

Strengthening interventions increase strength and improve activity after stroke: a systematic review

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Question: Is strength training after stroke effective (ie, does it increase strength), is it harmful (ie, does it increase spasticity), and is it worthwhile (ie, does it improve activity)? **Design:** Systematic review with meta-analysis of randomised trials. **Participants:** Stroke participants were categorised as (i) acute, very weak, (ii) acute, weak, (iii) chronic, very weak, or (iv) chronic, weak. **Intervention:** Strengthening interventions were defined as interventions that involved attempts at repetitive, effortful muscle contractions and included biofeedback, electrical stimulation, muscle re-education, progressive resistance exercise, and mental practice. **Outcome measures:** Strength was measured as continuous measures of force or torque or ordinal measures such as manual muscle tests. Spasticity was measured using the modified Ashworth Scale, a custom made scale, or the Pendulum Test. Activity was measured directly, eg, 10-m Walk Test, or the Box and Block Test, or with scales that measured dependence such as the Barthel Index. **Results:** 21 trials were identified and 15 had data that could be included in a meta-analysis. Effect sizes were calculated as standardised mean differences since various muscles were studied and different outcome measures were used. Across all stroke participants, strengthening interventions had a small positive effect on both strength (SMD 0.33, 95% CI 0.13 to 0.54) and activity (SMD 0.32, 95% CI 0.11 to 0.53). There was very little effect on spasticity (SMD -0.13, 95% CI -0.75 to 0.50). **Conclusion:** Strengthening interventions increase strength, improve activity, and do not increase spasticity. These findings suggest that strengthening programs should be part of rehabilitation after stroke. [Ada L, Dorsch S, Canning CG (2006) Strengthening interventions increase strength and improve activity after stroke: a systematic review. *Australian Journal of Physiotherapy* 52: 241–248]

Key words: Cerebrovascular Accident, Physical Therapy Techniques, Exercise Therapy, Rehabilitation, Review Systematic, Meta-Analysis, Randomized Controlled Trials, Muscle Weakness, Muscle Spasticity, Systematic Review of Function

Introduction

Stroke is the third most common cause of death in the western world and the most common cause of long term adult disability (Bath 2005). It is recognised that the negative motor impairments following stroke, eg, loss of strength and dexterity, contribute most to disability (Burke 1988). Furthermore, it now appears that weakness, ie, the loss of ability to generate normal amounts of force, is the major contributor to limitation of physical activity. Observational studies report a significant correlation between strength and activity (eg, Bohannon and Andrews 1990, Bohannon and Walsh 1991, Boissy et al 1999, Chae et al 2002, Kim and Eng 2003, Mercier and Bourbonnais 2004, Nakamura et al 1988). Moreover, studies comparing a range of impairments with activity report a higher correlation between strength and activity than any other impairment (Bohannon et al 1991, Canning et al 2004, Lin 2005, Nadeau et al 1999). Consequently, there has been a move to implement strength training as part of rehabilitation after stroke. This systematic review examines not only whether strength training after stroke is effective (ie, does it increase strength), but whether it is harmful (ie, does it increase spasticity) and whether it is worthwhile (ie, does it improve activity).

Strength training is commonly considered to be progressive resistance exercise but any intervention that involves attempted repetitive effortful muscle contractions can result in increased motor unit activity, thereby potentially increasing strength after stroke. Interventions could therefore include

electrical stimulation, biofeedback, muscle re-education, and mental practice in addition to progressive resistance exercise. Although there have been attempts to examine the effect of these interventions after stroke, the systematic reviews have been intervention-focussed and often do not examine strength as an outcome. For example, three meta-analyses of EMG biofeedback (Moreland and Thomson 1994, Moreland et al 1998, Schleenbaker and Mainous 1993) reported effects from 16 randomised controlled trials with strength reported from only two of them (Basmajian et al 1975, Burnside et al 1982). Furthermore, concentrating on the effect of one intervention usually means that there are not enough trials to perform a meta-analysis. For example, neither the Cochrane review on electrical stimulation (Pomeroy and Pollack 2006) nor the review of progressive resistance exercise (Morris et al 2004) had sufficient trials to do a meta-analysis of the effect of these interventions on strength.

