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Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke

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Objective: To examine the effectiveness of task-oriented progressive resistance strength training on lower extremity strength and functional performance in chronic stroke subjects.
Design: Single-blind, randomized controlled trial.
Setting: Medical centre and district hospital.
Subjects: Forty-eight subjects at least one year post stroke.
Interventions: Participants randomly allocated to two groups, control ($n = 24$) and experimental ($n = 24$). Subjects in the control group did not receive any rehabilitation training. Subjects in the experimental group were put on a four-week task-oriented progressive resistance strength training.
Main measures: Lower extremity muscle strength, gait velocity, cadence, stride length, six-minute walk test, step test, and timed up and go test.
Results: Muscle strength significantly improved in the experimental group for strong side muscle groups (ranged from 23.9% to 36.5%) and paretic side muscle groups (ranged from 10.1% to 77.9%). In the control group muscle strength changes ranged from 6.7% gain to 11.2% decline. The experimental group showed significant improvement in all selected measures of functional performance except for the step test. In the control group, the number of repetitions of the step test significantly decreased (−20.3%) with no change in other functional tests. There was a significant difference between groups for muscle strength and all functional measures. The strength gain was significantly associated with gain in the functional tests.
Conclusions: The task-oriented progressive resistance strength training programme could improve lower extremity muscle strength in individuals with chronic stroke and could carry over into improvement in functional abilities.

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Introduction

A stroke usually results in some degree of muscle weakness. The observed muscle weakness in the poststroke population has been attributed to reduced muscle fibre size, decreased firing rate, atrophy of type II muscle fibres, increased fatigue, decreased motor unit numbers and altered motor unit recruitment.[1] Several stroke studies have shown that muscle weakness is associated with reduced walking speed and endurance.[2,3] The torques generated mainly by the knee extensor, ankle plantarflexor and hip flexor muscles have been correlated with gait performance.[3–5] Muscle weakness has been suggested as a significant predictor of walking ability in chronic stroke individuals.[4,6]

Progressive resistance strength training refers to progressive increases in resistance to a muscle as training induces greater ability to produce and sustain force.[7] The key elements of progressive resistance strength training are to provide sufficient resistance, to progressively increase the amount of resistance as strength increases, and to continue the training programme for a sufficient duration (a minimum of four weeks) for benefits to accrue.[7] Progressive resistance strength training has been used successfully to restore function in older adults with chronic disease and frailty.[8] The early stroke rehabilitation literature raised concerns that resistance training might adversely affect movement performance by increasing spasticity.[9] In a recent systematic review, Morris *et al*. found that no empirical evidence supports these claims.[10] Moreover, there is mounting evidence that progressive resistance strength training is effective in improving muscle strength following stroke.[10] However, conflicting evidence exists regarding the effect of lower extremity strength gains on functional performance measures in long-term stroke survivors.[11–13] The discrepancy in these findings might have arisen due to different stroke severity or different duration/intensity of the training used. Also, it might be caused by different training body segments, e.g. training of the hemiparetic knee musculature[11] or training of the bilateral lower extremities musculature.[12,13]

Current approaches to stroke rehabilitation put emphasis on task-oriented training.[14] Advocates of task-oriented training utilize a training programme that focuses on specific functional tasks to engage the systems (musculoskeletal, neuromuscular, etc.). Previous studies illustrated the beneficial transfer effects of task-oriented strength training in disabled older adults and traumatic brain-injured patients.[15,16] Furthermore, a single-group pretest–posttest study also demonstrated that task-oriented strength training can induce improved functional performance even more than one year post stroke.[17] To our knowledge, no randomized controlled study has evaluated the effects of task-oriented progressive resistance strength training on changes in muscle strength and changes in functional outcome measures in individuals with stroke. We developed a progressive resistance strength training programme based on task-oriented concept. This programme was designed to strengthen muscles of the lower extremities while performing the functional activities. The purpose of the present study was to examine the effectiveness of task-oriented progressive resistance strength training on lower extremity strength and functional performance in chronic stroke subjects. We predicted that the task-oriented progressive resistance strength training programme would improve lower extremity muscle strength in individuals with chronic stroke, and would carry over into improvement in functional abilities.

