights to strengthen the affected leg muscles[18,19,22,23]; (4) heel lifts in standing to strengthen the affected plantarflexor muscles[22]; (5) standing with the base of support constrained, with feet in parallel and tandem conditions reaching for objects, including down to the floor, to improve standing balance[21]; (6) reciprocal leg flexion and extension using the Kinetron in standing to strengthen leg muscles[5,24]; (7) standing up from a chair, walking a short distance, and returning to the chair[25] to promote a smooth transition between the two tasks; the remaining stations (8) walking on a treadmill[5,22,24,26,27]; (9) walking over various surfaces and obstacles[22,28]; and (10) walking over slopes and stairs[22] provided the opportunity for practice of walking under variant conditions.

Each exercise class was 1 hour in duration, with subjects

Table 1: Initial Subject Characteristics, Means, and Standard Deviations in Parentheses Have Been Calculated Without the Subjects Who Withdrew From the Study

Group	Age (yrs)	Gender	Time Since Stroke (yrs)	Side of Hemiparesis	Walking Velocity for Group Allocation (cm/sec)	Walking Aid
E1*	53	M	3.2	Left	137	None
E2	66	F	1.7	Left	100	None
E3	63	M	2.3	Right	95	None
E4	73	M	2.0	Right	68	AFO + cane
E5‡	68	F	1.6	Right	37	AFO + quadstick
E6	74	F	2.9	Left	18	Cane
Mean	66.2 (68.8)		2.3 (2.1)		76 (64)	
SD	7.7 (4.7)		0.7 (0.5)		44 (36)	
C1	69	F	0.7	Right	114	None
C2	64	M	1.7	Right	113	None
C3*	50	M	1.0	Left	86	Cane
C4	61	M	2.9	Left	78	Cane
C5†	65	F	0.6	Right	53	Cane
C6	65	M	1.3	Right	13	AFO + quadstick
Mean	62.3 (64.8)		1.3 (1.7)		76 (80)	
SD	6.6 (3.3)		0.9 (0.9)		39 (47)	

* Subjects withdrew after pretraining test, one because of transportation costs.
† Subject withdrew after training, but before posttest, because of unrelated illness.
‡ Subject unavailable for follow-up evaluation.

practicing for 5 minutes at each of the 10 workstations, and then spending 10 minutes participating in walking relays and races. The classes, therefore, provided 1 hour of continuous practice of locomotor-related tasks incorporating aerobic and strengthening components. Two physiotherapists supervised each class and were responsible for ensuring that the amount and intensity of the exercise at each station was graded to each subject's level of functioning. For example, the height of the blocks and chairs used in the stepping and sit-to-stand workstations were set at a level to promote the use of the affected lower-limb muscles and to discourage the use of maladaptive (compensatory) behaviors. Subjects were encouraged to work as hard as possible at each station and were also given verbal feedback and instructions aimed at improving performance.

Subjects were also progressed through the 4-week program in a number of ways. Progression was determined by one of the physiotherapists (C.D.) and was based on observed performance. Progressions included increasing the number of repetitions completed within 5 minutes at a workstation and increasing complexity of the exercise performed at each workstation, such as increasing the speed of the treadmill, the distance reached in sitting and standing, the height of the blocks, and reducing the height of the chair during sit-to-stand.

The control group also participated in an exercise class. The organization and delivery of this training was similar in every respect to the experimental group training, except that the control class was designed to improve function of the affected upper limb. The control-group exercise class involved both a circuit component with subjects completing practice at a series of workstations (eg, wrist extension, supination, grasp, and release of various objects[18-22,29]) and also some exercises completed in small groups. Similar to the experimental group, subjects were progressed according to performance and given feedback (verbal and, in some instances, electromyographic biofeedback) and instructions designed to improve upper-limb function. This exercise class was considered "sham" lower-limb training and was included so that subjects would consider themselves involved in a training program and to eliminate an effect as a result of placebo or an effect as a result of the physical effort required to get to and from the rehabilitation center 12 times.

