Journal of Physiotherapy 64 (2018) 210–221

AUSTRALIAN PHYSIOTHERAPY ASSOCIATION

Journal of
PHYSIOTHERAPY

journal homepage: www.elsevier.com/locate/jphys

Research

Interventions involving repetitive practice improve strength after stroke: a systematic review

Davide G de Sousa [a,b,c], Lisa A Harvey [b,c], Simone Dorsch [d], Joanne V Glinsky [b,c]

[a] Graythwaite Rehabilitation Centre, Ryde Hospital; [b] John Walsh Centre for Rehabilitation Research, Kolling Institute; [c] Sydney Medical School Northern, University of Sydney; [d] Faculty of Health Sciences, Australian Catholic University, Sydney, Australia

KEY WORDS

Stroke
Strength
Repetitive practice
Systematic review
Meta-analysis

ABSTRACT

Questions: Do interventions involving repetitive practice improve strength after stroke? Are any improvements in strength accompanied by improvements in activity? **Design**: Systematic review of randomised trials with meta-analysis. **Participants**: Adults who have had a stroke. **Intervention**: Any intervention involving repetitive practice compared with no intervention or a sham intervention. **Outcome measures**: The primary outcome was voluntary strength in muscles trained as part of the intervention. The secondary outcomes were measures of lower limb and upper limb activity. **Results**: Fifty-two studies were included. The overall SMD of repetitive practice on strength was examined by pooling post-intervention scores from 46 studies involving 1928 participants. The SMD of repetitive practice on strength when the upper and lower limb studies were combined was 0.25 (95% CI 0.16 to 0.34, I^2 = 44%) in favour of repetitive practice. Twenty-four studies with a total of 912 participants investigated the effects of repetitive practice on upper limb activity after stroke. The SMD was 0.15 (95% CI 0.02 to 0.29, I^2 = 50%) in favour of repetitive practice on upper limb activity. Twenty studies with a total of 952 participants investigated the effects of repetitive practice on lower limb activity after stroke. The SMD was 0.25 (95% CI 0.12 to 0.38, I^2 = 36%) in favour of repetitive practice on lower limb activity. **Conclusion**: Interventions involving repetitive practice improve strength after stroke, and these improvements are accompanied by improvements in activity. **Review registration**: PROSPERO CRD42017068658. **[de Sousa DG, Harvey LA, Dorsch S, Glinsky JV (2018) Interventions involving repetitive practice improve strength after stroke: a systematic review. *Journal of Physiotherapy* 64: 210–221]**

Introduction

The loss of strength after stroke is a common and important impairment. The average strength of the affected upper and lower limb in people who have had a significant stroke ranges from 30 to 50% of age-matched controls.[1–4] This loss of strength can result in profound activity limitations[5–7] and participation restrictions.[8] Therefore, it is important to know which interventions are effective for improving strength after stroke. Progressive resistance training is commonly used to improve strength in people without disability[9] and can be used to improve strength in people after stroke.[10] Progressive resistance training is characterised by muscles working at high loads with low repetitions, that is, a load of 8 to 12 repetitions maximum (RM) for at least two sets with a progressive increase in the load.[9] However, progressive resistance training is not commonly used after stroke, and often when strengthening programs claim to be using progressive resistance training they are not adhering to the guidelines.[11] This may be because progressive resistance training is time-consuming to set up and difficult to implement in people with very weak muscles. In contrast, repetitive practice of tasks can be set up with minimal equipment and modified so that even people with very weak muscles can do some form of training.

Repetitive practice of tasks, such as walking, reaching and manipulation of objects, is a major component of rehabilitation after stroke. Some interventions used to promote repetitive practice include constraint-induced movement therapy, treadmill walking with body-weight support, or robotic devices. These interventions are typically performed with an emphasis on high repetitions and no added resistance to movement; hence, the principles of repetitive practice are very different to the principles of progressive resistance training. Repetitive practice is known to be effective for reducing activity limitations, with many systematic reviews confirming this.[12–15] However, less is known about the effects of repetitive practice on strength after stroke, and no systematic reviews have specifically investigated this issue. Eight systematic reviews with meta-analyses have investigated the effects of strengthening interventions on strength after stroke. These reviews included studies that used progressive resistance training[10,16–20] or an artificial drive of muscle contraction[21,22] (ie, electrical stimulation without attempts to move a limb) as an intervention and did not focus specifically on repetitive practice.

https://doi.org/10.1016/j.jphys.2018.08.004
1836-9553/

Since repetitive practice is widely used and recommended in rehabilitation after stroke,[23] it is important to understand if interventions involving repetitive practice are effective for improving strength.

Therefore, the research questions for this systematic review were:

1. Do interventions involving repetitive practice improve strength after stroke?
2. Are any improvements in strength accompanied by improvements in activity?

Method

Identification and selection of studies

Participants

Studies involving adult participants of either gender at any time after stroke were included. Studies that also involved participants with other types of acquired brain injury (eg, trauma) were excluded unless > 80% of participants had a diagnosis of stroke.

Intervention

Studies that examined the effectiveness of interventions that involved repetitive practice on land or in water (ie, hydrotherapy or aquatic physiotherapy) were included. Repetitive practice was defined as repetitive voluntary contraction of muscles of the affected upper or lower limb and included repetitive practice of a whole task (eg, sitting, standing up, walking) or components of a task (eg, elbow extension/flexion as a component of reaching and manipulation). Where constraint-induced movement therapy was used, studies that merely constrained the unaffected upper limb without active practice using the affected upper limb were excluded. Studies were excluded if: the intervention only included an artificial drive of muscle contraction (eg, passive robotics or electrical stimulation without attempts to move a limb), the intervention did not require voluntary muscle contraction (eg, mental practice, massage, passive movement), or the intervention involved progressive resistance strength training (ie, 1 to 3 sets, 8 to 12 repetitions of 60 to 70% 1RM with progression of resistance).

Comparison

The comparisons of interest were no intervention or a sham intervention. Studies with co-interventions were included provided the co-intervention was delivered to both groups (eg, repetitive practice plus usual therapy versus usual therapy).

Outcome measures

The primary outcome for this systematic review was strength. Studies were included if one of their outcomes was strength of the affected upper or lower limb in muscles that were trained. Strength could be measured in a number of ways, including: maximum force, maximum torque, manual muscle testing using the Medical Research Council (MRC) scale, or composite scales of multiple muscle groups such as the Motricity Index. Where multiple measures of strength were reported, the measure that best reflected the training was used. For example, if upper limb training primarily involved manipulation tasks, then hand grip strength was chosen rather than elbow extension strength. If studies reported outcomes at multiple time-points, then data collected at the time-point closest to the end of the intervention were extracted.

The secondary outcomes for this systematic review were activity of the affected upper and lower limb, measured using any continuous or ordinal measure of activity. These secondary outcomes were only collected from studies that met the inclusion criteria for the review. That is, studies that measured activity were only included if they also measured strength, because the analysis of activity was a secondary analysis used to determine whether improvements in strength were accompanied by improvements in activity. Where multiple measures of activity were reported, the measure that best reflected the training was used. For example, if the repetitive practice targeted the lower limb, a lower limb measure such as the 10-m walk test was used rather than a measure of upper limb activity. Priority for the upper and lower limb measures of activity were given to the Action Research Arm Test and the 10-m walk test, respectively, because these outcome measures have been recommended for use in clinical studies by the international research community.[24]

Box 1. Inclusion criteria.