Methods

Subjects

Subjects were recruited from local participating hospitals and through referrals from a local volunteer database. The age, sex, paretic side, and onset time of hemiparesis were obtained from patient interviews, and confirmed via medical records review. Subjects were eligible for enrollment if they were: hemiparetic from a single stroke occurring at least a year earlier, not presently receiving any rehabilitation services, able to walk 10 m independently without an assistive device, medically stable enough to allow participation, and able to understand instructions and follow commands. Subjects were excluded if they had any medical condition that would prevent participation in the training programme and had any uncontrolled health condition for which exercise is contraindicated.

Procedure

The study protocol was reviewed and approved by the Institutional Review Board. Prior to data collection, the purposes and procedures were fully explained, and informed consents were obtained from the patients. Fifty-five individuals were identified as potential participants for this study (Figure 1). Five individuals were excluded because they failed to meet the inclusion criteria. Two individuals did not sign an informed consent. Of the original pool, 48 subjects met eligibility criteria and provided written informed consent. Subjects were randomized to the control group or experimental group by an independent person who picked one of the sealed envelopes 30 min before the start of the intervention. All subjects were evaluated before commencement of training (pre-training) and at the end of the four-week training period (post training). The 24 subjects in the control group did not receive any rehabilitation training. The remaining 24 subjects in the experimental group received task-oriented progressive resistance strength training.

Task-oriented progressive resistance strength training intervention

Subjects in the experimental group participated in 30 min of task-oriented progressive resistance strength training three times a week for four weeks. The progressive resistance strength training programme was designed as a circuit class, with subjects completing practice at a series of workstations. The workstations were designed to strengthen the muscles in the bilateral lower limbs in a functionally relevant way. The six workstations incorporated into the circuit were: (1) standing and

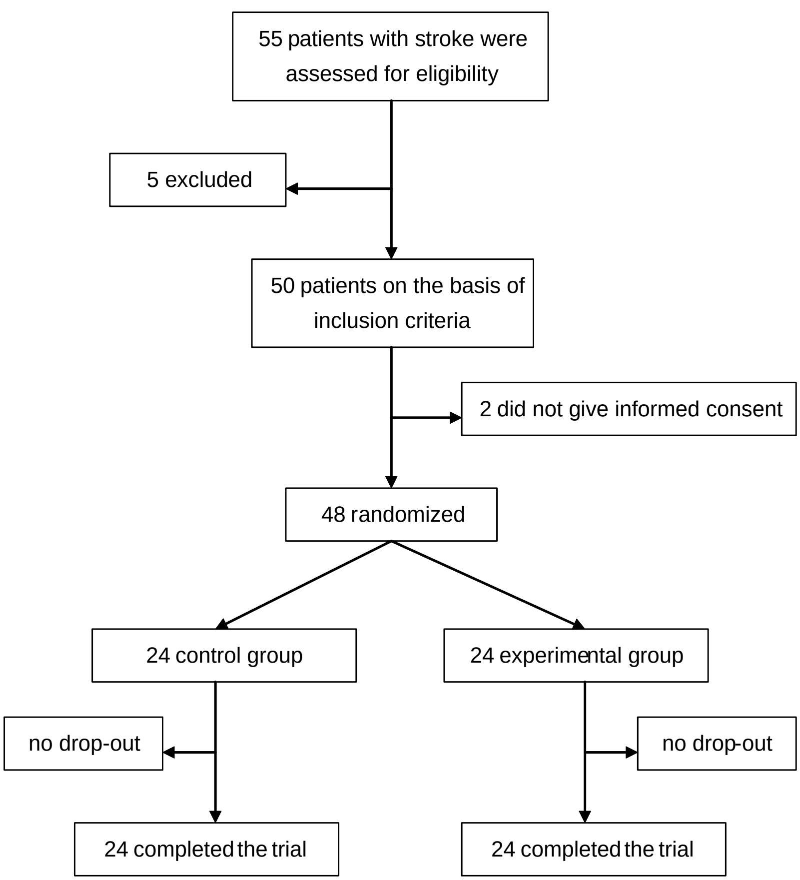

Figure 1 Flow diagram of the study.

