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Low intensity strength training for ambulatory stroke patients

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Abstract

Purpose: To investigate feasibility and effectiveness of an individually-directed, group strength-training programme on knee muscle strength after stroke.

Method: Ten volunteers (62 ± 11 years, mean ± SD), 6-12 months after first-ever unilateral stroke, walking independently with or without aids were recruited. Using an A1-B-A2 design, 3 sets of baseline measures were taken at 2 weekly intervals; volunteers then attended twice weekly sessions of low intensity progressive strengthening exercises and were assessed after each series of 8 sessions to a maximum of 24 sessions; post training, measures were repeated after 4-6 weeks. Measures included isometric and concentric knee extensor muscle strength and 10m walking velocity.

Results: Strength of knee extensor muscles was improved after training (ANOVA, $p<0.05$). On cessation of training, isometric strength increased by 58 ± 19% and concentric strength at 30°/s by 51 ± 14%; walking velocity quickened from 0.47 ±

0.06 ms^{-1} to 0.57 ± 0.08 ms^{-1} ($t=-3.31$, $p<0.01$). These gains were maintained 4-6 weeks after completion of training.

Conclusions: These findings support the use of low intensity strength training after stroke and confirm published evidence. It was feasible for one therapist to deliver the training programmes for 4-6 participants at a time; an important feature when resources are limited.

Introduction

Muscle weakness is considered a cardinal feature of stroke and in recent years, there has been increased attention to muscle weakness as a primary factor limiting recovery of physical function. Muscle strength, defined as maximal capacity of a muscle to generate peak tension measured during isometric or concentric contraction, has been shown to have moderate to strong correlation with gait velocity [1,2]. Thus, with increasing recognition of the problem of muscle weakness, the use of strength training and other forms of exercise training after stroke has generated clinical debate and experimental investigation of its benefits and detriment [3,4].

Recent systematic reviews of exercise [5,6] and strength training [7] have examined published evidence and summarised current understanding of the effectiveness of these interventions. Although limitations of available evidence restrict definitive conclusions, Morris et al [7] who reviewed progressive resistance strength training studies and included non-randomised experimental designs, inferred that strength training programmes led to gains in strength with no significant changes in spasticity but the effects on functional activity and social participation were undetermined. Subsequently, positive effects of high-intensity resistance training on self-reported function have been reported [8]. Although there is growing support for the use of strength-training in stroke rehabilitation, several issues require further consideration in relation to planning and implementing such programmes in clinical practice.

One key issue, highlighted by Morris et al [7] and Saunders et al [5], is variability in training methods and training intensity of strength-training programmes. Guidelines for strength training of healthy adults recommend training frequency of 2-3 days per week involving 1-3 set of 8-12 repetitions at 60-80% of 1 repetition maximum (1RM) of 8-10 exercises for major muscle groups [9]. Published recommendations for people after stroke suggest that higher repetitions with reduced loads may be prudent and suggest 10-15 repetitions for each set [10]. In terms of dose response for strength gains for healthy individuals, Rhea et al [11] concluded that training intensities of 60% of 1RM elicited maximal gains in untrained individuals (defined as those with less than 1 year experience of weight training). Seynnes et al [12] investigating the effectiveness of low (40%) and high (80%) intensity training with frail elderly participants found that both training intensities resulted in significant gains in strength but a dose-response effect was observed. Other studies of older adults indicate that loads of 50% to 80% of 1RM result in similar strength gains [13,14].

Determining what exercises to include in a strength-training programme requires consideration. Studies of pattern of muscle weakness after stroke have indicated that the non-paretic lower limb is weaker than normal and physiological flexors and extensors are similarly affected in the paretic lower limb [15,16]. Studies of the relationship between the strength of paretic lower limb muscle groups and locomotor performance have shown that strength of lower limb muscles such as hip flexor, knee extensor and ankle plantarflexor muscles influence gait velocity [1,2,17]. Kim and Eng [17] highlighted non-paretic limb muscle strength as a contributor to gait velocity. Variation exists in the relationship between strength of specific lower limb muscles and gait velocity but knee extensors are consistently reported as determinants of gait velocity [1,2].