Evaluation

Subjects were evaluated three times: before the training (pretraining), at the end of the training (posttraining), and 2 months later (follow-up). At the pretraining and posttraining evaluations, subjects participated in a clinical assessment as well as a biomechanical laboratory assessment undertaken on separate days. At the follow-up, only the clinical assessments were conducted.

Clinical Measures

Four clinical measures of lower-limb function were obtained. Walking speed was measured by timing subjects over 10 meters with a stopwatch. To avoid the effects of acceleration and deceleration, measurements were taken over the middle 10 meters of a 14-meter walkway. Subjects completed two 10-meter walk tests. The first test was performed using their preferred assistive device, and the second without the assistive device. The 6-minute walk test[30] was used to measure walking endurance. Subjects walked for 6 minutes up and down a 50-meter walkway that had 5-meter increments marked discretely on the wall. The total distance covered in 6 minutes was determined by counting the laps, using the wall markers and measuring the distance covered from the last marker with a tape measure to the nearest centimeter. The third test of lower-limb function was the step test.[31] This test was used to evaluate the ability of the affected lower limb to support and balance the body mass while stepping with the unaffected limb. Briefly, subjects started with their feet parallel 5cm in front of a 7.5-cm-high wooden block. They were required to place their unaffected foot wholly onto the block, then return it to the floor repeatedly as fast as possible for 15 seconds. The number of completed steps in a 15-second period was recorded. The final lower-limb functional test was the timed up and go (TUG).[25] Subjects were required to stand up from a chair with armrests, walk 3 meters, turn around, return to the chair, and sit down. The time taken to complete this task was measured with a stopwatch.

At the clinical evaluations, strength and dexterity of the affected upper limb were also measured to minimize the chance that subjects in the control group would realize that they were participating in "sham" lower-limb training. Grip strength of the affected hand was measured with a Jamar dynamometer.[a] The best attempt from three trials was recorded. Dexterity of the affected hand during unimanual and bimanual tests was measured using the Purdue Pegboard.[32] For the unimanual test, the number of pegs placed in 30 seconds was recorded. For the bimanual test, the number of pairs of pegs placed in 30 seconds was recorded.

The clinical assessments, with the exception of the 6-minute walk, were conducted by an independent rater who was blinded to subject allocation. However, this blinding may have been unmasked as a result of this observer inadvertently viewing one training session. The 6-minute walk was undertaken after the laboratory walking assessment because of the proximity of the walking track and the laboratory. One of the investigators (C.D.) conducted the 6-minute walk test. To minimize observer bias, the instructions were standardized and the investigator remained behind the subject to avoid affecting the performance. In addition, to minimize observer bias for all assessments, the results of previous assessments were not available.

Laboratory Measures

Sit-to-stand and walking were evaluated in two laboratories at the pretraining and posttraining evaluations. For sit-to-stand, subjects were seated on a stool adjusted to 115% of lower-leg length, which was defined as the distance from the lateral knee joint line to the floor. Each foot rested on one of two adjacent AMTI force plates.[b] Subjects were free to choose their initial foot position. They were then requested to stand up from sitting with their weight evenly distributed. The mean peak vertical ground reaction force through the affected foot from three trials was extracted for analysis and expressed as a percentage of body weight.

Walking was measured with a custom built two-dimensional video system[c] combined with a forceplate, footswitches, and specialized software.[33] During the laboratory walking assessment, subjects were not allowed to use assistive devices. Subjects were videotaped from the side as they walked along a 10-meter walkway that had an embedded AMTI forceplate.[b] Subjects stepped on the forceplate with the affected foot. Footswitches were taped to the heel, midfoot, and toe of each shoe and used to define the phases of gait. Reflective markers were placed over seven landmarks: the shoulder, greater trochanter, lateral femoral condyle, mid-shank, lateral malleolus, head of fifth metatarsal, and heel of the affected side. Affected hip, knee, and ankle movement profiles, moments of force, and mechanical powers were calculated by the software. The mean of between two and five trials for each subject was extracted and plotted for further descriptive analyses.