Another issue is that these single-intervention systematic reviews do not differentiate between trials with different types of participants, such as participants at different times after stroke and with different initial levels of strength. The effect of strength training may depend on the time after stroke, since the mechanism underlying loss of strength changes over time. Immediately following a stroke, reduced force production is due to a loss of descending input to the spinal motor neurone pool reducing the activation of motor units, whereas six months after stroke, reduced force production is also due to a decrease of cross sectional

area of muscle (Ryan et al 2002) and a reduction of motor units (Hara et al 2000) due to disuse. Also, the effect of strength training may depend on the level of initial strength. For example, only certain interventions such as electrical stimulation, biofeedback, and mental practice are possible for patients who cannot move a limb against gravity and therefore cannot undertake interventions involving lifting weights.

Strength training will only be widely adopted if it is found to be worthwhile, ie, it improves activities such as standing up, walking, reaching for, and grasping objects. In addition, it needs to be found to be not harmful since, historically, it has been avoided due to a belief that it would increase spasticity (Bobath 1990). Therefore the primary question of this systematic review was *Is strength training effective?* ie, do strengthening interventions increase strength in people who are suffering the effects of acute and chronic stroke, and who are very weak and weak after stroke. Secondary questions were *Is strength training harmful?* ie, do strengthening interventions increase spasticity after stroke, and *Is strength training worthwhile?* ie, do strengthening interventions improve activity after stroke.

Method

Identification of trials Searches were conducted of MEDLINE (1966 to January 2005), CINAHL (1982 to January 2005), EMBASE (1974 to January 2005) and PEDro (to January 2005). Searches were performed without language restrictions using words related to stroke and randomised or quasi-randomised controlled trials (according to the Cochrane Stroke Group) and words related to strengthening interventions such as electrical stimulation (according to Pomeroy and Pollock 2006), biofeedback (according to Woodford and Price 2003), progressive resistance exercise (according to Saunders et al 2004), and mental practice (see Appendix 1 on the eAddenda for the complete search strategy). Titles and abstracts (where available) were displayed and screened to identify relevant trials. Full paper copies of relevant trials were obtained and their reference lists were screened. Hand searching of the most recent conference proceedings of World Congress of Physical Therapists and the Australian Physiotherapy Association National Neurology Group was also carried out to identify relevant trials.

Selection of trials To determine whether a trial should be included, reviewers (CC, SD, and Lyndel Hodgson) reviewed the trials independently using predetermined criteria. Trials had to meet a number of criteria for inclusion. The trial had to be a randomised or quasi-randomised controlled trial and the participants had to have had a stroke. The experimental intervention had to be of a type and dose that could be expected to improve strength following stroke, ie, it had to involve attempts at repetitive, strong, effortful muscle contractions, and it had to be stated or implied that the intervention was progressed as the participants' abilities changed. The control intervention had to be: nothing, sham/placebo, or a therapy that was not a strengthening intervention. Outcome measures had to include strength as this indicated that the authors expected the intervention to have an effect on strength, and the strength measurement had to be of force generation such as manual muscle test or torque.

Description of trials *Quality* The quality of included trials was assessed by extracting PEDro scores from the

Physiotherapy Evidence Database (PEDro, www.fhs.usyd.edu.au/pedro/) (Maher et al 2003). Where additional information was obtained from authors, the score was adjusted accordingly. Where the trial was not included on the database, it was assessed by two reviewers independently (CC, SD).

Participants Participants who were less than 6 months after stroke on admission to the trial were categorised as acute, and participants who were more than 6 months after stroke on admission to the trial were categorised as chronic. Participants who were unable to move a limb through full range of movement against gravity were categorised as *very weak* and participants who could move through full range against gravity but had less than normal strength were categorised as *weak*. Therefore, participants were categorised as (i) acute, very weak, (ii) acute, weak, (iii) chronic, very weak, or (iv) chronic, weak.

Intervention Interventions were categorised as (i) biofeedback, including EMG, force, or positional biofeedback, (ii) electrical stimulation, including activity-triggered electrical stimulation, such as EMG, or position-triggered electrical stimulation, (iii) muscle re-education if the intervention progressed from passive and assisted movements to active and resisted movements, including robot-assisted movements, (iv) progressive resistance exercise if the intervention consisted of movement against progressively increased resistance, including robot-resisted movements, or (v) mental practice if the intervention consisted of the cognitive rehearsal of an attempt to move.