reaching in different directions for objects located beyond arm's length to promote loading of the lower limbs and activation of lower limb muscles; (2) sit-to-stand from various chair heights to strengthen the lower limb extensor muscles; (3) stepping forward and backward onto blocks of various heights to strengthen the lower limb muscles; (4) stepping sideways onto blocks of various heights to strengthen the lower limb muscles; (5) forward step-up onto blocks of various heights to strengthen the lower limb muscles; (6) heel(s) raise and lower while maintaining in a standing posture to strengthen the plantarflexor muscles.[14] Each workstation was 5 min in duration for each exercise class. Each subject participated in a one-to-one therapy. A qualified and experienced physical therapist supervised each class and was responsible for ensuring that the amount and intensity of the exercise at each station was graded to each subject's functional level. Subjects were encouraged to work as hard as possible at each workstation and were also given verbal feedback and instructions aimed at improving performance. Progressions included increasing the number of repetitions completed within 5 min at a workstation and increasing complexity of the exercise performed at each workstation, such as the distance reached in standing, reducing the height of the chair during sit-to-stand, and the height of the blocks.

Measurement

Subjects were evaluated by a separate physical therapist who was not involved in the training programme and did not know about the subject's group. The outcome was assessed by the following measurements.

Muscle strength

Lower extremity muscle strength was evaluated using a handheld dynamometer (PowerTrack II; JTech Medical, USA). All tests done were 'make' tests where the dynamometer was held stationary by the examiner while the subjects exert a maximum force against it. The muscle groups were measured including hip flexors, hip extensors, knee flexors, knee extensors, ankle dorsiflexors and ankle plantarflexors. The hip flexors strength and knee extensors strength were obtained in the sitting position. The hip extensors strength, knee flexors strength and ankle plantarflexors strength were obtained in the prone position. The ankle dorsiflexors strength was obtained in the supine position. The intra-rater reliability of hip extensors, knee flexors, knee extensors, and ankle dorsiflexors in our sample was determined to be good with intraclass correlation coefficients ranging from 0.76 to 0.89. The intra-rater reliability of hip flexors and ankle plantarflexors in our sample was fair with intraclass correlation coefficients ranging from 0.56 to 0.65.

Gait performance

Gait was measured using GAITRite (CIR Systems Inc, USA), an instrumented walkway. The GAITRite system provided temporal (time) and spatial (distance) gait parameters via an electronic walkway connected to the serial port of a personal computer. The standard GAITRite walkway contained six sensor pads encapsulated in a roll-up carpet with an active area of 3.7 m long and 0.6 m width. As the subject walked through the walkway, the sensors captured each footfall as a function of time and transferred the gathered information to a personal computer to process the raw data into footfall patterns. The computer computed the temporal and spatial gait parameters. The validity and reliability of the GAITRite system has been well established.[18,19] The test–retest reliability of velocity, cadence and stride length was excellent (intraclass correlation coefficients between 0.90 and 0.95) in a subset of stroke survivors in our lab. Subjects were asked to walk at their comfortable speed without assistive device through a 10-m hallway for three times. The GAITRite walkway was placed in the middle of the 10-m hallway to eliminate the effect of acceleration or deceleration. Gait parameters of interest were velocity, cadence and stride length.

Six-minute walk test

Six-minute walk test was used to measure walking endurance.[20,21] Subjects walk for 6 min up and down a 25-m walkway that has 1-m increments marked discretely on the floor. In this study, subjects were instructed to walk back and forth, unaided if possible, along the 25-m walkway. Rests were taken as needed. The total distance covered in 6 min was determined by counting the laps, using the floor markers and measuring the distance covered from the last marker with a tape measure to the nearest centimetre. An intra-rater coefficient of 0.99 with hemiparesis after stroke has been demonstrated.[22]