Data Analysis

Due to the small sample size of this pilot study, nonparametric analyses were chosen to examine between group differences. Two effects between the groups were examined. Change scores computed by subtracting pretraining scores from posttraining scores were used to examine an immediate effect. A retention effect was evaluated by the change scores obtained by subtracting the pretraining scores from the follow-up scores. The between-group comparisons were analysed using the Mann-Whitney U test with an α level set at .05. Statistical tests were completed using the SPSS version 7.5 software.[d] In addition, individual change scores and baseline values were plotted for each lower-limb measure.

From the laboratory walking measures, the movement profiles of the hip, knee, and ankle joints of the affected leg during the gait cycle were graphically presented for descriptive analysis. Key variables, selected to represent movement patterns reported for healthy elderly subjects,[34] were obtained from the movement profiles. The variables selected for further analysis were: peak measures of hip extension, knee extension, and ankle dorsiflexion in the stance phase, critical for supporting the body mass and moving it forward over the stance foot; peak hip and knee flexion in swing phase, critical for clearing the foot during swing phase; and peak ankle plantarflexion in early swing phase, defined as within the first 6% of the gait cycle after toeoff, and critical for propulsion at the end of stance.

RESULTS

Overall, analysis of the change scores indicated that the experimental group performed significantly better than the control group on a number of measures immediately after training (immediate) and 2 months later (retention). These beneficial effects in the experimental group are illustrated in the individual subject data presented in figure 1. Although the subjects in both groups had a range of abilities at pretraining, all subjects in the experimental group demonstrated improvements on all clinical lower-limb tests, whereas the changes in test performance were smaller and more variable for subjects in the control group (table 2).

6-Minute Walk Test

The experimental group increased the distance walked to a significantly greater extent than the control group in both the immediate and retention periods (fig 1A). The increase in distance for the experimental group ranged from 14.5 to 91.1 meters and from 16.8 to 82.4 meters for the immediate and retention periods, respectively, compared with ranges of −2.4 to 8.7 meters and −4.3 to 8.3 meters for the control group (fig 1A).