Measures When multiple measures of strength were reported, the measure that reflected the body part to which the training was applied was used. Where possible, a measurement of spasticity of the same muscle group(s) that underwent the strengthening intervention was used. Where possible, direct measures of activity were used, eg, 10-m Walk Test or the Box and Block Test. Scales that measure dependence or level of care needs such as the Barthel Index were used if they were the only measure of activity.

Data extraction The relevant details were extracted from the included trials by one of two reviewers (SD and Lyndel Hodgson) and cross checked by two reviewers (LA, CC). Information about the method (ie, design, participants, intervention, measures) and results (ie, number of participants and mean (SD) of strength, spasticity and activity) were extracted. Where information was not available in the published trials, details were requested from the author listed for correspondence.

Analysis of effect of strengthening interventions Since more trials reported pre- and post-intervention scores than change scores, post-intervention scores were used in the meta-analysis. Every attempt was made to include data in the meta-analysis. If the post-intervention scores were not available, the post-intervention mean was calculated from the pre-intervention and change means and the SD of the pre-intervention scores was used. If only the median and range of outcomes were available, mean and SD were calculated from them as described by Hozo et al (2005). If it was appropriate to use the measures from several different muscles, ie, these muscles had been targeted in the intervention, then the means and SD of the individual measurements were summed.

The data were entered into the Cochrane Collaboration's

Review Manager program (RevMan 4.1) and pooled estimates of the effect of strengthening interventions on strength, spasticity and activity were obtained using a random effects model. Since many different methods were used to measure the outcomes of interest on many different muscles, the effect sizes were reported as standardised mean differences (SMD) and 95% CI. Where data were not available to be included in the pooled analysis, the outcome of the between-groups analysis was reported.

Results

Identification and selection of trials 258 references were retrieved from the search strategy. 102 trials were assessed for inclusion criteria; the remainder were able to be excluded on reading of the abstract. Of these 102 trials, 80 did not meet the inclusion criteria. One trial included data that were reported in another article. This left 21 discrete trials that were included (Table 1). Additional information about the method was obtained for eight trials and additional outcome data for six trials. Five trials investigated acute, very weak participants; six trials investigated acute, weak participants; two trials investigated chronic, very weak participants; and eight trials investigated chronic, weak participants.

Description of trials Quality The mean PEDro score of the trials was 4.7 (Table 1). Twenty were randomised controlled trials and one was quasi-randomised (Kraft). Common failings were: not concealing the allocation sequence (60%), not blinding the assessor (62%), not obtaining one key outcome from more than 85% of the participants (52%), and not applying 'intention-to-treat' analysis (86%). No trials blinded participants or therapists, which is difficult or impossible using these interventions.

Participants Across all the trials, the mean age ranged from 50 to 70.5 years; 51% of participants were male and 49% female. In the trials of acute participants, the mean time after stroke on entering the trial ranged from 2 weeks to 4.5 months, whereas in the trials of chronic participants it ranged from 2 to 8 years.

Intervention Strengthening interventions examined in the trials of very weak participants included electrical stimulation (two activity-triggered and one cyclical electrical stimulation trial), biofeedback (two EMG-biofeedback trials), and muscle re-education (one robot-applied and two therapist-applied trials) (Table 1). In the electrical stimulation trials, the experimental intervention was carried out over 4–8 weeks, 5–7 days/week, for 45–150 minutes per day. In the biofeedback trials, the experimental intervention was carried out over 5–6 weeks, 3 days/week, for 40–60 minutes per day. In the muscle re-education trials, intervention was carried out over 6 weeks, 5 days/week, for 45–90 minutes/day. There were no trials of mental practice that met the inclusion criteria.

Strengthening interventions examined in the trials of weak participants included electrical stimulation (four activity-triggered and one cyclical electrical stimulation trial), muscle re-education (one robot-applied trial), and progressive resistance exercise (eight trials) (Table 1). In the electrical stimulation trials, the experimental intervention was carried out over 2–12 weeks, 3–6 days/week, for 0.3–6 hours/day. In the muscle re-education trial, intervention was carried out over 8 weeks, 3 days/week, for 60 minutes/day. In the progressive resistance exercise trials, the experimental intervention was carried out over 2–12 weeks, 3–5 days/week, for 30–90 minutes/day.