Design
- Randomised

Participants
- Adults (> 18 years old)
- Diagnosis of stroke

Intervention
- Repetitive practice

Comparisons
- Repetitive practice versus no intervention
- Repetitive practice versus a sham intervention

Outcome measures
- Muscle strength measured as maximum force/torque, or composite scales of multiple muscle groups, or manual muscle testing, measured immediately after the intervention in the muscles that were trained

Searches were conducted of MEDLINE (Ovid) (1946 to 24 January 2017), EMBASE (Ovid) (1947 to 24 January 2017), AMED (1985 to 24 January 2017), CINAHL (Ebsco) (1982 to 24 January 2017), SCOPUS (inception to 24 January 2017), SPORTDiscus (Ebsco) (inception to 24 January 2017), Web of Science (inception to 24 January 2017), Cochrane Central Register of Controlled Trials (CENTRAL) (1986 to 24 January 2017) and PEDro (inception to 13 February 2017) for relevant studies written in English with no date restrictions. Search terms included words related to stroke, randomised trials, repetitive practice and muscle strength (see Appendix 1 on the eAddenda). Hand searching of the reference lists of the included studies and relevant systematic reviews was undertaken. Authors of conference abstracts were contacted for full reports of unpublished studies. One reviewer independently screened all titles and abstracts to identify relevant studies. All titles and abstracts were also equally divided and independently screened by three other reviewers, ensuring that all titles and abstracts were screened by two people. Full-text copies of relevant studies were retrieved and reviewed independently by each reviewer using predetermined eligibility criteria (Box 1). If two reviewers disagreed about the eligibility of a study, a third reviewer arbitrated until a consensus was reached.

Assessment of risk of bias

One reviewer independently assessed risk of bias of the included studies using the Cochrane Risk of Bias Tool. Each study was rated as high risk, unclear risk or low risk on the following domains: sequence generation; concealed allocation; blinding of participants and therapists; blinding of outcome assessors; incomplete outcome data; selective outcome reporting; and other bias. Studies were checked online against published PEDro scores to assist with decisions regarding bias, and disagreements were resolved by a second reviewer. Studies that reported incomplete data in more than 15% of participants were deemed to have high risk of bias from incomplete outcome data. Studies that did not report a clinical trial registration number or registered the protocol retrospectively were deemed to have unclear risk of bias in the category of 'other bias'.

Data extraction and analysis

Two reviewers independently extracted outcome data and details of the experimental and control interventions. The number of participants, age and time since stroke were recorded to describe the participants. Post-intervention data were retrieved in preference to change data because these were the most commonly provided data and the data needed to be in the same format for meta-analyses expressed as standardised mean differences (SMD). Authors were contacted if there were missing outcome data or post-intervention data were not provided. Differences between the two reviewers were resolved by discussion, and when necessary, arbitrated by a third reviewer.

Separate meta-analyses were performed on studies involving the same intervention for strength, upper limb activity and lower limb activity. Meta-analyses were only considered if there were sufficient data to pool and there was not excessive between-trial heterogeneity (ie, I^2 values were not $\geq$ 75%). A fixed-effect model was used if there was no apparent clinical heterogeneity and the I^2 value was $\leq$ 50%. A random-effects model was used if there was no apparent clinical heterogeneity and the I^2 value was > 50%. Pooled estimates were reported as SMD (95% CI) for all analyses because outcomes were measured in different ways. If post-intervention data were not available, separate meta-analyses were conducted of studies that only provided change data. This was done to avoid pooling of post-intervention data with change data, given that the results of all analyses were reported as SMD.

Sensitivity analyses

Sensitivity analyses were conducted to examine the robustness of the primary meta-analysis for strength. The sensitivity analyses explored the effects of various methodological aspects of the included studies, including: methods for generating the randomisation sequence (only trials with adequate methods); effects of allocation concealment (only trials with concealed allocation); blinding of assessors (only trials with blinded assessors); selective outcome reporting (only trials without selective outcome reporting); incomplete outcome data (only trials with $\leq$ 15% missing data); and other bias (only trials without other bias).

Subgroup analyses

Subgroup analyses on the strength data were performed to explore four factors. The first subgroup comparison was based on the limbs that were trained (upper limb versus lower limb) because the upper limb may respond differently to repetitive practice than the lower limb. The second comparison related to time since stroke (< 6 months versus > 6 months) because people early after stroke may respond differently to people late after stroke. The third comparison was based on dosage ($\leq$ 24 hours versus > 24 hours of repetitive practice) because people may respond differently to higher doses of repetitive practice than lower doses. If actual dosage (frequency plus duration of therapy sessions) was reported, these data were used in preference to scheduled therapy time. The last subgroup comparison was based on initial strength (weak ie, $\leq$ 3/5 MRC versus strong ie, $\geq$ 4/5 MRC) since people who are weaker may respond differently to repetitive practice than those who are stronger.

All data were analysed using Review Manager software[a].

Results

Flow of studies through the review

The electronic search strategy identified 4533 studies (excluding duplicates). After screening titles, abstracts, and reference lists, 129 full reports of studies were retrieved. After inspecting the full reports, 52 studies were included. Seventy-seven studies were excluded and the reasons for exclusion are summarised in Figure 1.

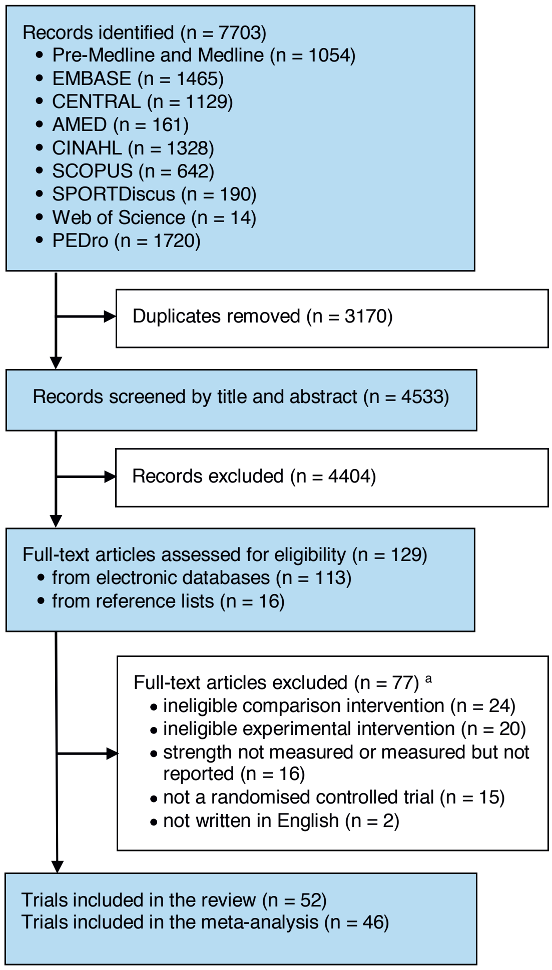

Figure 1. Flow of studies through the review.
[a] Studies may have been excluded for failing to meet more than one inclusion criterion.