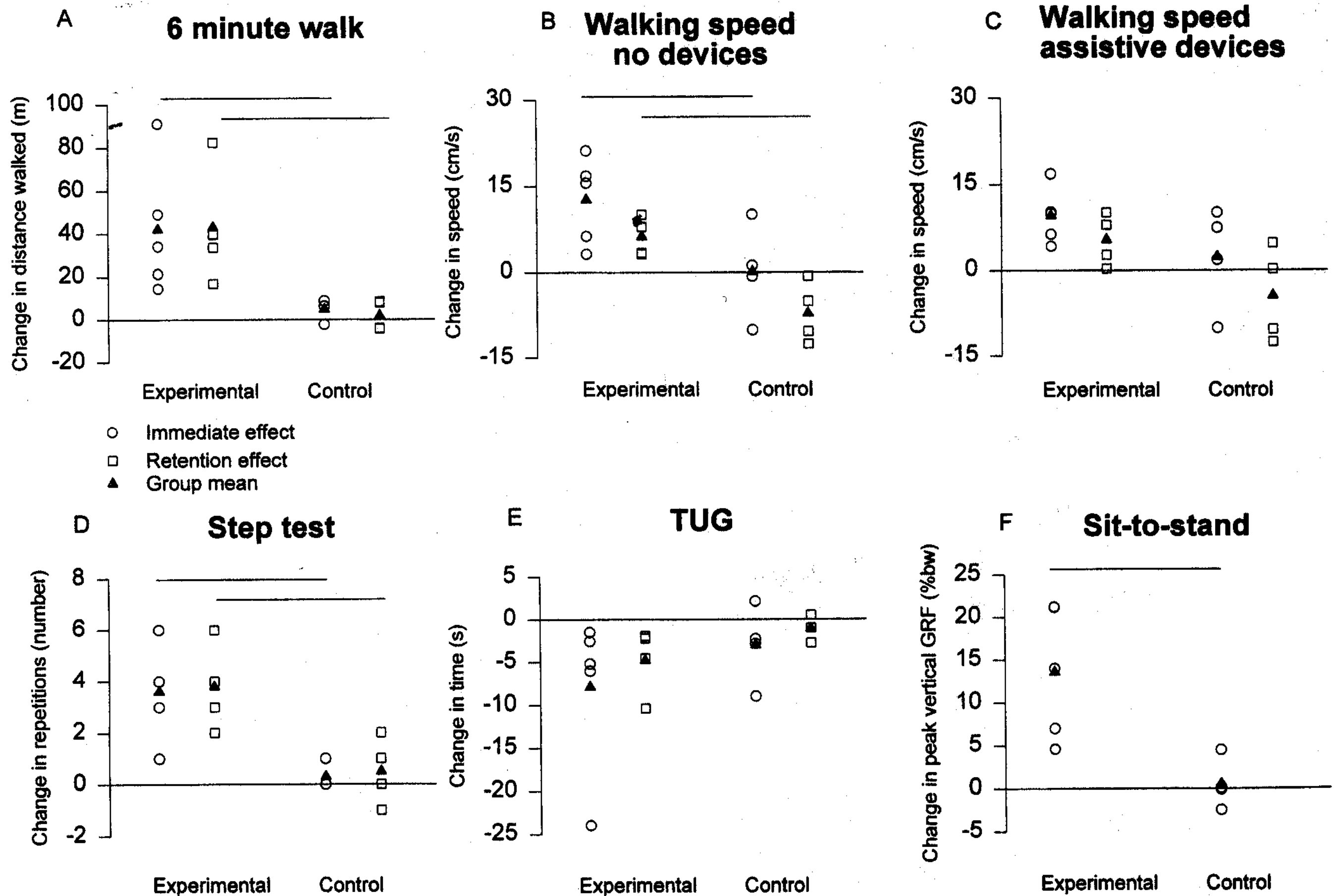

Fig 1. Group means (▲) and individual subject data for change scores for the immediate (○) and retention (□) effects for 6 clinical lower-limb tests: (A) 6-minute walk; (B) walking speed without devices; (C) walking speed with assistive devices; (D) step test; (E) timed up and go (TUG) test; (F) sit-to-stand. Horizontal lines indicate significant differences ($p \leq .05$) between the groups. GRF, ground reaction force; bw, body weight.

Table 2: Group Means, Standard Deviations, and Ranges (in parentheses) for All Variables at the Three Evaluations for Subjects in the Experimental and Control Groups

Variables	Experimental Group			Control Group		
	Pretraining (n = 5)	Posttraining (n = 5)	Follow-Up (n = 4)	Pretraining (n = 4)	Posttraining (n = 4)	Follow-Up (n = 4)
Lower-limb tests						
Distance walked in 6 minutes (m)	207.9 ± 119.0 (61.5-332.7)	250.0 ± 135.0 (110.5-423.8)	277.7 ± 130.5 (101.3-415.1)	259.6 ± 154.6 (44.4-377.1)	264.3 ± 159.1 (42.0-383.5)	261.5 ± 157.3 (40.1-373.0)
Walking speed without assistive devices (cm/sec)	58.1 ± 50.9 (0-113.1)	70.7 ± 48.3 (21.2-129.9)	78.8 ± 48.4 (21.6-121.0)	85.3 ± 53.3 (10.9-125.0)	85.4 ± 54.2 (10.2-133.3)	78.1 ± 48.3 (10.2-112.8)
Walking speed with assistive devices (cm/sec)	70.7 ± 41.8 (17.7-113.1)	80.2 ± 42.8 (27.6-129.9)	84.0 ± 46.7 (20.4-121.0)	86.1 ± 52.6 (12.7-125.0)	88.4 ± 52.2 (14.5-133.3)	81.5 ± 47.2 (12.8-112.8)
Repetitions in the step test (number)	6.2 ± 4.4 (0-11)	9.8 ± 4.0 (6-15)	10.3 ± 4.4 (6-14)	5.5 ± 4.2 (0-11)	5.8 ± 4.3 (0-10)	6.0 ± 5.0 (0-11)
Time taken to complete the TUG (sec)	27.4 ± 23.2 (11.5-68.0)	19.5 ± 14.1 (9.9-44.0)	23.6 ± 22.9 (9.3-57.6)	29.1 ± 29.4 (11.3-73.0)	26.1 ± 25.4 (10.5-64.0)	28.1 ± 29.5 (10.6-72.0)
Peak vertical GRF during STS (% BW)	48.6 ± 8.8 (36.7-57.2)	62.2 ± 7.8 (56.0-75.7)	not assessed	46.1 ± 11.2 (35.1-57.8)	46.6 ± 9.6 (35.2-55.3)	not assessed
Upper-limb tests						
Grip strength (kg)	21.2 ± 11.0 (3.2-33.2)	20.1 ± 13.1 (0-36.4)	20.5 ± 16.7 (0-40.9)	13.3 ± 11.4 (2.3-29.1)	15.7 ± 11.0 (4.5-30.5)	15.2 ± 13.8 (0-31.8)
Unimanual Purdue Pegboard (no. of pegs)	4.6 ± 3.5 (0-9)	5.2 ± 3.4 (0-9)	4.5 ± 3.3 (0-9)	3.3 ± 3.8 (0-7)	4.8 ± 5.6 (0-11)	4.8 ± 5.5 (0-10)
Bimanual Purdue Pegboard (no. of pairs)	3.8 ± 2.9 (0-8)	4.0 ± 2.6 (0-7)	3.0 ± 2.2 (0-5)	2.8 ± 3.2 (0-6)	4.0 ± 4.6 (0-8)	3.3 ± 3.8 (0-7)