The control intervention varied across trials (Table 1). Conventional therapy was either neurodevelopmental treatment (11 trials) or motor relearning/task specific therapy (four trials). Sham interventions were passive movements (two trials) or stretching and active and passive movements (two trials). The control intervention was nothing in one trial and education in one trial.

Measures All measures of strength were of maximum voluntary force production, either continuous measures of force or torque (18 trials), or ordinal measures such as manual muscle tests (three trials). There were three trials that measured many muscle groups, one where the results were presented as averaged scores, and two where the results were summed scores. There were eight trials that measured the strength of more than one muscle. Where these trials presented results for strength of individual muscles using the same units, these measures were summed to provide one value to enter into the pooled analysis (eight trials). Where trials presented results for males and females separately, these measures were averaged (weighted by the number of participants) (one trial). Spasticity was measured using the modified Ashworth Scale (two trials), a custom made scale (two trials), or the Pendulum Test (two trials). One trial reported two measures of spasticity from individual limbs using the same unit, and these were summed to provide one value to enter into the pooled analysis. Most trials measured activity using scales (11 trials) but some used direct measures of activity such as walking velocity during the 10-m Walk Test (four trials), number of blocks moved in the Box and Block Test (two trials), or time taken to move pegs in the Nine-Hole Peg Test (one trial).

Effect of strengthening interventions Strength The overall effect of the strengthening interventions on strength was examined by pooling post intervention data from 14 trials (Duncan, Heckmann, Kim, Kimberley, Kraft, Lippert-Gruner, Logigian, Lum, Merletti, Ouellette, Stein, Teixeira-Salmela, Winchester, Winstein) (Figure 1, see also Figure 2 on the eAddenda for detailed forest plot). Overall, strengthening interventions increased strength by 0.33 SD (95% CI 0.13 to 0.54, $p = 0.001$).

In acute, very weak stroke participants, the effect of strengthening interventions on strength was examined by pooling post intervention data from three trials (Heckmann, Logigian, Winchester). Strengthening interventions increased strength by 0.33 SD (95% CI -0.05 to 0.72, $p = 0.08$). Of two trials unable to be included in the pooled analysis, one (Powell) reported a significant effect of electrical stimulation on strength, and one (Dickstein) reported no significant effect of muscle re-education on strength.

In acute, weak stroke participants, the effect of strengthening interventions on strength was examined by pooling post intervention data from four trials (Duncan, Lippert-Gruner, Merletti, Winstein). Strengthening interventions increased strength by 0.45 SD (95% CI 0.12 to 0.78, $p = 0.01$). Of two trials unable to be included in the pooled analysis, one (Bowman) reported a significant effect of electrical stimulation on strength, and one (Inaba) reported a significant effect of progressive resistance exercise on strength.

In chronic, very weak stroke participants, the effect of strengthening interventions on strength was examined by calculating the effect from the change scores from one trial since post-intervention scores were not available

Table 1. Summary of included trials.