Characteristics of included trials

Fifty-two studies investigated the effect of repetitive practice on strength after stroke, and some of these studies also included measures of activity (see Table 1). Additional information was requested from the authors for 15 studies[25–39] and received from eight authors.[26,29–31,33,34,38,39] Two studies met the inclusion criteria; however, strength measures were either not reported or authors were unable to provide the data.[25,40] These studies were included in the review but excluded from all meta-analyses. Four studies only reported change data for strength, and authors were unable to provide post-intervention data.[27,28,35,38] These studies were included in the review but data were analysed separately. Forty-six studies reported post-intervention data and were used to determine the overall SMD of repetitive practice on strength.

Risk of bias

The risk of bias in the 52 included studies in this systematic review was variable (see Figure 2 for details). Thirty-six studies (69%) used adequate methods for generating the randomisation sequence. Sixteen studies (31%) used adequate methods to conceal allocation. No studies were able to blind participants or therapists due to the nature of the intervention. Thirty-seven studies (71%) blinded assessors of outcomes to group allocation. Forty-three studies (83%) had complete outcome data. Forty-six studies (89%) were free of selective outcome reporting, and twelve studies (23%) were free of other bias.

Participants

The mean age of participants across the studies ranged from 47 to 79 years. The mean time since stroke ranged from 6 days to

Table 1
Characteristics of included studies (n = 52).

Study	Participants[a]	Comparison	Outcome measures[b]
Alberts (2004)[25]	n = 10/10 Exp age *(yr)* = 65 (8) Con age *(yr)* = 63 (16) Exp time since stroke *(mth)* = 6.4 (1.1) Con time since stroke *(mth)* = 5.6 (1.5)	Exp = CIMT 360 min × 5/wk × 2 wk Con = no intervention	Strength = hand grip – force *(N)* Activity = WMFT *(sec)* Endpoint: 2 wk
Almhdawi (2016)[26]	n = 20/20 Exp age *(yr)* = 61 (10) Con age *(yr)* = 63 (9) Exp time since stroke *(mth)* = 62.3 (45.2) Con time since stroke *(mth)* = 61.9 (49.4)	Exp = task-specific UL training 90 min × 2/wk × 6 wk Con = no intervention	Strength = EE – isometric force *(lb)* Activity = WMFT *(sec)* Endpoint: 7 wk
An (2016)[67]	n = 18/38 Exp age *(yr)* = 51 (10) Con age *(yr)* = 47 (11) Exp time since stroke *(mth)* = 50.6 (34.6) Con time since stroke *(mth)* = 62.7 (41.0)	Exp = weight-bearing exercise + cycling 30 min × 3/wk × 5 wk Con = no intervention Both = usual therapy	Strength = KE – isokinetic torque *(Nm/kg)* Activity = self-selected walking speed *(m/s)* Endpoint: 5 wk
Atteya (2004)[60]	n = 4/4 Exp age *(yr)* = 55 (3) Con age *(yr)* = 56 (16) Exp time since stroke *(mth)* = 5.6 (0.3) Con time since stroke *(mth)* = 4.7 (1.2)	Exp = CIMT 60 min × 3/wk × 10 wk Con = no intervention	Strength = hand grip – force *(kg)* Activity = ARAT *(/57 points)* Endpoint: 10 wk
Barker (2008)[68]	n = 23/33 Exp age *(yr)* = 67 (8) Con age *(yr)* = 69 (11) Exp time since stroke *(mth)* = 40.8 (31.2) Con time since stroke *(mth)* = 36.0 (30.0)	Exp = SMART arm training 60 min × 3/wk × 4 wk Con = no intervention	Strength = UL reaching – force *(N)* Activity = MAS *(/7 points)* Endpoint: 4 wk
Bi (2008)[41]	n = 37/77 Exp age *(yr)* = 58 (9) Con age *(yr)* = 60 (7) Exp time since stroke *(mth)* = 45.5 (30.1) Con time since stroke *(mth)* = 42.9 (34.7)	Exp = task-specific UL training + placebo-TENS 60 min × 5/wk × 8 wk Con = no intervention	Strength = hand grip – force *(N)* Activity = WMFT *(sec)* Endpoint: 8 wk
Bowman (1979)[40]	n = 30/30 Exp age *(yr)* = NR Con age *(yr)* = NR Exp time since stroke *(mth)* = NR Con time since stroke *(mth)* = NR	Exp = position-triggered FES 30 min × 2/day × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = WE – isometric torque *(Nm)* Activity = nil Endpoint: 4 wk
Burgar (2011)[27]	n = 36/54 Exp age *(yr)* = 59 (10) Con age *(yr)* = 63 (9) Exp time since stroke *(mth)* = 0.5 (0.3) Con time since stroke *(mth)* = 0.6 (0.4)	Exp = high-dose robotic training 60 min × 30 over 3 wk Con = low-dose robotic training[c] Both = usual therapy	Strength = composite UL (14 muscle groups) – MMT *(/70 points)* Activity = WMFT *(sec)* Endpoint: 3 wk
Chan (2015)[28]	n = 25/37 Exp age *(yr)* = 56 (7) Con age *(yr)* = 59 (10) Exp time since stroke *(mth)* = 41.8 (28.7) Con time since stroke *(mth)* = 47.3 (29.8)	Exp = task-specific trunk training + placebo TENS 60 min × 5/wk × 6 wk Con = health education on measuring BP and monitoring falls[c]	Strength = TE – isometric torque *(Nm)* Activity = lateral seated reach affected *(cm)* Endpoint: 6 wk
Chu (2004)[76]	n = 12/13 Exp age *(yr)* = 62 (9) Con age *(yr)* = 63 (8) Exp time since stroke *(mth)* = 36.0 (24.0) Con time since stroke *(mth)* = 50.4 (25.2)	Exp = water-based endurance program 60 min × 3/wk × 8 wk Con = arm function program[c]	Strength = composite LL (HF/HE/KF/KE) – isokinetic torque *(Nm/kg)* Activity = self-selected walking speed *(m/s)* Endpoint: 8 wk
Cooke (2010)[29]	n = 54/109 Exp age *(yr)* = 71 (11) Con age *(yr)* = 66 (14) Exp time since stroke *(mth)* = 1.1 (0.5) Con time since stroke *(mth)* = 1.2 (0.7)	Exp = functional strength training 60 min × 4/wk × 6 wk Con = no intervention Both = usual therapy	Strength = KE – isokinetic torque *(Nm)* Activity = walking speed *(m/s)* Endpoint: 6 wk
Cowles (2013)[42]	n = 22/29 Exp age *(yr)* = 79 (8) Con age *(yr)* = 76 (12) Exp time since stroke *(mth)* = 0.6 (0.2) Con time since stroke *(mth)* = 0.6 (0.2)	Exp = observation-to-imitate + physical practice 60 min × 5/wk × 3 wk Con = no intervention Both = usual therapy	Strength = UL – Motricity Index *(/100 points)* Activity = ARAT *(/57 points)* Endpoint: 3 wk
de Sousa (2016)[52]	n = 39/40 Exp age *(yr)* = 62 (15) Con age *(yr)* = 60 (16) Exp time since stroke *(mth)* = 1.4 (1.1) Con time since stroke *(mth)* = 1.7 (1.4)	Exp = FES cycling 17 to 32 min × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = KE – isometric torque *(Nm)* Activity = FIM – mobility *(/21 points)* Endpoint: 4 wk
Dean (2000)[43]	n = 9/12 Exp age *(yr)* = 66 (8) Con age *(yr)* = 62 (7) Exp time since stroke *(mth)* = 27.6 (8.4) Con time since stroke *(mth)* = 15.6 (10.8)	Exp = UL exercise class 60 min × 3/wk × 4 wk Con = lower limb exercise class[c]	Strength = hand grip – force *(kg)* Activity = Unimanual Purdue Pegboard *(no. of pegs)* Endpoint: 4 wk