Abbreviations: GRF, ground reaction force; STS, sit-to-stand; BW, body weight; TUG, timed up and go.

Walking Speed

There were significantly different immediate and retention effects between groups for walking speed measured without assistive devices over 10 meters (fig 1B). For the experimental group, the improvement in walking velocity without assistive devices ranged from 3.2 to 21.2cm/sec. One subject (E5) was unable to walk without assistive devices at the pretest, and therefore had an initial speed of 0cm/sec. Following training, however, she was able to walk without assistive devices at 21.2cm/sec. There were no significant between-group effects for walking speed measured using preferred assistive devices (Fig 1C).

Step Test

Subjects in the experimental group, but not the control group, increased the number of repetitions of the step test over both the immediate and retention periods (fig 1D). These results indicate that the experimental subjects improved their ability to balance and support the body mass on the affected leg while stepping repeatedly with the unaffected leg.

TUG

Although all subjects in the experimental group reduced the time taken to complete the TUG test (fig 1E), there were no significant differences between the groups.

Sit-to-Stand

Over the 4-week period, the experimental group significantly increased the peak vertical ground reaction force through the affected foot during sit-to-stand compared with the control group. The mean increase in peak vertical ground reaction force through the affected foot was 13.6% body weight for the experimental group and 0.5% body weight for the control group (fig 1F).

Laboratory Walking Measures

The laboratory walking measures confirmed that in both groups, there was a large range of walking abilities. For example, walking velocity measured in the laboratory at pretraining ranged from 14 to 108cm/sec for the experimental group and from 16 to 122 cm/sec for the control group. Because of this large disparity in skill level, it was unlikely that one single parameter could adequately characterize changes for all subjects, so descriptive analyses were undertaken, and there were some noteworthy observations. First, in comparison with normative data for healthy elderly subjects walking at natural cadence,[34] 5 of the 9 subjects (E4, E5, E6, C4, C6) exhibited a marked reduction in the excursion of joint motion at the hip and knee (fig 2) at both the pretraining and posttraining evaluations. Second, when reviewing the joint angle plots of pretraining values for key movement variables, it became obvious that the reductions in joint excursions demonstrated by these 5 subjects were associated with decreased hip extension in stance, decreased knee flexion in swing, and decreased ankle plantarflexion in early swing. These three movement deficits persisted at posttraining despite the fact that most of the experimental subjects had small improvements in hip extension in stance and knee flexion in swing phase.