Trial	Quality (PEDro score)	Characteristics of participants	Intervention	Outcome measure		
				Strength	Spasticity	Activity
Basmajian et al 1975 <i>Chronic, very weak</i>	3	Number = 20 Admission to trial = 34 mth	EMG-biofeedback + CT vs CT 40 min × 3/wk × 5 wk	DF (kg)	Nil	Custom made scale (0–5)
Bowman et al 1979 <i>Acute, weak</i>	3	Number = 30 Admission to trial = 3 wk–4 mth	Triggered-ES + CT vs CT 60 min × 5/wk × 4 wk	Wrist ext (Nm)	Nil	Nil
Cauraugh et al 2000 <i>Chronic, weak</i>	3	Number = 11 Admission to trial = 3.5 yr	Triggered-ES vs CT 60 min × 3/wk × 2 wk	Wrist ext (Impulse)	Nil	Box and Block Test (Number/60s)
Dickstein et al 1986 <i>Acute, very weak</i>	4*	Number = 95** Admission to trial = 16 d	MRE vs CT 45 min × 5/wk × 6 wk	DF (kg) Wrist ext (kg)	Custom made scale (0–4)	Barthel Index (0–100)
Duncan et al 2003 <i>Acute, weak</i>	8	Number = 100 Admission to trial = 76 d	PRE vs CT 3/wk × 12 wk	Σ DF and knee ext (Nm)	Nil	10-m Walk Test (m/s)
Heckmann et al 1997 <i>Acute, very weak</i>	4*	Number = 28 Admission to trial = 59 d	Triggered-ES + CT vs CT 45 min × 5/wk × 4 wk	Σ Wrist ext and DF (MMT 0–5)	Σ UL and LL Pendulum Test (relaxation index)	Barthel Index (0–100)
Inaba et al 1973 <i>Acute, weak</i>	3	Number = 54** Admission to trial = < 3 mth	PRE + CT vs CT 15 rep × 7/wk × 4 wk	LL ext (lb 10RM)	Nil	Custom made scale (0–2 on 8 items)
Inglis et al 1984 <i>Chronic, very weak</i>	3	Number = 30 Admission to trial = 18 mth	EMG-biofeedback + CT vs CT 60 min × 3/wk × 6 wk	17 UL movements (MMT 0–5)	Nil	Brunnstrom Stages of Recovery (1–6)
Kim et al 2001 <i>Chronic, weak</i>	8*	Number = 20 Admission to trial = 4 yr	PRE vs sham 3 × 10 RM × 3/wk × 6 wk	Σ Knee ext and DF (Nm)	Nil	10-m Walk Test (m/s)
Kimberley et al 2004 <i>Chronic, weak</i>	7*	Number = 16 Admission to trial = 36 mth	Triggered-ES + ES vs sham 360 min × 3/wk × 3 wk	2nd MCP ext (N)	Nil	Box and Block Test (Number/60s)
Kraft et al 1992 <i>Chronic, weak</i>	2	Number = 11** Admission to trial = 26 mth	Triggered-ES vs nothing 60 min × 3/wk × 12 wk	Grip strength (lb)	Nil	UL Fugl-Meyer (0–60)
Lippert-Gruner & Gruner 1999 <i>Acute, weak</i>	3*	Number = 20 Admission to trial = 4–6 wk	PRE + CT vs CT 30 rep × 5/wk × 2 wk	Σ Wrist flex and wrist ext (N)	Nil	Nil
Logigian et al 1983 <i>Acute, very weak</i>	3	Number (males + females) = 42 Admission to trial = < 7 wk	MRE vs CT 60–90 min × 5/wk × Unknown	Σ 22 UL movements (MMT 0–7)	Nil	Barthel Index (0–100)
Lum et al 2002 <i>Chronic, weak</i>	7*	Number = 27 Admission to trial = 29 mth	MRE vs CT 60 min × 3/wk × 8 wk	Σ Shoulder flex, Ext, IR, ER, Abd, Add, Elbow flex, Ext (Nm)	Nil	UL Fugl-Meyer proximal
Merletti et al 1978 <i>Acute, weak</i>	3	Number = 49 Admission to trial = 4.5 mth	ES + CT vs CT 20 min × 6/wk × 4 wk	DF (Nm)	Nil	Nil
Ouellette et al 2004 <i>Chronic, weak</i>	7	Number = 42 Admission to trial = 29 mth	PRE vs sham 3 × 70%×1 RM × 3/wk × 12 wk	Leg press (N)	Nil	10-m Walk Test (m/s)