Step test

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.[23] Subjects started with their feet parallel 5 cm in front of a 7.5-cm-high wooden block. They were required to place their unaffected foot wholly onto the block, and then return it to the floor repeatedly as fast as possible for 15 s. The number of completed steps in a 15-s period was recorded. The step test is a validated and reliable functional, dynamic test of standing balance in individuals with stroke.[23]

Timed up and go test

This is a lower limb functional test.[24] Subjects were required to stand up from a chair, walk 3 m, turn around, return to the chair, and sit down. The time taken to complete this task was measured with a stopwatch. This test has previously demonstrated high intra-rater reliability.[22]

Data analysis

Data from all subjects were entered into a computerized database and analyzed using the SPSS statistical package (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated for the clinical characteristics of each group. To compare the baseline demographic characteristics and the pretraining variables between groups, independent-samples *t*-tests were used for means and chi-square tests were used for frequencies. To elucidate the effect of training, the differences on all dependent variables between the pre- and post-training phases within group were analysed by paired *t*-tests. Difference scores were calculated for each patient by subtracting the pretraining data from the posttraining data. Mean difference scores and the standard deviation of these changes scores were calculated for each variable. Multivariate analysis of variance (MANOVA) was used to determine differences of mean difference scores of each dependent variable between groups. To examine correlation between the change in muscle strength and change in functional performance, Pearson correlation coefficients were assessed for all 48 subjects. A significance level of 0.05 was set for all analyses.

Results

Descriptive characteristics and intervention compliance

Of the 48 subjects, 24 were randomly allocated to the control group, and the other 24 subjects were randomly allocated to the experimental group. Table 1 indicates the group means and standard deviations for age and stroke onset and the frequency counts for gender and hemiparetic side. There were no statistically significant differences between groups for age, stroke onset, gender and hemiparetic side. All subjects successfully completed the study protocol. In the experimental group, the attendance rate was 100% for the four-week training programme. All participants were able to perform the exercises as planned.

Table 1 Baseline demographic characteristics

	Control ($n=24$)	Experimental ($n=24$)	*P*-value
Age (years)	60.0 (10.4) (50 ~ 74)	56.8 (10.2) (45 ~ 74)	0.3
Months post stroke	64.0 (40.4) (36 ~ 120)	62.7 (27.4) (42 ~ 120)	0.9
Gender			
Male	16 (66.7%)	16 (66.7%)	1
Female	8 (33.3%)	8 (33.3%)	
Hemiparetic side			
Right	12 (50.0%)	8 (33.3%)	0.4
Left	12 (50.0%)	16 (66.7%)	

Values are mean (standard deviation) (range) or frequency (percentage).

Muscle strength

At baseline, there were no differences between groups for bilateral hip flexors, hip extensors, knee flexors, knee extensors, ankle dorsiflexors and ankle plantarflexors. Lower extremity muscle strength significantly improved in the experimental group for all muscle groups tested (Table 2). However, improved muscle strength was not demonstrated in the control group. On the contrary, decreased muscle strength occurred over the four-week period for paretic hip flexors ($P = 0.01$), strong knee flexors ($P < 0.001$), paretic knee flexors ($P = 0.01$) and strong ankle dorsiflexors ($P < 0.001$) (Table 2). The mean difference scores of the pretraining and posttraining scores for all muscle groups tested were compared for the control and experimental groups with the use of MANOVA. The analysis revealed significant differences between the two groups for all muscle groups tested, as illustrated in Table 2.

Functional performance

There were no significant differences between groups for any selected functional measure at baseline. All selected measures of functional performance improved after the four-week task-oriented progressive resistance strength training with exception of the step test (Table 3). In the control group, there were no significant changes over the four-week period for all selected functional measures except for step test (Table 3). Subjects in the control group decreased the number of repetitions of the step test over the four-week period ($P = 0.001$). The mean difference scores of the pretraining and posttraining scores for gait velocity, cadence, stride length, six-minute walk test, step test and timed up and go test were compared for the control and experimental groups with the use of MANOVA. The analysis revealed significant differences between the two groups for all functional measures, as illustrated in Table 3.