Examination of power generation curves was undertaken only for the 4 subjects whose hip, knee, and ankle joint movement patterns at the posttraining evaluation closely resembled the normative data. These 4 subjects, 2 from each group (E2, E3, C1, C2), walked at speeds over 100cm/sec at the posttraining evaluations. The 2 subjects in the experimental group (E2, E3) had, after 4 weeks of training, improved their walking speed as measured in both the laboratory and clinical assessments, walking endurance as measured by the 6-minute walk test, and the power generated at the ankle and hip joints. Specifically, these subjects had increased power generation at the ankle during the A2 "push-off" burst and also at the hip,

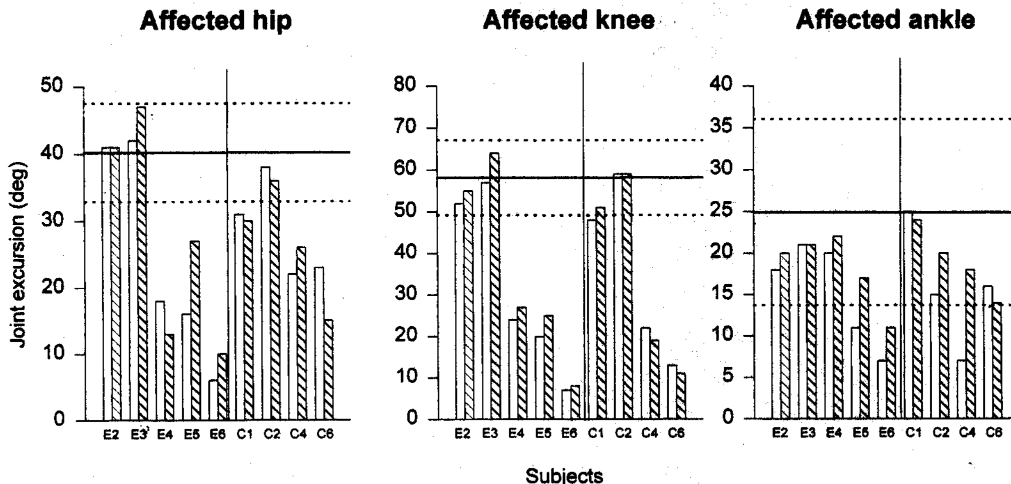

Fig 2. Mean excursion of the affected hip, knee, and ankle joints for individual subjects collected at pretraining (□) and posttraining (▧) evaluations. The mean (solid line) ±2 SD (dashed lines) for normative data collected on healthy elderly subjects walking at a natural cadence are also plotted.[34]

corresponding to the H3 "pull-off" burst.[34] In contrast, the 2 subjects in the control group demonstrated a decline in walking velocity and only small changes in walking endurance, and did not change the power generated at the hip and ankle (table 3).

Upper-Limb Tests

There were no significant differences between the groups in grip strength or dexterity measures over the immediate or retention periods. However, 2 of the 4 subjects in the control group (C1, C2) improved on all three upper-limb tests. Consistent change was not demonstrated by any of the subjects in the experimental group.

Compliance and Subject Satisfaction

During training, subjects appeared motivated to improve performance and also appeared to enjoy both the exercise and the social interaction. The compliance was high, with the 9 participants attending at least 75% of the sessions. In addition, at the end of the training, the subjects were surveyed for their opinions of the program. Overall, regardless of group allocation, the responses were positive—all but 1 control (C4) subject recommending the programs to others. In general, responses were specific to the type of training, with experimental subjects reporting improvements in walking, sit-to-stand and general activity, and the control subjects in their ability to use the affected arm and hand.

DISCUSSION

The major finding of this pilot study was that subjects with chronic stroke who participated regularly in a 4-week group exercise class supervised by physiotherapists and designed to improve the strength and endurance of the affected lower limb and functional performance demonstrated improvement that was specific to the training. Over the training period, walking speed and endurance, force production through the affected foot during sit-to-stand, and the ability to balance on the affected leg while stepping with the unaffected leg (step test) improved. Moreover, these improvements were maintained 2 months after the cessation of training. Improvements were not seen in the control group. Since the control group attended the rehabilitation setting the same number of times as the experimental group, the significant differences between the groups reflects the efficacy of the experimental exercise program, and not merely the physical effort required to get to and from the rehabilitation center for training.