Table 1 (*Continued*)

Study	Participants[a]	Comparison	Outcome measures[b]
Dean (2012)[44]	n = 133/151 Exp age *(yr)* = 67 (14) Con age *(yr)* = 68 (10) Exp time since stroke *(mth)* = 80.4 (80.4) Con time since stroke *(mth)* = 62.4 (64.8)	Exp = LL exercise class 45 min × 40 over 52 wk Con = upper limb exercise class[c]	Strength = KE – isometric force *(kg)* Activity = fast walking speed *(m/s)* Endpoint: 52 wk
Donaldson (2009)[30]	n = 18/30 Exp age *(yr)* = 73 (12) Con age *(yr)* = 73 (15) Exp time since stroke *(mth)* = 0.7 (0.6) Con time since stroke *(mth)* = 0.4 (0.2)	Exp = functional strength training 60 min × 4/wk × 6 wk Con = no intervention Both = usual therapy	Strength = EE – isometric force *(N)* Activity = ARAT *(/57 points)* Endpoint: 6 wk
Dorsch (2014)[53]	n = 33/33 Exp age *(yr)* = 66 (12) Con age *(yr)* = 69 (13) Exp time since stroke *(mth)* = 0.5 (0.2) Con time since stroke *(mth)* = 0.6 (0.2)	Exp = EMG-triggered FES 4 UL muscle groups × 30 reps × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = composite UL (SF/EE/WE/TA) – MMT *(/20 points)* Activity = MAS *(/19 points)* Endpoint: 4 wk
GAPS (2004)[62]	n = 65/70 Exp age *(yr)* = 68 (11) Con age *(yr)* = 67 (10) Exp time since stroke *(mth)* = 0.7 (0.5) Con time since stroke *(mth)* = 0.8 (0.6)	Exp = additional physiotherapy 60 to 80 min × 5/wk (duration NR) Con = no intervention Both = usual therapy	Strength = composite (UL/LL) – MI *(/200 points)* Activity = RMI *(/15 points)* Endpoint: 12 wk
Gordon (2013)[45]	n = 116/128 Exp age *(yr)* = 63 (9) Con age *(yr)* = 65 (11) Exp time since stroke *(mth)* = 12.8 (3.6) Con time since stroke *(mth)* = 11.8 (3.6)	Exp = overground walking 15 to 30 min × 3/wk × 12 wk Con = massage[c]	Strength = LL – Motricity Index *(/100 points)* Activity = 6MWT *(m)* Endpoint: 12 wk
Harris (2009)[46]	n = 103/103 Exp age *(yr)* = 69 (12) Con age *(yr)* = 69 (15) Exp time since stroke *(mth)* = 0.7 (0.2) Con time since stroke *(mth)* = 0.7 (0.2)	Exp = GRASP 60 min × 6/wk × 4 wk Con = education book on stroke recovery and general health[c] Both = usual therapy	Strength = hand grip – force *(kg)* Activity = ARAT *(/57 points)* Endpoint: 4 wk
Heckmann (1997)[54]	n = 28/28 Exp age *(yr)* = 50 (14) Con age *(yr)* = 54 (11) Exp time since stroke *(mth)* = 1.8 (0.8) Con time since stroke *(mth)* = 2.0 (1.3)	Exp = EMG-triggered FES 4 UL/LL muscle groups × 15 reps × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = DF – MMT *(/6 points)* Activity = BI *(/100 points)* Endpoint: 4 wk
Higgins (2006)[47]	n = 91/91 Exp age *(yr)* = 73 (8) Con age *(yr)* = 71 (12) Exp time since stroke *(mth)* = 7.1 (2.4) Con time since stroke *(mth)* = 7.9 (2.7)	Exp = task-specific UL training ≈90 min × 3/wk × 6 wk Con = walking training[c]	Strength = hand grip – force *(kg)* Activity = Box and Block *(no. of blocks)* Endpoint: 6 wk
Hsieh (2011)[57]	n = 12/18 Exp age *(yr)* = 56 (14) Con age *(yr)* = 52 (2) Exp time since stroke *(mth)* = 21.3 (7.2) Con time since stroke *(mth)* = 13.0 (7.0)	Exp = high-intensity robotic training 90 to 105 min × 5/wk × 4 wk Con = low-intensity robotic training[c]	Strength = average UL (eight muscle groups) – MMT *(/48 points)* Activity = FMA (UL) *(/66 points)* Endpoint: 4 wk
Hsieh (2012)[31]	n = 36/54 Exp age *(yr)* = 57 (10) Con age *(yr)* = 52 (12) Exp time since stroke *(mth)* = 28.7 (13.7) Con time since stroke *(mth)* = 23.3 (15.4)	Exp = high-intensity robotic training 90 to 105 min × 5/wk × 4 wk Con = low-intensity robotic training[c]	Strength = UL – MMT *(/6 points)* Activity = FMA (UL) *(/66 points)* Endpoint: 4 wk
Hwang (2012)[58]	n = 15/17 Exp age *(yr)* = 50 (4) Con age *(yr)* = 51 (3) Exp time since stroke *(mth)* = 7.3 (6.3) Con time since stroke *(mth)* = 5.3 (5.9)	Exp = active robotic hand training 40 min x 5/wk × 4 wk Con = passive/active robotic hand training[c]	Strength = hand grip – force *(kg)* Activity = Jebsen Taylor Test *(sec)* Endpoint: 4 wk
Kim (2015)[74]	n = 19/29 Exp age *(yr)* = 58 (8) Con age *(yr)* = 62 (1) Exp time since stroke *(mth)* = 10.1 (5.6) Con time since stroke *(mth)* = 13.7 (7.1)	Exp = mirror therapy + BF-FES 30 min × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = hand grip – force *(kg)* Activity = Jebsen Taylor Test *(sec)* Endpoint: 4 wk
Kwakkel (1999)[32 d] Cooke (2010)[78]	n = 60/101 Exp age *(yr)* = 65 (10) Con age *(yr)* = 64 (15) Exp time since stroke *(mth)* = 0.2 (0.1) Con time since stroke *(mth)* = 0.2 (0.1)	Exp = task-specific LL training 30 min × 5/wk × 20 wk Con = immobilisation of LL[c] Both = usual therapy	Strength = LL – Motricity Index *(/100 points)* Activity = fast walking speed *(m/s)* Endpoint: 20 wk
Lannin (2016)[69]	n = 9/9 Exp age *(yr)* = 63 (10) Con age *(yr)* = 51 (21) Exp time since stroke *(mth)* = 2.5 (1.7) Con time since stroke *(mth)* = 4.7 (6.1)	Exp = Saebo-Flex 45 min × 5/wk × 8 wk Con = no intervention Both = usual therapy	Strength = hand grip – force *(kg)* Activity = Box and Block *(no. of blocks)* Endpoint: 8 wk
Lee (2008)[65]	n = 24/52 Exp age *(yr)* = 67 (11) Con age *(yr)* = 65 (6) Exp time since stroke *(mth)* = 52.4 (2.2) Con time since stroke *(mth)* = 65.8 (42.3)	Exp = cycling 30 min × 3/wk × 10 to 12 wk Con = sham cycling[c] Both = sham PRT	Strength = composite LL (HE/KE/KF/PF/DF) – isometric force *(N)* Activity = fast walking speed *(m/s)* Endpoint: 12 wk