Relationship between change in muscle strength and change in function

Table 4 showed the results of the correlation analysis, demonstrating the relationship between change in muscle strength and change in functional performance. As presented in Table 4, strength gain was significantly associated with gain in functional tests such as gait velocity, cadence, stride length, six-minute walk test, step test and timed up and go test.

Discussion

This is the first randomized controlled clinical trial to examine the effectiveness of task-oriented progressive resistance strength training on lower extremity strength and functional performance in chronic stroke subjects. We found that strengthening can be accomplished using a task-oriented, circuit progressive resistive exercise programme supervised by a physical therapist. More importantly, the task-oriented progressive resistance strength training programme can improve lower extremity strength and functional performance, and the lower extremity strength gain is significantly associated with gain in functional tests such as gait velocity, cadence, stride length, six-minute walk test, step test, and timed up and go test.

The progressive resistance strength training programme has been demonstrated to improve muscle strength after stroke.[10,13] However, there were equivocal results for progressive resistance strength training on the performance of functional activities of daily living, such as moving from sitting to standing, walking and stair-climbing.[11–13] Carr and Shepherd have indicated that transfer is unlikely to occur unless subjects are also practising the task to be learned.[14] Critical to the regaining of effective performance is the development of flexibility of performance, which is achieved by practising the action under a variety of different task contexts.[14] Repetitive practice of the action to be learned can therefore have dual benefits, enabling the patient to practise the action as well

Clinical messages

- Task-oriented progressive resistance strength training can improve lower extremity strength and functional performance.
- The lower extremity strength gain is significantly associated with gain in functional tests.

Table 2 Muscle strength (in pounds) for both groups

Strength (pound)	Scores						Change scores		
	Control ($n = 24$)			Experimental ($n = 24$)			Control ($n = 24$)	Experimental ($n = 24$)	
	Pretest	Posttest	*P*-value[a]	Pretest	Posttest	*P*-value[a]	Post−pre	Post−pre	*P*-value[b]
Hip flexors									
Strong side	51.2 (16.4)	51.2 (3.9)	1	53.7 (25.3)	63.1 (16.9)	0.001	−0.0 (16.3)	9.4 (11.6)	0.03
Paretic side	34.1 (8.4)	29.8 (9.9)	0.01	37.1 (13.7)	54.7 (12.0)	< 0.001	−4.3 (7.9)	17.6 (5.3)	< 0.001
Hip extensors									
Strong side	44.4 (9.1)	44.2 (10.2)	0.7	40.9 (7.5)	51.6 (9.2)	< 0.001	−0.3 (3.2)	10.7 (9.1)	< 0.001
Paretic side	33.1 (13.8)	32.9 (14.6)	0.6	27.2 (13.0)	31.9 (12.3)	0.001	−0.2 (2.1)	4.7 (6.0)	0.001
Knee flexors									
Strong side	26.2 (4.1)	24.8 (3.8)	< 0.001	24.7 (7.6)	31.2 (13.7)	0.004	−1.3 (1.1)	6.5 (9.9)	< 0.001
Paretic side	14.4 (5.1)	12.8 (4.2)	< 0.001	14.2 (3.4)	15.9 (5.5)	0.01	−1.6 (1.0)	1.7 (3.0)	< 0.001
Knee extensors									
Strong side	56.2 (6.2)	53.8 (9.9)	0.3	50.8 (20.8)	60.7 (14.9)	0.001	−2.4 (12.0)	9.9 (12.0)	0.001
Paretic side	38.1 (11.1)	37.6 (9.6)	0.2	38.3 (12.4)	50.6 (15.8)	< 0.001	−0.5 (1.9)	12.3 (5.2)	< 0.001
Ankle dorsiflexors									
Strong side	50.4 (3.2)	44.3 (8.9)	0.01	48.3 (7.5)	58.5 (6.1)	< 0.001	−6.1 (10.5)	10.3 (9.1)	< 0.001
Paretic side	29.1 (10.8)	28.6 (12.8)	0.3	30.3 (16.1)	41.2 (8.0)	< 0.001	−0.5 (2.2)	11.0 (12.5)	< 0.001
Ankle plantarflexors									
Strong side	53.4 (7.4)	50.7 (5.5)	0.2	48.6 (18.2)	62.3 (15.3)	< 0.001	−2.7 (10.4)	13.8 (8.9)	< 0.001
Paretic side	33.8 (15.6)	34.1 (12.9)	0.6	35.0 (17.9)	46.4 (17.8)	< 0.001	0.3 (2.7)	11.4 (9.3)	< 0.001

Values are mean (standard deviation).
[a]Within-group comparison.
[b]Between-group comparison.