There was a large range of functional abilities in the subjects recruited for this study. Nonetheless, all subjects in the experimental group, regardless of skill level, made some improvement in performance on the lower-limb tests. Interestingly, after training, 2 experimental subjects (E2, E3) had achieved levels of functioning that were comparable with similarly aged healthy subjects in walking velocity,[35] the TUG test,[25] and the step test.[31] The laboratory walking assessment indicated that this improvement was associated with concomitant increases in the power generated by the ankle plantarflexors and hip flexors in late stance and early swing, with these changes being larger at the ankle compared with the hip. This observation provides support for the proposal that at near-normal walking speeds (ie, in excess of 1.0m/sec), plantarflexor strength may be one important determinant of walking speed.[36-38]

The improvement in peak vertical ground reaction force through the affected foot during sit-to-stand demonstrated by experimental subjects suggests that these subjects had improved the force generating capacity of the affected lower-limb muscles during that action.[39] Further analysis of center of pressure data identified that the improvement seen in the experimental subjects was mediated by one or more of the following factors: a reduction in movement time, increased loading of the affected lower limb, and/or a change in preferred foot position. A more backward placement of the affected foot, which was encouraged and practiced in the exercise class, facilitates the contribution of the affected lower limb during sit-to-stand.[40,41] The improvement in sit-to-stand suggests that experimental subjects at the end of training had learned a strategy that increased the participation of the affected lower limb in sit-to-stand. Continued use of this new strategy during everyday life may be beneficial in providing some stimulus for the maintenance of affected lower-limb strength.

Table 3: Change Scores From Pretraining to Posttraining Evaluations for 4 Gait Variables for the 4 Subjects Whose Kinematics at Posttraining Were Similar to Those of Healthy Subjects

Variables	Experimental Subjects		Control Subjects	
	E2	E3	C1	C2
Endurance (m)	91.1	34.1	6.4	8.7
Velocity (cm/sec)	11.4	17.6	−12.4	−13.2
Ankle "push-off" (A2) power burst (W/kg)	.36	1.03	−.75	.08
Hip "pull-off" (H3) power burst (W/kg)	.23	.17	.09	−.12

The large variability in initial skill level raises the issue of sensitivity and appropriateness of measurement tools. The failure to find a significant result in the TUG test probably reflects a ceiling effect for this measurement tool for 2 experimental subjects (E2, E3). These subjects, with small improvements over the training period, were able to obtain scores comparable with healthy subjects. In contrast, 1 control subject (C6) improved by 10 seconds, yet his performance was still impaired, taking over 1 minute to perform the task. The finding suggests that the TUG test is useful in detecting change in individuals with lower levels of function and supports the observation by Richards and colleagues[42] that, according to functional abilities, some outcome measures are more appropriate than others.

The failure to demonstrate improvement in upper-limb function in the control group probably reflects many factors, including small sample size, subject inclusion criteria, and measurement tools, and raises some important issues for further research into training upper-limb function in subjects with chronic stroke. The Purdue Pegboard was used to measure dexterity in this study and is a task that requires the ability to grasp a narrow peg, manipulate it within the hand, and place it in a small hole. This measurement tool therefore is prone to floor effects, because it requires a high level of skill to score a single point. Two of the control subjects (C4, C6) had almost no voluntary movement in their affected upper limb at the beginning of training. Although these two subjects learned to activate muscles in gravity-eliminated positions, this increase was insufficient to cause improvement in performance on the Purdue Pegboard. This observation suggests that upper-limb training in subjects with chronic stroke should be aimed at individuals with some minimal level of function in the upper limb and hand. Taub and colleagues,[12] who have reported improvements in upper-limb function using the "forced-use" intervention, used a criterion of some wrist and finger movements. In addition, using measurement tools that evaluate performance on a range of tasks such as the upper-limb items of the Motor Assessment Scale for stroke[43] or the TEMPA[44] may be more appropriate and sensitive than the Purdue Pegboard in detecting change in subjects with different levels of upper-limb function.