Table 1 (*Continued*)

Study	Participants[a]	Comparison	Outcome measures[b]
Lee (2012)[71]	n = 40/40 Exp age *(yr)* = 54 (11) Con age *(yr)* = 54 (11) Exp time since stroke *(mth)* = 13.3 (5.9) Con time since stroke *(mth)* = 14.0 (6.3)	Exp = standing balance training (video games) 20 min × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = KE – MMT *(/6 points)* Activity = walking speed *(s)* Endpoint: 4 wk
Lee (2013)[70]	n = 14/14 Exp age *(yr)* = 72 (9) Con age *(yr)* = 76 (6) Exp time since stroke *(mth)* = 7.3 (1.4) Con time since stroke *(mth)* = 8.3 (3.4)	Exp = UL therapy (video games) 30 min × 3/wk × 6 wk Con = no intervention Both = usual therapy	Strength = EE – MMT *(/10 points)* Activity = FIM (scale NR) Endpoint: 6 wk
Lee (2016)[75]	n = 27/30 Exp age *(yr)* = 56 (7) Con age *(yr)* = 54 (6) Exp time since stroke *(mth)* = 36.8 (26.1) Con time since stroke *(mth)* = 42.5 (33.9)	Exp = mirror therapy + FES 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = DF – isometric force *(lb)* Activity = 6MWT *(sec)* Endpoint: 4 wk
Lincoln (1999)[63]	n = 189/282 Exp age *(yr)* = 73 (12) Con age *(yr)* = 73 (12) Exp time since stroke *(mth)* = 0.4 (0.2) Con time since stroke *(mth)* = 0.4 (0.2)	Exp = additional physiotherapy ≈ 2 hrs/wk × 5 wk Con = no intervention Both = usual therapy	Strength = hand grip – force *(% of unaffected UL)* Activity = ARAT *(/57 points)* Endpoint: 5 wk
Masiero (2007)[33]	n = 30/35 Exp age *(yr)* = 63 (12) Con age *(yr)* = 69 (11) Exp time since stroke *(mth)* = NR Con time since stroke *(mth)* = NR	Exp = robotic UL training 20 to 30 min × 2/day × 5/wk × 5 wk Con = unaffected UL exposed to robot[c] Both = usual therapy	Strength = ShAbd – MMT *(/6 points)* Activity = FIM motor *(/79 points)* Endpoint: 5 wk
Ng (2007)[48]	n = 40/88 Exp age *(yr)* = 57 (8) Con age *(yr)* = 57 (9) Exp time since stroke *(mth)* = 56.4 (49.2) Con time since stroke *(mth)* = 62.4 (34.8)	Exp = task-specific LL training + placebo-TENS 60 min × 5/wk × 4 wk Con = no intervention	Strength = PF – isometric torque *(Nm)* Activity = self-selected walking speed *(cm/s)* Endpoint: 4 wk
Pang (2005)[34]	n = 60/63 Exp age *(yr)* = 66 (9) Con age *(yr)* = 65 (8) Exp time since stroke *(mth)* = 62.4 (60.0) Con time since stroke *(mth)* = 61.2 (43.2)	Exp = FAME program 60 min x 3/wk × 19 wk Con = seated UL program[c]	Strength = KE – isometric force *(N)* Activity = 6MWT *(m)* Endpoint: 19 wk
Rodgers (2003)[64]	n = 105/123 Exp age *(yr)* = 74 (NR) Con age *(yr)* = 75 (NR) Exp time since stroke *(mth)* = 0.2 (0.1) Con time since stroke *(mth)* = 0.2 (0.1)	Exp = additional physiotherapy 30 min × 5/wk × 6 wk Con = no intervention Both = usual therapy	Strength = UL – Motricity Index *(/100 points)* Activity = ARAT *(/57 points)* Endpoint: 3 mth
Ross (2009)[49]	n = 37/40 Exp age *(yr)* = 60 (21) Con age *(yr)* = 59 (19) Exp time since stroke *(mth)* = 2.3 (2.7) Con time since stroke *(mth)* = 0.7 (2.0)	Exp = task-specific UL training 60 min × 5/wk × 6 wk Con = no intervention Both = usual therapy	Strength = composite UL (nine muscle groups) – MMT *(/45 points)* Activity = ARAT *(/57 points)* Endpoint: 6 wk
Rydwik (2006)[59]	n = 9/18 Exp age *(yr)* = 75 (9) Con age *(yr)* = 75 (5) Exp time since stroke *(mth)* = 42.6 (18.2) Con time since stroke *(mth)* = 54.9 (20.0)	Exp = Stimulo robotic therapy 30 min × 3/wk × 6 wk Con = no intervention	Strength = PF – torque *(Nm)* Activity = fast walking speed *(m/s)* Endpoint: 6 wk
Sanchez-Sanchez (2016)[50]	n = 15/15 Exp age *(yr)* = 58 (12) Con age *(yr)* = 62 (11) Exp time since stroke *(mth)* = 41.3 (34.3) Con time since stroke *(mth)* = 33.8 (26.3)	Exp = UL exercise program 75 min × 33 over 12 wk Con = LL exercise program[c]	Strength = hand grip – force *(kg)* Activity = WMFT – average functional score *(/6 points)* Endpoint: 12 wk
Shin (2008)[55]	n = 14/14 Exp age *(yr)* = 61 (8) Con age *(yr)* = 54 (4) Exp time since stroke *(mth)* = 18.6 (4.2) Con time since stroke *(mth)* = 19.7 (7.7)	Exp = EMG-triggered FES 30 min × 2/day × 5/wk × 10 wk Con = no intervention Both = usual therapy	Strength = isometric MPJ extension force *(kg)* Activity = Box and Block *(no. of blocks)* Endpoint: 10 wk
Sullivan et al (2007)[35]	n = 36/80 Exp age *(yr)* = 58 (15) Con age *(yr)* = 63 (9) Exp time since stroke *(mth)* = 23.1 (15.0) Con time since stroke *(mth)* = 28.4 (19.0)	Exp = BWSTT 60 min × 4/wk × 6 wk Con = UL ergometry[c] Both = cycling	Strength = composite LL (HE, KE, PF) – isometric torque *(Nm)* Activity = fast walking speed *(m/s)* Endpoint: 6 wk
Sunderland (1992)[36]	n = 61/132 Exp age *(yr)* = 67 (NR) Con age *(yr)* = 70 (NR) Exp time since stroke *(mth)* = 0.3 (NR) Con time since stroke *(mth)* = 0.3 (NR)	Exp = additional physiotherapy Intervention period = NR Con = no intervention Both = usual therapy	Strength = UL – Extended Motricity Index (scale NR) Activity = Frenchay Arm Test *(/5 pass or fail)* Endpoint: 4 wk
Tankisheva (2014)[72]	n = 13/15 Exp age *(yr)* = 57 (13) Con age *(yr)* = 65 (4) Exp time since stroke *(mth)* = 92.5 (103.2) Con time since stroke *(mth)* = 63.4 (43.2)	Exp = whole body vibration training 30 min × 3/wk × 6 wk Con = no intervention	Strength = KE – isometric torque *(Nm)* Activity = Sensory Organisation Test (condition 6) Endpoint: 6 wk