Table 3 Functional performance measures for both groups

Parameter	Scores						Change scores		
	Control (n = 24)			Experimental (n = 24)			Control (n = 24)	Experimental (n = 24)	
	Pretest	Posttest	*P*-value[a]	Pretest	Posttest	*P*-value[a]	Post–pre	Post–pre	*P*-value[b]
Gait									
Velocity (cm/s)	77.9 (14.3)	77.7 (15.4)	0.8	84.0 (12.7)	92.5 (13.5)	< 0.001	− 0.2 (3.9)	8.5 (7.4)	< 0.001
Cadence (step/min)	97.2 (5.2)	96.4 (5.9)	0.3	97.4 (10.2)	103.7 (9.8)	< 0.001	− 0.8 (4.0)	6.3 (2.7)	< 0.001
Stride length (cm)	104.6 (29.6)	103.2 (29.8)	0.1	110.2 (12.8)	113.9 (12.2)	0.02	− 1.4 (4.5)	3.7 (7.4)	0.005
Six-minute walk test (m)	335.0 (79.6)	341.3 (126.8)	0.5	352.3 (71.7)	392.8 (54.2)	< 0.001	6.3 (47.2)	40.6 (47.8)	0.02
Step test (number/15 s)	13.7 (4.6)	11.3 (5.9)	0.001	11.8 (3.2)	12.2 (2.8)	0.5	− 2.3 (2.9)	0.3 (2.2)	0.001
Timed up and go test (s)	14.3 (7.0)	14.4 (6.7)	0.3	14.6 (7.4)	12.9 (6.5)	< 0.001	0.1 (0.5)	− 1.7 (1.1)	< 0.001

Values are mean (standard deviation).
[a]Within-group comparison.
[b]Between-group comparison.

as increasing muscle strength.[25] In the present study, the task-oriented progressive resistance strength training programme improved lower extremity strength and resulted in reductions in functional limitations. These results suggest that it is possible for task-oriented progressive resistance strength training to induce increases in muscle strength that can be transferred to improved functional performance.

In previous studies in which the relationships between strength gains and functional performance changes have been evaluated, the results have also been conflicting.[26,27] The task-oriented programme we used in this study was specially designed to strengthen lower extremity muscles. One might argue that various components such as balance and co-ordination comprised in these functional tasks may have led to the functional improvement. Previous studies using task-oriented intervention have demonstrated significant improvement in functional abilities.[28,29] It is important to clarify the relation between strength gain and improvement in measures of functional performance. Our results showed a significant association between strength change and change in functional performance (Table 4). These results suggested that strength gain obtained by task-oriented progressive resistance strength training could be an important factor in improvement of functional abilities. Taken together, these results demonstrated some association between restoring strength and enhancing functional performance after stroke.

In the present study, strength changes can be seen represent about 23.9–36.5% (average 30.7%) strength gains on the strong side muscle groups and about 10.1–77.9% (average 41.1%) of the strength gains on the paretic side muscle groups for the experimental group. The rate of improvement in the experimental group is consistent with previously reported gains in strength in long-term stroke survivors undergoing resistance training intervention alone. Sharp and Brouwer, using an isokinetic lower extremity progressive resistance strength training programme, showed that relative gains in muscle strength for paretic lower limb ranged from 15.8% to 153.9%.[11] Weiss *et al.*, using a lower extremity progressive resistance strength training programme, reported that relative gains in muscle strength on the strong

Table 4 Correlation between change in muscle strength and change in functional performance ($n = 48$)