This study aimed to assess the benefits of a low-intensity (maximum of 50 % of 1RM) strength-training programme targeting knee extensor muscles in particular and to ascertain the feasibility of delivering the programme in a group format within a typical hospital setting.

Method

Subjects

Twelve participants were recruited from those recently discharged from Stroke Units at St. Andrews Hospital, Bow and Homerton Hospital, London. Inclusion criteria were as follows: first-ever unilateral stroke resulting in motor impairment of lower limb, 6 to 12 months post onset, and discharged home and walking independently either with or without assistive devices. Exclusion criteria were: ongoing physical treatment, co-morbid neurological conditions, joint or muscular problems affecting lower extremities and uncontrolled hypertension or cardiac condition as determined by the consultant physician. All participants gave informed consent to the experimental procedures which had been approved by East London and The City Health Authority Research Ethics Committee and University of East London Research Ethics Committee.

Experimental Design and Procedure

A non-randomised self-controlled experimental study using A1-B-A2 design was used. Participants completed three baseline measures conducted at two weekly intervals prior to commencing the exercise programme. Participants were requested to attend a minimum of 16 sessions and up to a maximum of 24 sessions. Repeat assessments were conducted after attendance at a minimum of 8 and 16 training sessions, immediately after cessation of training and 4-6 weeks after cessation of training.

Measures

Maximal strength of knee extensor and flexor muscle groups was assessed using Loredan Lido Active dynamometer. Both paretic (affected) and non-paretic (intact) limbs were assessed and the non-paretic limb was tested first on each occasion. Tests were conducted in a seated position in accordance with manufacturer’s protocol on positioning and stabilisation. Isometric strength of knee extensor muscles only was assessed initially through range at 20º increments from 90º - 10º knee flexion. Participants performed 5 second contractions at each position with 30 seconds rest between each contraction. Concentric muscle strength was assessed at velocities of 30, 60, 120 and 180 º/s through a maximum range of 90º - 0º knee flexion. Participants performed five concentric knee extensor and concentric knee flexor contractions at each velocity with 2 minutes rest between each velocity.

Gait velocity over ten metres was assessed. Two successive 10m walks were timed using a standard stopwatch. Subjects were instructed to walk at their self-selected pace using any assistive devices they would normally use walking around their home. Muscle tone was monitored using the modified Ashworth scale.

Training Protocol

Exercise sessions were held twice weekly over a period of 6 months in the physiotherapy gym of St. Andrews Hospital, Bow. Up to six participants attended any one session, which were directed by a physiotherapist. The exercise programme was designed to target antigravity muscles particularly knee extensors through low-intensity progressive resistive muscle exercise and movement tasks. The exercise programme consisted of the following components: (1) warm-up on unloaded cycle ergometer for 3-5 minutes; (2) therapist-assisted stretches of lower limb muscle groups; (3) a circuit of the following exercises: resisted knee extension using Westminster pulley system; resisted hip abduction and resisted hip extension using elasticated exercise bands; body squats using wall to provide stabilisation; knee extension in standing using 15cm or 25cm steps and (4) warm-down activities. Participants completed 3 sets of 10 repetitions on both paretic and non-paretic limb for each exercise in the circuit. Training load for resisted knee extensors was determined by 1 repetition maximum (1RM), the maximum load lifted once only on the Westminster Pulleys. Initial training load was set to 20% of 1RM to minimise post-exercise stiffness and increased up to 50% 1RM. 1RM was assessed every 4-6 sessions. Hip exercises were progressed by increasing the strength of the elastic bands and squats and steps were progressed by increasing movement excursion in line with progression of knee extensor exercise. Participants' feedback about adverse effects to preceding sessions, such as post exercise pain and stiffness, was also considered in progression of exercise.

Data measurement and analysis

For concentric contractions, torque and angle data was extracted in ASCII format from Loredan Lido Active software and processed using a custom Matlab^{TM} routine to establish velocity of movement. Maximal strength was recorded as the peak torque achieved during concentric contractions if the velocity of movement was no less than 10% lower than the desired test velocity. Maximal isometric strength was measured as the peak torque achieved during the 5 second isometric contraction. The faster of the two recordings of walking velocity was used in analysis.