Table 1 (*Continued*)

Study	Participants[a]	Comparison	Outcome measures[b]
Tian (2007)[66]	n = 80/80 Exp age *(yr)* = 58 (NR) Con age *(yr)* = 58 (NR) Exp time since stroke *(mth)* = NR Con time since stroke *(mth)* = NR	Exp = THERA-vital cycling 30 min × 6/wk × 4 wk Con = no intervention Both = usual therapy	Strength = LL – MMT *(/6 points)* Activity = ADL *(/8 grades)* Endpoint: 4 wk
Tihanyi (2010)[73]	n = 20/20 Exp age *(yr)* = 58 (5) Con age *(yr)* = 58 (8) Exp time since stroke *(mth)* = 0.9 (0.3) Con time since stroke *(mth)* = 0.8 (0.3)	Exp = whole body vibration training 3/wk × 4 wk Con = no intervention Both = usual therapy	Strength = KE – isometric torque *(Nm)* Activity = nil Endpoint: 4 wk
Tung (2010)[37]	n = 32/32 Exp age *(yr)* = 51 (21) Con age *(yr)* = 53 (14) Exp time since stroke *(mth)* = 26.9 (16.0) Con time since stroke *(mth)* = 12.8 (12.3)	Exp = STS training 15 min × 3/wk × 4 wk Con = no intervention Both = usual therapy	Strength = KE – force *(% normalised to body-weight)* Activity = Berg Balance Scale *(/56 points)* Endpoint: 4 wk
Tyson (2015)[38]	n = 85/94 Exp age *(yr)* = 64 (15) Con age *(yr)* = 64 (13) Exp time since stroke *(mth)* = 0.9 (0.6) Con time since stroke *(mth)* = 1.2 (0.9)	Exp = patient-led mirror therapy 30 min × 7/wk × 4 wk Con = patient-led LL exercise[c] Both = usual therapy	Strength = hand grip – force (units NR) Activity = ARAT *(/57 points)* Endpoint: 4 wk
Winchester (1983)[56]	n = 40/40 Exp age *(yr)* = 57 (13) Con age *(yr)* = 60 (10) Exp time since stroke *(mth)* = 1.5 (1.2) Con time since stroke *(mth)* = 1.9 (1.3)	Exp = position-triggered FES + ES 30 min × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = KE – isometric torque *(Nm)* Activity = nil Endpoint: 4 wk
Winstein (2004)[39]	n = 40/64 Exp age *(yr)* = 58 (10) Con age *(yr)* = 50 (10) Exp time since stroke *(mth)* = 0.5 (0.2) Con time since stroke *(mth)* = 0.5 (0.2)	Exp = task-specific UL training 60 min × 5/wk × 4 wk Con = no intervention Both = usual therapy	Strength = composite UL (ShE, ShF, EE, EF, WE, WF) – isometric torque *(kg/cm)* Activity = FTHUE *(/18 points)* Endpoint: 4 to 6 wk
Yang (2006)[51]	n = 48/48 Exp age *(yr)* = 57 (10) Con age *(yr)* = 60 (10) Exp time since stroke *(mth)* = 62.7 (27.4) Con time since stroke *(mth)* = 64 (40.4)	Exp = task-specific strength training 30 min × 3/wk × 4 wk Con = no intervention	Strength = KE – isometric force *(lb)* Activity = self-selected walking speed *(cm/s)* Endpoint: 4 wk
Yoon (2014)[61]	n = 18/26 Exp age *(yr)* = 64 (9) Con age *(yr)* = 61 (17) Exp time since stroke *(mth)* = 0.6 (0.3) Con time since stroke *(mth)* = 0.8 (0.4)	Exp = CIMT 360 min × 5/wk × 2 wk Con = independent exercise program[c] Both = usual therapy + independent exercise program	Strength = hand grip – force *(kg)* Activity = WMFT *(sec)* Endpoint: 2 wk

ARAT = Action Research Arm Test, ADL = activities of daily living, BI = Barthel Index, BP = blood pressure, BWSTT = body-weight-supported treadmill training, CIMT = constraint-induced movement therapy, Con = control group, DF = dorsiflexors, EE = elbow extensors, EF = elbow flexors, EMG = electromyography, ES = electrical stimulation, Exp = experimental group, FAME = Fitness and Mobility Exercise, FES = Functional Electrical Stimulation, FMA = Fugl-Meyer Assessment, FTHUE = Functional Test for the Hemiparetic Upper Extremity, GRASP = Graded Repetitive Arm Supplementary Program, HAbd = hip abductors, HE = hip extensors, HF = hip flexors, KE = knee extensors, KF = knee flexors, LL = lower limb, MAS = Motor Assessment Scale, MI = Motricity Index, MMT = Manual Muscle Test, MPJ = metacarpophalangeal joint, NR = not reported, PF = plantarflexors, RM = repetition maximum, RMI = Rivermead Mobility Index, ShAbd = shoulder abductors, ShAdd = shoulder adductors, ShE = shoulder extensors, ShER = shoulder external rotators, ShF = shoulder flexors, ShIR = shoulder internal rotators, TA = thumb abductors, TE = trunk extension, TENS = transcutaneous electrical nerve stimulation, UL = upper limb, WE = wrist extensors, WF = wrist flexors, WMFT = Wolf Motor Function Test.

[a] n = number of participants analysed/number of participants randomised. Age *(yr)* and time since stroke *(mth)* = mean (SD).
[b] Outcome measures and endpoint used in data analysis.
[c] Considered to be equivalent to no intervention or of lower dosage when compared with the experimental group.
[d] Data obtained from Kwakkel (1999) and Cooke et al (2010).

8 years, with 28 of the 52 studies including participants who were more than 6 months after their stroke.