Powell et al 1999 <i>Acute, very weak</i>	7	Number = 60 Admission to trial = 23 d	ES + CT vs CT 90 min × 7/wk × 8 wk	Wrist ext (Nm)	Modified Ashworth (0–4)	Nine-Hole Peg Test (Number/s)
Stein et al 2004 <i>Chronic, weak</i>	6	Number = 18 ** Admission to trial = 2 yr	PRE vs sham 60 min × 3/wk × 6 wk	Mean of shoulder flex, Ext, Abd, Add (N)	Modified Ashworth (0–4)	UL Fugl-Meyer (0–66)
Teixeira-Salmela et al 1999 <i>Chronic, weak</i>	3	Number = 13 Admission to trial = 8 yr	PRE vs nothing 3 × 10 × 50% 1 RM × 3/wk × 10 wk	Σ Knee ext and DF (Nm)	Pendulum Test (corrected relaxation index)	10-m Walk Test (m/s)
Winchester et al 1983 <i>Acute, very weak</i>	5*	Number = 40 Admission to trial = 52 d	Triggered-ES + ES + CT vs CT 150 min × 5/wk × 4 wk	Knee ext (Nm)	Custom made scale (0–3)	Nil
Winstein et al 2004 <i>Acute, weak</i>	6	Number = 42** Admission to trial = 16 d	PRE + CT vs CT 5/wk × 4 wk	Σ Shoulder flex, Ext, Elbow flex, Ext, Wrist flex, Ext (kg/cm)	Nil	UL Fugl-Meyer motor (0–66)

*not on PEDro or rating based on extra information supplied by the author, **the number of participants in the arms of the trial that were included in pooled analysis, #outcome measures listed are those that were used in this systematic review; there may have been other measures used in the trial. ES = electrical stimulation, MRE = muscle re-education, PRE = progressive resistance exercise, CT = conventional therapy, MMT = manual muscle test, RM = repetition maximum. DF = dorsiflexion, PF = plantarflexion, Flex = flexion, Ext = extension, Abd = abduction, Add = adduction, IR = internal rotation, ER = external rotation, MCP = metacarpophalangeal, UL = upper limb, LL = lower limb, Σ = summed.

(Basmajian). EMG biofeedback increased strength by 0.91 SD (95% CI –0.02 to 1.84, $p = 0.05$). One trial unable to be included in the pooled analysis (Inglis), reported no significant effect of EMG biofeedback on strength.

In chronic, weak stroke participants, the effect of strengthening interventions on strength was examined by pooling post intervention data from seven trials (Kim, Kimberley, Kraft, Lum, Ouellette, Stein, Teixeira-Salmela). Strengthening interventions increased strength by 0.18 SD (95% CI –0.22 to 0.58, $p = 0.38$). One trial unable to be included in the pooled analysis (Cauraugh) reported a significant effect of electrical stimulation on strength.

Spasticity The overall effect of the strengthening interventions on spasticity was examined by pooling post intervention data from three trials that measured spasticity (Heckmann, Stein, Teixeira-Salmela (Figure 3, see also Figure 4 on the eAddenda for detailed forest plot). Overall, strengthening interventions had very little effect on spasticity (SMD –0.13, 95% CI –0.75 to 0.50, $p = 0.69$). Three trials unable to be included in the pooled analysis (Dickstein, Powell, Winchester) reported no significant effect on spasticity.

Activity The effect of the strengthening interventions on activity was examined by pooling post-intervention data from 12 trials that measured activity (Basmajian, Duncan, Heckmann, Kim, Kimberley, Kraft, Logigian, Lum, Ouellette, Stein, Teixeira-Salmela, Winstein) (Figure 5, see also Figure 6 on the eAddenda for detailed forest plot). The overall effect of strengthening interventions on activity was 0.32 SD (95% CI 0.11 to 0.53, $p = 0.002$).

In acute, very weak participants, the effect of strengthening interventions on activity was examined by pooling post intervention data from two trials (Heckmann, Logigian). Strengthening interventions improved activity by 0.46 SD (95% CI 0.11 to 0.81, $p = 0.009$). Of two trials unable to be included in the pooled analysis, one (Dickstein) reported no significant effect of muscle re-education on activity and one (Powell) reported no significant effect of electrical stimulation on activity.

In acute, weak participants, the effect of strengthening interventions on activity was examined by pooling post intervention data from two trials (Duncan, Winstein). Strengthening interventions improved activity by 0.56 SD (95% CI 0.14 to 0.98, $p = 0.01$). One trial unable to be included in the pooled analysis (Inaba) reported a significant effect of progressive resistance training on activity.

In chronic, very weak stroke participants, the effect of strengthening interventions on activity was examined by calculating the effect from post intervention data from one trial (Basmajian). The strengthening intervention improved activity by 0.63 SD (95% CI –0.27 to 1.54, $p = 0.17$).