	Gait velocity		Cadence		Stride length		Six-minute walk		Step test		Timed up and go	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Hip flexors												
Strong side	0.06	0.7	0.2	0.2	0.3	0.03	−0.04	0.8	0.3	0.03	−0.3	0.05
Paretic side	0.4	0.002	0.5	<0.001	0.1	0.5	0.4	0.02	0.2	0.2	−0.7	<0.001
Hip extensors												
Strong side	−0.01	0.9	0.5	0.001	−0.1	0.5	0.5	<0.001	0.3	0.08	−0.4	0.01
Paretic side	−0.2	0.1	−0.1	0.5	−0.2	0.2	0.4	0.002	0.6	<0.001	−0.1	0.4
Knee flexors												
Strong side	0.1	0.2	0.5	0.001	0.7	<0.001	0.2	0.3	0.5	0.001	−0.8	<0.001
Paretic side	0.2	0.2	0.6	<0.001	−0.07	0.7	0.2	0.2	0.2	0.2	−0.2	0.3
Knee extensors												
Strong side	−0.009	1.0	0.2	0.1	0.1	0.2	0.2	0.1	−0.05	0.7	−0.2	0.1
Paretic side	0.7	<0.001	0.7	<0.001	0.6	<0.001	0.4	0.01	0.5	<0.001	−0.8	<0.001
Ankle dorsiflexors												
Strong side	−0.01	0.9	0.1	0.3	−0.2	0.4	0.2	0.1	−0.1	0.4	−0.2	0.1
Paretic side	0.04	0.8	0.5	0.001	−0.2	0.2	0.5	0.001	0.3	0.05	−0.3	0.04
Ankle plantarflexors												
Strong side	0.4	0.007	0.7	<0.001	0.04	0.8	0.01	0.9	0.09	0.5	−0.6	<0.001
Paretic side	0.6	<0.001	0.6	<0.001	−0.09	0.5	0.5	0.001	0.2	0.3	−0.4	0.002

and paretic side averaged 48% and 68%, respectively.[12] Ouellette *et al.*, using a progressive resistance strength training programme similar to that used by Weiss *et al.*,[12] showed relative improvements in strength increase of 14.7–38.2% for the strong side and 31.4–66.7% for the paretic side.[13] These results suggested that improved rate of task-oriented progressive resistance strength training was similar to that of traditional progressive resistance strength training. Therefore, the task-oriented progressive resistance strength training could be an effective training means to improve muscle strength in individuals at least one year after stroke onset.

Despite the universal improvements in strength for all lower extremity muscle groups, the step test was the only functional performance measure that did not improve after the task-oriented progressive resistance strength training intervention. In contrast with the experimental group, participants in the control group significantly decreased the number of repetitions of the step test over the four-week period. Our results also showed that the change in step test was significantly correlated with strength gains in strong hip flexors, paretic hip extensors, strong knee flexors and paretic knee extensors. These results suggested, therefore, that strength gain may have contributed to the maintenance of stepping ability. However, the lack of improvement in the step test may indicate that there are other components determining stepping ability to a greater degree than just muscle strength. Balance and co-ordination are also important components in this functional task. In a future study, it would be valuable to evaluate the contribution of these potential components during the step test.

There are several limitations in this study. First, the major limitation of this study was a lack of follow-up. We could not speculate whether the subjects in the experimental group can maintain these changes. Second, the study was limited to subjects who volunteered; they were, therefore, were a self-selected group of willing and highly motivated individuals. This may affect the generalizability of the present findings to the whole stroke population.

These findings show that a task-oriented progressive resistance strength training programme could improve lower extremity muscle strength in both strong and paretic limbs in individuals one year post stroke, and that the strength gains due to the task-oriented progressive resistance strength training intervention could be carried over to improvements in functional abilities. Although the physiological mechanisms underlying these effects cannot be determined on the basis of the current data, it is possible that improved motor unit recruitment[30] and motor learning (the development of neuromotor patterns of co-ordination between agonist and antagonist muscles through practice of a skill)[31,32] may have contributed to some degree. Future studies may be needed to clarify this hypothesis.

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