Intervention

The experimental intervention, repetitive practice, was provided in the following ways: task-specific training[26,28–30,32,34,35,37,39,41–51] (provided in a group setting or on a one-to-one basis) (20 studies); electromyography-triggered functional electrical stimulation (FES) or FES combined with active movement[40,52–56] (six studies); robotics[27,31,33,57–59] (six studies); constraint-induced movement therapy[25,60,61] (three studies); Bobath[62–64] (three studies); cycling[65,66] (two studies); mixed therapies that included a number of interventions[36,67] (two studies); assistive technology[68,69] (SMART Arm & SAEBO) (two studies); video games[70,71] (two studies); whole body vibration combined with active movement[72,73] (two studies); mirror therapy and FES combined with active movement[74,75] (two studies); mirror therapy[38] (one study); and water-based exercise[76] (one study). The frequency and duration of therapy sessions, and intensity and progression of practice was variable (see Appendix 2 on the eAddenda). The duration of therapy sessions ranged from 15 to 360 minutes including rest breaks. Overall average dosage (frequency plus duration of therapy sessions) ranged from 2.2 hours over 4 weeks to 60 hours over 2 weeks. Sixteen studies reported total repetitions of active practice ranging from five repetitions per exercise to 1800 repetitions per therapy session. These repetitions were counted throughout a session or specified prior to each therapy session. Thirty-three studies compared repetitive practice to no intervention[25,26,29,30,36,37,39–42,48,49,51–56,59,60,62–64,66–75] and 19 studies compared repetitive practice to a sham intervention.[27,28,31–35,38,43–47,50,57,58,61,65,76]

Outcome measures

Strength of the affected upper or lower limb was measured in the following ways: maximum force[25,26,30,34,38,41,43,44,46,47,50,51,55,58,60,61,65,68,69,74,75] (21 studies); torque[28,29,35,39,40,48,52,56,59,67,72,73,76] (13 studies); Motricity Index[32,42,45,62,64] (five studies); Extended Motricity Index[36] (one study); manual muscle testing[27,31,33,49,53,54,57,66,70,71] (10 studies); and percentage of strength normalised to body-weight[37] or expressed as a percentage of the unaffected side[63] (two studies).

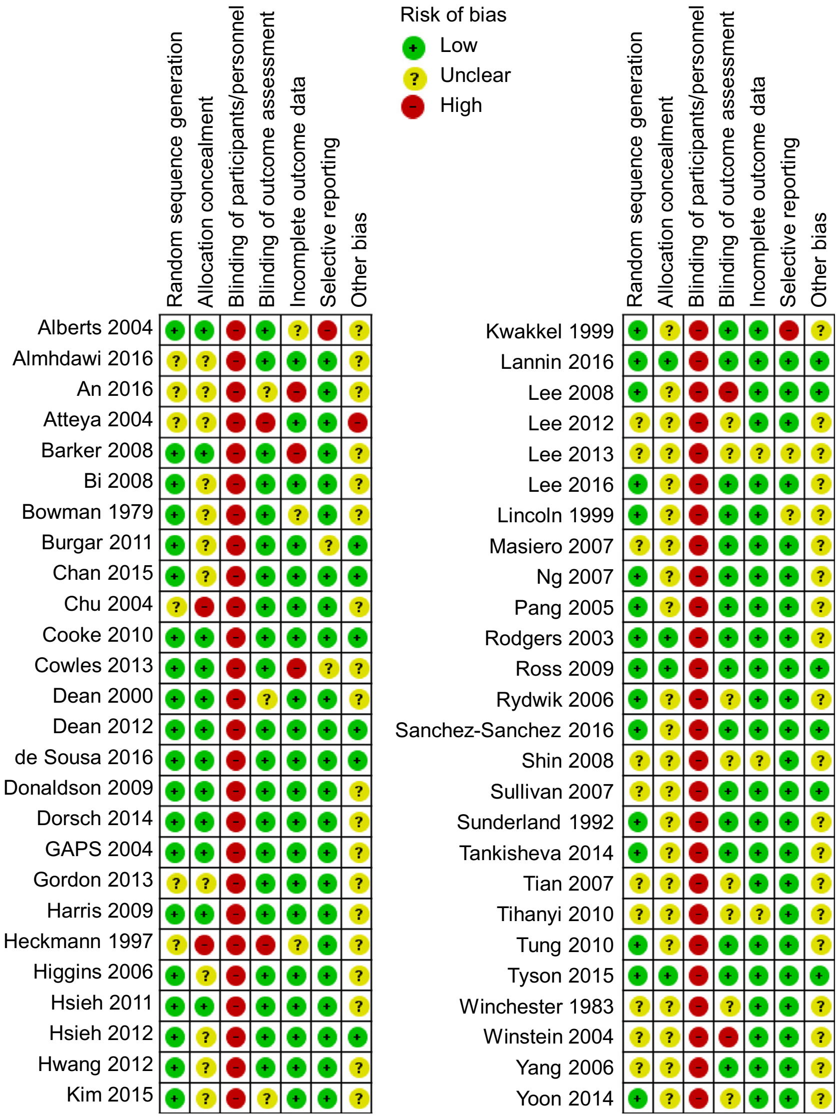

Figure 2. The risk of bias in the included studies (n = 52).
Green = low risk of bias, yellow = unclear risk of bias, red = high risk of bias.

Activity of the upper and lower limb was measured using various scales (see Appendix 3 on the eAddenda).

Effects of repetitive practice

Strength

Forty-six studies with a total of 1928 participants investigated the effects of repetitive practice on strength after stroke. The overall SMD of repetitive practice on strength when the upper and lower limb studies were combined was 0.25 (95% CI 0.16 to 0.34, I^2 = 44%) in favour of repetitive practice (Figure 3, see Figure 4 on the eAddenda for a detailed forest plot). These studies involved 12 different types of interventions that were analysed in separate meta-analyses. The most common intervention was task-specific training, with 18 studies and a total of 931 participants. The SMD was 0.21 (95% CI 0.08 to 0.34, I^2 = 36%) in favour of task-specific training on strength. The intervention with the largest effect on strength was constraint-induced movement therapy, with two studies and a total of 22 participants. The SMD was 1.49 (95% CI 0.44 to 2.54, I^2 = 57%) in favour of constraint-induced movement therapy on strength. The intervention with the next largest effect on strength was assistive technology, with two studies and a total of 32 participants. The SMD was 1.02 (95% CI 0.26 to 1.78, I^2 = 29%) in favour of assistive technology on strength. Four studies[27,28,35,38] with a total of 182 participants only reported change data for strength; however, statistical heterogeneity was too high to pool results in a meta-analysis.

Upper limb activity

Twenty-four studies with a total of 912 participants investigated the effects of repetitive practice on upper limb activity after stroke. The SMD was 0.15 (95% CI 0.02 to 0.29, I^2 = 50%) in favour of repetitive practice on upper limb activity (Figure 5, see Figure 6 on the eAddenda for a detailed forest plot). This translates to an absolute mean increase of 3.1/57 points (95% CI 0.4 to 5.8) on the ARAT (upper limb activity) when the results are back converted using the largest, least biased and most representative study of those included in the analysis.[46] These studies involved eight different types of interventions that were analysed in separate meta-analyses. The most common intervention involving repetitive practice was task-specific training, with 10 studies and a total of 392 participants. The SMD was 0.21 (95% CI 0.01 to 0.41, I^2 = 0%) in favour of task-specific training on upper limb activity. Two studies[27,38] with a total of 121 participants only reported change data for upper limb activity after stroke. The SMD was –0.12 (95% CI –0.50 to 0.25, I^2 = 0%) in favour of no intervention or a sham intervention.