Demographical details are reported as mean ± SD. Other results are reported as mean ± SEM. Normality of data distribution was established and parametric analysis applied. Repeated measures analysis of variance was used to determine statistically significant differences in muscle strength and walking velocity. For strength variables, two main effects, differences between paretic and non-paretic limbs and differences between six assessment points (three baseline, after 8 training sessions, cessation of training and post-training tests) were examined along with their interaction. Significance level was established at $p < 0.05$ and post-hoc analysis was conducted using t-test to confirm differences between paretic and non-paretic limbs and/or differences between successive tests in each limb. Further post-hoc analysis was conducted at key assessment points of 3rd baseline, cessation of training and post-training tests for presentation of results.

Results

Of the twelve participants recruited to the study, one participant did not complete due to unrelated illness and a second did not attend the minimum of 16 training sessions. Ten participants who completed training attended on average 21 ± 4 sessions with 4 attending the minimum number of sessions. Of those, 5 were male and 5 female, with an average age of 62 ± 11 years. There was equal number of incidents of right and left cerebrovascular accidents and the average time post-onset was 8.5 ± 2 months. Nine participants walked independently with the aid of an assistive device, predominantly a walking stick and one participant walked independently without an aid. Their average walking velocity over 10 metres was 0.47 ± 0.06 ms^{-1}.

Muscle strength prior to training

Concentric strength of knee musculature was assessed at velocities of 30, 60, 120 and 180 °/s. Table 1 shows mean torque values of baseline measurements for the number of participants who achieved the target velocities. The majority of participants did not record a value for strength of affected knee extensor muscles at velocities of 120 and 180 °/s and for strength of knee flexor muscles at 60, 120 and 180 °/s. At 30º/s, paretic /non-paretic strength ratio for knee extensor and flexor muscles was 31 ± 6 % and 33 ± 4 % respectively.

Isometric strength of knee extensor of paretic and non-paretic limbs at 90º of knee flexion was 128 ± 10 Nm and 37 ± 7 Nm respectively. Peak torque was recorded at joint angle of 70% knee flexion (136 ± 13 Nm and 44 ± 8 Nm respectively).

[Insert: Table 1]

Effects of training

Repeated measures ANOVA showed that paretic muscles remained significantly weaker than intact muscles ($p < 0.001$) in all analyses and this main effect is not presented in further detail. Table 2 summarizes the effect of training on muscle strength together with the statistical analysis at three assessment points. Significant differences in isometric and concentric strength of knee extensor muscles were observed but there were no significant changes in knee flexor muscle strength.

[Insert: Table 2]

Changes in knee extensor muscle strength

Concentric muscle strength at 30 and 60 °/s showed significant differences in muscle strength over successive assessments ($F_{df=5}$ = 5.9 to 8.9, $p < 0.01$) but no significant interactions. Post-hoc t-tests showed that there was a significant increase in intact muscle strength from after 8 training sessions to cessation of training ($p < 0.02$) at 30°/s but no significant successive gains at 60°/s. Affected muscle strength significantly increased from baseline to after 8 training sessions at 30°/s ($p < 0.006$) and from after 8 training sessions to cessation of training at 60°/s ($p < 0.03$).

At the faster velocity of 120°/s, the number of participants who achieved the test velocities on the affected side increased from 2 to 6.

Repeated measures ANOVA showed that there was significant differences in isometric muscle strength at 90° knee flexion over successive assessments ($F_{df=5}$ = 11.5, $p < 0.01$) and significant interaction of main effects ($F_{df=5}$ = 2.6, $p < 0.05$). Post hoc t-tests, used to examine gains in strength between successive assessments, showed that though there was a significant increase in strength between baseline and post-training assessments, there was no significant increase in non-paretic muscle strength between successive assessments. Paretic limb muscle strength significantly increased from baseline to after 8 training sessions ($p < 0.007$) and further increased after subsequent training sessions ($p < 0.053$).