In chronic, weak stroke participants, the effect of strengthening interventions on activity was examined by pooling post intervention data from seven trials (Kimberley, Kim, Kraft, Lum, Ouellette, Stein, Teixeira-Salmela). The strengthening interventions improved activity by 0.22 SD (95% CI –0.11 to 0.54, $p = 0.20$). One trial unable to be included in the pooled analysis (Cauraugh) reported a significant effect of electrical stimulation on activity.

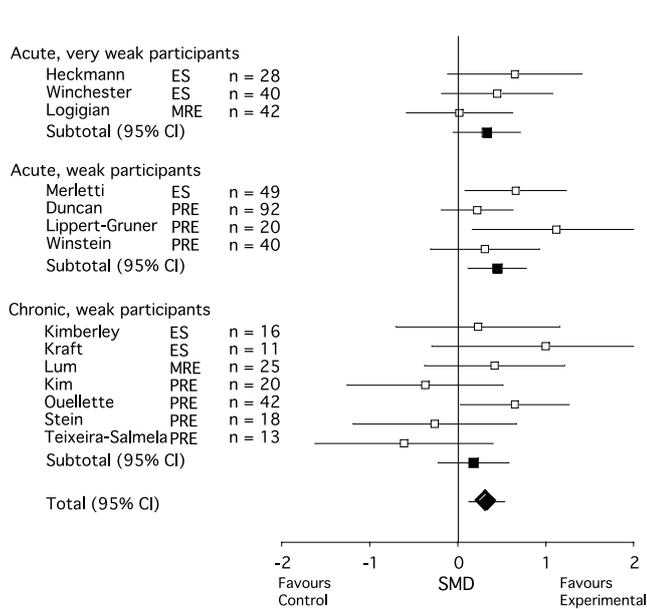


Figure 1. Examination of the effect of strengthening interventions on strength by pooling post-intervention data from 14 trials. ES = electrical stimulation, MRE = muscle re-education, PRE = progressive resistance exercise, SMD = standardised mean difference.

Discussion

This systematic review provides evidence that interventions to increase strength after stroke can improve strength and activity and do not necessarily increase spasticity. This is the first systematic review to pool data from different types of interventions that have the potential to increase strength and examine their effects according to initial weakness and time after stroke. Given that 8 was the likely maximum PEDro score achievable because it was not usually possible to blind the therapist or the participants, the mean PEDro score of 4.7 for the trials included in this review represents moderately high quality. Added to this, the number of participants is higher than that used in previous systematic reviews. Even though data from only about half of the participants in the 21 trials were available for inclusion in the meta-analysis, 476 participants were included in the pooled estimate for strength, 59 in the pooled estimate for spasticity, and 359 in the pooled estimate for activity. Taken together, this suggests that the findings are credible and can be generalised cautiously.

We set out to answer three questions in this systematic review. The first was *Is strength training effective after stroke?* This review shows that the implementation of strengthening interventions after stroke can increase strength. On examination of the subgroups, strengthening interventions appear to be effective early after stroke whereas they are not particularly effective later after stroke. Nevertheless, while the overall effect is positive, it is small (SMD 0.33). It is difficult to translate standardised mean differences into meaningful clinical effect sizes. For example, if we examine muscles where the effect size was similar to the

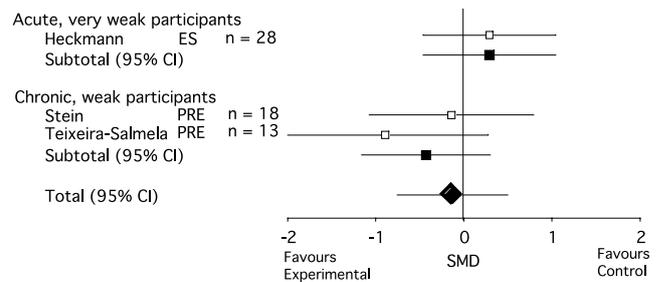


Figure 3. Examination of the effect of strengthening interventions on spasticity by pooling post-intervention data from 3 trials. ES = electrical stimulation, PRE = progressive resistance exercise, SMD = standardised mean difference.

pooled estimate, the effect of the strengthening intervention in one trial (Duncan) was to increase knee extension torque by about 4 Nm (or 4%) but in another trial (Winstein) it was to increase wrist extension force by 6 kg/cm (or 35%) compared to the control. The small non-significant effect found later after stroke (SMD 0.18) may be because the strengthening interventions were not of sufficient intensity and/or duration. For example, the average duration of progressive resistance exercise programs examined in this review was only seven weeks. In addition, although the protocols were progressive, they were not consistently administered at the intensity recommended by the American College of Sports Medicine (2002) for producing optimal strength gains. Future research needs to examine the effect of using higher doses of these interventions, particularly later after stroke.