One of the most consistent observations in stroke rehabilitation is that patients spend large proportions of the day alone and inactive.[45-47] In addition, Belmont and colleagues[48] observed that individuals after stroke are less likely to complete practice when left unattended. These observations suggest that individuals after stroke are at risk of becoming socially isolated and more disabled after discharge from rehabilitation, particularly since most individuals are discharged with functional ambulation skills that are inferior to the level required for effective community ambulation.[1,49] The group exercise class used in this pilot study provided both social interaction and exercise specifically designed to improve ambulation skills. The fact that all subjects in the experimental group, despite a large range of abilities, demonstrated some improvement in all lower-limb tests suggests that the organization of the exercise class into a circuit of workstations is an efficient way to provide training to a group of subjects while still tailoring the intensity and amount of training to each subject's capability. The inclusion of walking races and relays at the end of each session may also have been beneficial in motivating subjects to improve performance by promoting competition and cooperation.

Similar to healthy individuals, participation in some regular physical activity appears necessary to provide the stimulus for stroke patients to, at the very least, maintain functional gains obtained in formal rehabilitation. All experimental subjects reported that they felt better, were more confident, and doing more after the training stopped, and it is likely that this increased activity and confidence underlies the retained improvement demonstrated at the follow-up evaluation. Further research needs to evaluate whether the functional improvements demonstrated in this study carry over to real changes in community ambulation.

One of the major challenges of stroke management is the provision of ongoing programs that maintain and/or improve performance and fitness, rather than allowing secondary disuse and adaptive behaviors to increase the disability remaining after discharge from rehabilitation. Many factors such as location, cost, intensity, frequency, and duration of such programs warrant further investigation. Financial handicap frequently accompanies chronic neurologic conditions, and suggests that for ongoing programs to be successful and accessible to all, costs need to be minimized. Using existing community resources and facilities may be one way to minimize such costs. The high compliance and positive responses in the subject-satisfaction survey indicate that individuals with chronic stroke will participate in these programs if financial and transportation requirements can be met.

The positive results of this pilot study contribute to the growing body of research demonstrating that, with intervention, chronic stroke subjects are able to improve the performance of everyday tasks.[11-16] This suggests that to maximize potential, stroke rehabilitation needs to continue in the long term, rather than cease within 3 months to 1 year poststroke. Accessible ongoing programs that are designed to increase the strength of the affected limbs and improve functional performance may not only improve quality of life, but also reduce the need for, and duration of, future institutionalized care.

One way to monitor physical performance and activity after discharge is to expand the routine medical follow-up of individuals after stroke. Typically, such individuals are screened regularly to prevent further strokes. Expanding such screening to include assessment of physical function and review of physical activity levels may be a useful way to ensure that intervention is timely. Tests of walking speed and endurance and the step test could be completed within 10 minutes and require little equipment or expertise to conduct. Individuals identified as deteriorating in function could be referred for a short period of increased intervention, and those maintaining or increasing function would be given positive reinforcement to continue current activity patterns.

In conclusion, this pilot study demonstrated that it was feasible to conduct an exercise class for a group of patients with chronic stroke with a large range of functional abilities. Although the results were positive, because of the small sample size and potential for type 1 errors arising from the number of statistical comparisons, the study should be replicated with a larger number of subjects. Such a study should include measures of quality of life, community participation, and handicap, and may allow for detailed analysis of the relationship between impairment levels, functional changes, and handicap. Future research may lead to the development and provision of efficient and effective long-term programs that optimize performance and reduce disability and handicap after stroke.

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Suppliers

a. Jamar Dynamometer, Lafayette Instrument Company, PO Box 5729, Lafayette, IN 47903.
b. Advanced Mechanical Technology Inc. (AMTI), 179 Waltham Street, Watertown, MA 02172.
c. Groupe de recherche en réadaptation physique de l'Université Laval, Institut de réadaptation en déficience physique de Québec, 525 Boulevard Wilford-Hamel, Quebec, G1M 2S8 Canada.
d. SPSS Inc., 444 North Michigan Avenue, Chicago, IL 60611.