Variability in response to training.

While there was an overall increase in knee extensor strength, variability in individual response to training was noted. Figures 1 and 2 illustrate individual differences in muscle strength over the baseline and training periods. Mean differences in intact isometric muscle strength during both periods were 16 ± 4 Nm and 13 ± 4 Nm respectively. Mean differences in paretic muscle were 2 ± 3 Nm and 16 ± 3 Nm respectively. Isometric measures of intact limb muscle strength showed a learning effect during the baseline period and a marked training effect of intact/paretic muscles in some individuals.

[Insert: Figures 1 and 2]

Equivalent mean differences in strength over the baseline and training period for concentric muscle strength were 1 ± 6 Nm and 14 ± 7 Nm for intact and 3 ± 1 Nm and 12 ± 3 Nm for paretic muscles. Three participants did not show gains in strength with training in either limb.

Changes in walking velocity and muscle tone

Figure 3 shows the effects of training on walking velocity. Repeated measures ANOVA showed that walking velocity was significantly increased ($F_{df=5} = 6.67$, $p < 0.01$) and post-hoc t-tests confirmed that a significant increase occurred between 3rd baseline measure and after 8 training sessions.

[Insert: Figure 3]

Tone of lower limb musculature was monitored using the modified Ashworth scale. Prior to training, increase in muscle tone, that is a grading greater than 0, was more prevalent at the ankle than the knee or hip (occurrence: ankle n=6; knee n=2; hip n=0). One participant presented with a grading of 2 at ankle and knee and the remainder had a grading of 1. During and after training, there were no substantive changes in muscle tone (occurrence: ankle n=5; knee n=3; hip n=0). One participant showed an increase of one scale point at the knee and two participants showed a decrease of one scale point at the knee and ankle respectively.

Discussion

Our study investigated the effects of an individually directed group strength-training programme on strength of knee musculature, walking velocity and muscle tone of participants who had suffered a stroke in the previous twelve months. It was feasible for the physiotherapists delivering the training programme to work with up to six participants but attendance of participants was dependent on the provision of suitable transport facilities.

Participants recruited to the study were required to be able to ambulate independently either with or without walking aids and it was anticipated that they would demonstrate mild to moderate muscle weakness and be able to complete the testing protocol which examined concentric contractions at velocities up to 180°/s. As expected, participants showed a velocity-dependent decrease in knee muscle strength with increasing velocity. However, the majority of these ambulant patients were unable to contract their muscles at the required velocity at test velocities of 120 and 180 °/s. Sharp & Brouwer [18] and Engardt et al [3] used similar measures of isokinetic knee muscle strength at velocities up to 120 and 180°/s in people after stroke undergoing a strength training programme. They did not report non-achievement of test velocities but both studies reported greater values for knee extensor strength than observed in this study. Engardt et al [3] reported concentric strength at 60º/s of 61.8 ± 7.6 Nm in comparison to 28 ± 8 Nm in this study. In both studies [3,18], the time post-onset of stroke and the reported gait velocities of patients were greater (e.g. 27.8 ± 12 months [3] in comparison to 8.5 ± 2 months; 0.66 ± 0.11 ms^{-1} [18] in comparison to 0.47 ± 0.06 ms^{-1}). In a cohort of 10 patients with of similar age and time post-onset [19], knee extensor strength at 30º/s was greater, 58.8 ± 9.4 Nm in comparison to 32 ± 9 Nm but knee flexor strength was reduced, 12.8 ± 4.6 Nm in comparison to 17 ± 3 Nm. Indications are that, with paretic/non-paretic ratios of around 30%, knee muscles of the participants prior to training were markedly weaker in this present study.