The second question was *Is strength training after stroke harmful?* Although this systematic review showed no increase in spasticity as a result of strengthening interventions, this finding was based on only three trials in the pooled analysis. In addition, the total number of participants contributing to the pooled estimate for spasticity was much lower than for strength or activity, leading to wider confidence intervals and therefore less certainty. However, uncontrolled trials of strength training after stroke have also found no increase in spasticity (Brown and Kautz 1998, Miller and Light 1997, Sharp and Brouwer 1997, Sterr and Freivogel 2004). Furthermore, a systematic review examining progressive resistance exercise training after stroke, found evidence to suggest that effortful exercise does not increase spasticity (Morris et al 2004). Therefore, it appears that strength training does not increase spasticity after stroke, ie, the fear of worsening a patient's spasticity is not a reason to avoid strength training.

The third question was *Is strength training worthwhile after stroke?* While increased strength is accompanied by increased activity, this carryover effect is small (SMD 0.32). There are two plausible reasons for this. First, in over half of the trials that measured activity (58%), only one or two muscle groups were trained which is unlikely to have a large impact on the function of that limb. Second, in half of the trials that measured activity broad scales of tasks such as 'going to the toilet independently' were used, which are

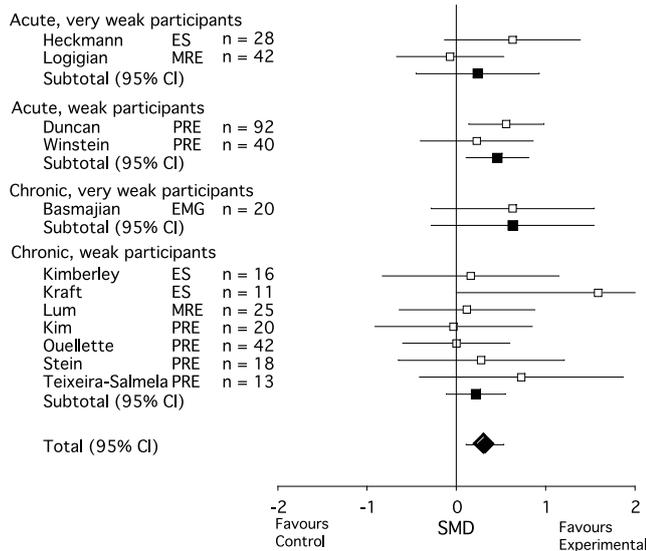


Figure 5. Examination of the effect of strengthening interventions on activity by pooling post-intervention data from 12 trials. EMG = EMG-biofeedback, ES = electrical stimulation, MRE = muscle-re-education, PRE = progressive resistance exercise, SMD = standardised mean difference.

unlikely to be improved as a result of increasing strength in one muscle of a limb. Future research needs to examine the effect of strengthening interventions when they are applied to several muscles of a limb using direct measures of performance (eg, 10-m Walk Test or Nine-Hole Peg Test) to reflect improvements in activity.

In conclusion, this systematic review has demonstrated that strengthening interventions are effective, can be worthwhile, and are not harmful. Because previous systematic reviews of single interventions have not shown a carryover of increased strength to improved activity (Moreland and Thomson 1994, Moreland et al 1998, Morris et al 2004), it has been suggested that there is no value in strength training (Van Peppen et al 2004). Therefore, the results of this systematic review are valuable since they show that strengthening interventions can have a beneficial effect not only on strength but also on activity. We recommend that strengthening should be a part of stroke rehabilitation, particularly in the first six months following stroke. The challenge is now to find the most effective way to ensure that a substantial increase in strength can be achieved and translated into a beneficial improvement in activity.

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eAddenda Figures 2, 4 and 6, and Appendix available at www.physiotherapy.asn.au/AJP

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