With strength-training, we observed that knee extensor muscle strength significantly increased with a targeted training programme but knee flexor strength did not change. Muscle tone was unaltered and gait velocity was significantly increased. Overall, these results concur with the results of previously reported studies [3,4,8,18,20,21] and reviews [5,7,22]. Weiss et al [21] examined the time course of strength gains of seven stroke subjects using progressive resistive exercise and reported that the greatest increase occurred by the eighth week of training i.e. after 16 sessions. In our study, significant gains in strength and gait velocity were observed after 8 sessions and continued over the training period. Gains were maintained in the short-term (4-6 weeks) after cessation of training. The percentage increase in strength was in the order of 48-58% in paretic muscles in both isometric and concentric (30º/s) modes. Comparable gains have been reported in some studies [3,4,21] but in other studies, lower gains have been recorded for knee extensor muscles [8,18].

Training intensity needs to be considered and the variances in effectiveness of the intervention explored in view of the observed weakness of the participants. Training intensities and the exercises utilised in training studies with people after stroke have varied but, where reported, high intensity exercise at 80-100% of 1 RM has generally been used. In our study, 3 sets of 10 repetitions at 50% of 1RM were utilised for knee extensor exercises. Indications are that trained adults, untrained adults and athletes demonstrate variance in optimal dose response to training [11,23]. Training at 60% of 1RM is most effective for untrained adults [11]. In older adults, it appears that a range of training intensity can be successfully used [13,14]. With a group of frail elderly, while training at an intensity of 80% resulted in greater gains in strength, training at an intensity of 40% also resulted in significant gains in knee extensor strength [12].

Identification of optimal training intensities for stroke subjects is an important issue for planning and implementing strength-training programmes within a rehabilitative context. Though the programme implemented in this study was successful overall in increasing strength and gait velocity, some subjects showed marked gains with training while others did not improve. It is possible that training intensity in these cases was not sufficient to induce physiological and functional changes and that greater attention should have been paid to individual variation in the pattern of muscle weakness and to exercises targeting those muscle groups [16]. Further investigation is required to explain individual variation in response to strength-training programmes.

In this study, we successfully implemented a strength training programme for ambulant stroke survivors in a typical UK hospital setting. The results illustrate the beneficial effects of strength-training but require verification using independent controls. Clinical issues that arise from this study are the training intensity and exercises to use in strengthening muscles after stroke but indications are that low intensity exercise targeting knee extensor muscles is beneficial for muscle strength and gait velocity for the majority of stroke participants.

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Table 1: Baseline values for concentric muscle strength (mean ± SEM)

	Knee Extensors (Nm)		**Knee Flexors (Nm)**	
°/s	**Paretic**	**Intact**	**Paretic**	**Intact**
30	32 ± 9 (n=10)	102 ± 10 (n=10)	17 ± 3 (n=8)	50 ± 6 (n=10)
60	28 ± 8 (n=9)	88 ± 9 (n=10)	17 ± 3 (n=3)	41 ± 6 (n=10)
120	41± 22 (n=2)	67 ± 7 (n=9)	- (n=0)	36 ± 6 (n=3)
180	- (n=0)	58 ± 5 (n=8)	- (n=0)	- (n=0)

Table 2: Summary of effects of training on knee extensor and flexor muscle strength (mean ± SEM) (Post hoc t-test**:** significant difference from baseline - * p<0.05, **p< 0.01, ***p<0.001)

		Knee Extensors (Nm)		
°/s		**Baseline (3rd test)**	**Cessation of training**	**Post-training**
0	Paretic (n=10)	44 ± 8	59 ± 8***	57 ± 10***
	Intact (n=10)	136 ± 13	144 ± 12*	143 ± 14
30	Paretic (n=10)	32 ± 9	43 ± 8**	44 ± 7**
	Intact (n=10)	102 ± 10	116 ± 7	115 ± 8
60	Paretic (n=9)	28 ± 8	37 ± 7*	37 ± 6*
	Intact (n=10)	88 ± 9	103 ± 8	99 ± 8
			Knee Flexors (Nm)	
30	Paretic (n=7)	18 ± 4	18 ± 4	14 ± 3
	Intact (n=10)	50 ± 6	53 ± 5	51 ± 6

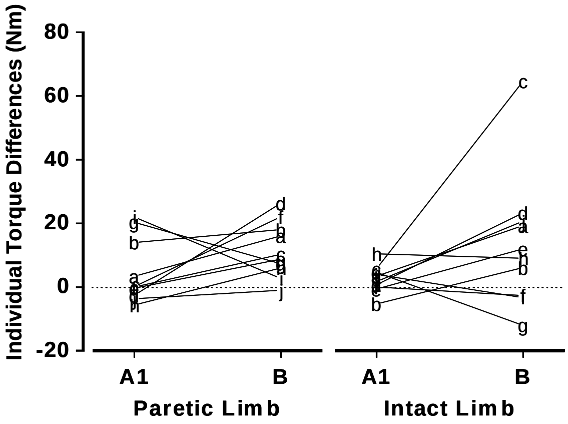

Figure 1: Individual differences in paretic and intact isometric knee extensor strength over baseline period (A1) and training period (B)

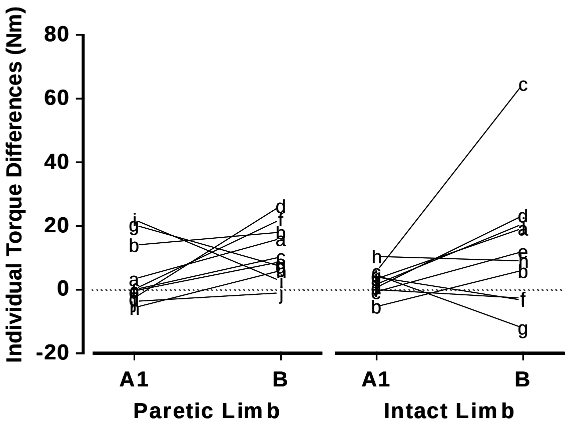

Figure 2: Individual differences in paretic and intact concentric (30 °/s) knee extensor strength over baseline period (A1) and training period (B)

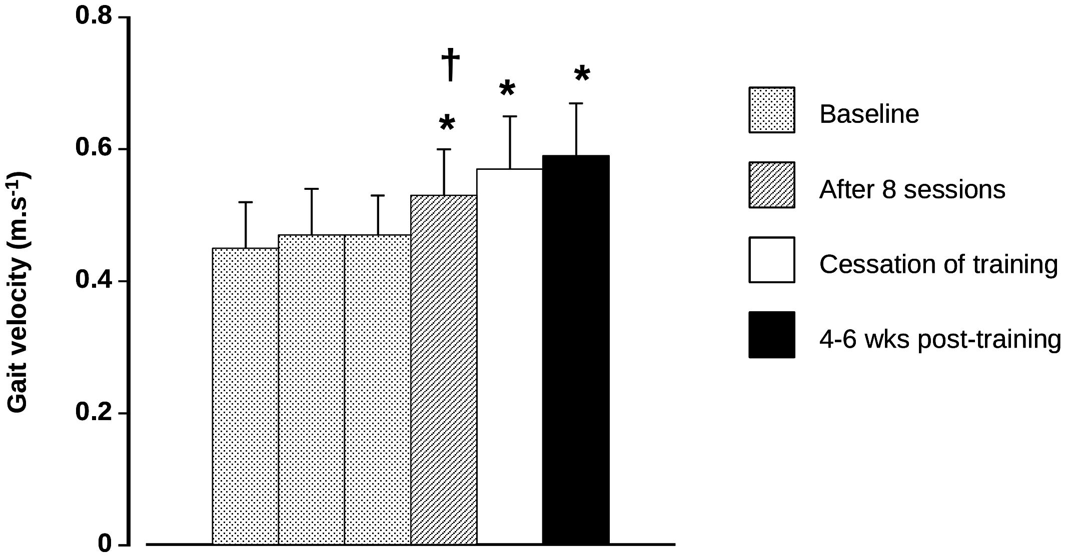

Figure 3: Self-selected walking velocity (mean ± SEM) prior to training (3 baseline measures), after 8 sessions, cessation of training and 4-6 weeks post-training (Post hoc t-tests: * significant difference from baseline ($p<0.05$); † significant difference between successive tests ($p< 0.05$))