Lower limb activity

Twenty studies with a total of 952 participants investigated the effects of repetitive practice on lower limb activity after stroke. The SMD was 0.25 (95% CI 0.12 to 0.38, I^2 = 36%) in favour of repetitive practice on lower limb activity (Figure 7, see Figure 8 on the eAddenda for a detailed forest plot). This translates to an absolute mean increase of 0.13 m/s (95% CI 0.06 to 0.20) in walking speed

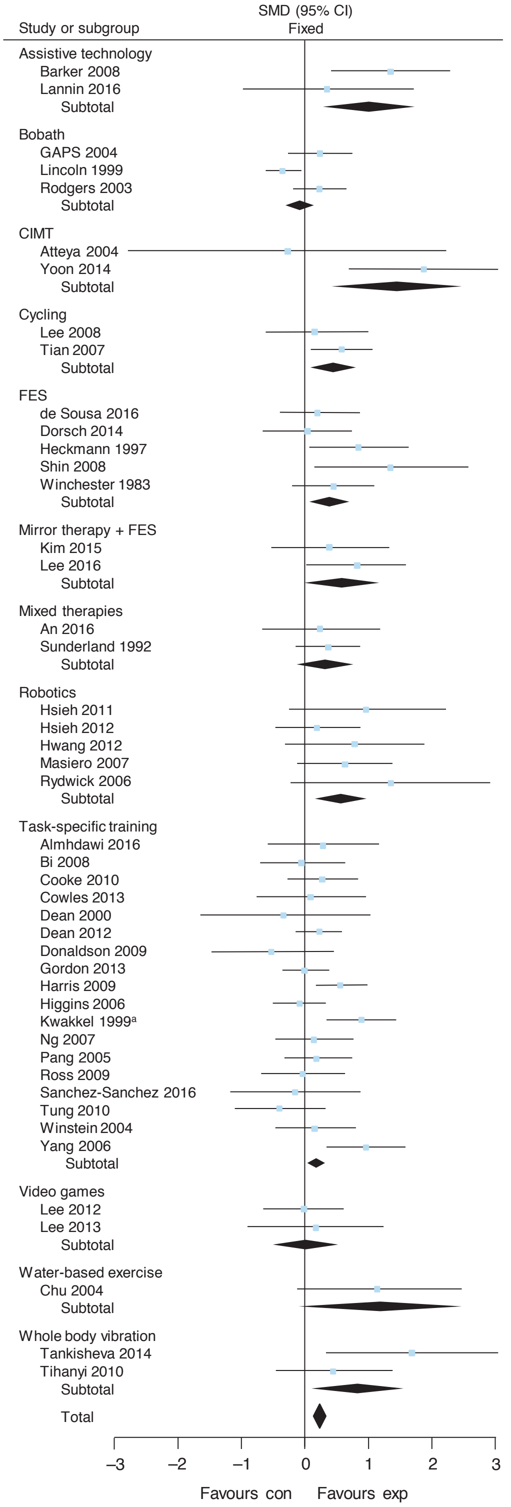

Figure 3. The effect of repetitive practice versus no intervention or sham on strength (n = 1928).
Effects are expressed as SMD (95% CI).
[a] Means (SD) obtained from Cooke et al 2010.

when the results are back converted using the largest, least biased and most representative study of those included in the analysis.[44] These studies involved 10 different types of interventions that were analysed in separate meta-analyses. The most common intervention involving repetitive practice was task-specific training, with nine studies and a total of 593 participants. The SMD was 0.32 (95% CI 0.16 to 0.48, I^2 = 35%) in favour of task-specific training on lower limb activity. One study with a total of 25 participants only reported change data for lower limb activity after stroke.[28] The MD in lateral seated reach to the affected side was 4.30 cm (95% CI 1.57 to 7.03) in favour of repetitive practice on lower limb activity.

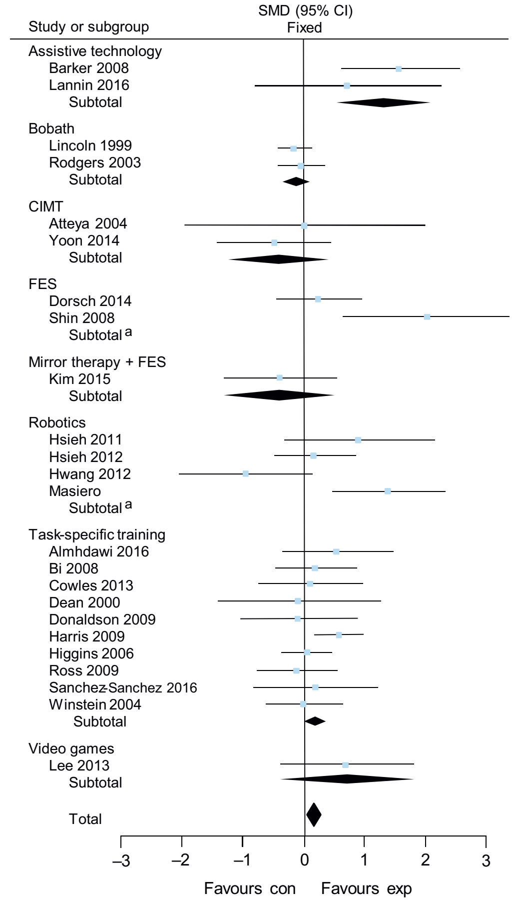

Figure 5. The effect of repetitive practice versus no intervention or sham on upper limb activity (n = 912).
Effects are expressed as SMD (95% CI).
A negative time score reflects improvement in speed on the Wolf Motor Function Test and Jebsen Taylor Test.
[a] No subtotals are presented for FES or Robotics because the I^2 value was > 75%.

Subgroup analyses

When studies were grouped according to upper and lower limb, there were 25 studies with a total of 973 participants that investigated the effects of repetitive practice on upper limb strength and 21 studies with a total of 955 participants that investigated the effects of repetitive practice on lower limb strength. The SMD was 0.16 (95% CI 0.03 to 0.29, I^2 = 47%) in favour of repetitive practice on upper limb strength and 0.34 (95% CI 0.22 to 0.47, I^2 = 34%) in favour of repetitive practice on lower limb strength (see Figures 9 and 10 on the eAddenda for the detailed forest plots). This translates to an absolute mean increase of 1.28 kg (95% CI 0.24 to 2.32) in hand grip strength and 5.75 Nm (95% CI 3.72 to 7.94) in knee extensor strength when the results are back converted using the largest, least biased, and most representative study of those included in the analysis.[29,46]

When the studies were grouped according to time after stroke, there were 21 studies with a total of 1054 participants that investigated the effects of repetitive practice on strength early after stroke and 25 studies with a total of 874 participants that examined the effects of repetitive practice on strength late after stroke. The SMD was 0.32 (95% CI 0.13 to 0.52, I^2 = 53%) in favour of repetitive practice early after stroke and 0.31 (95% CI 0.13 to 0.49, I^2 = 36%) in favour of repetitive practice late after stroke.

When studies were grouped according to dosage, there were 35 studies with a total of 1572 participants that provided repetitive practice for a total of $\leq$ 24 hours, and 11 studies with a total of 356 participants that provided repetitive practice for a total of > 24 hours. The SMD was 0.24 (95% CI 0.14 to 0.34, I^2 = 41%) in favour of repetitive practice provided for a total of $\leq$ 24 hours and 0.31 (95% CI 0.10 to 0.53, I^2 = 53%) in favour of repetitive practice provided for a total of > 24 hours.

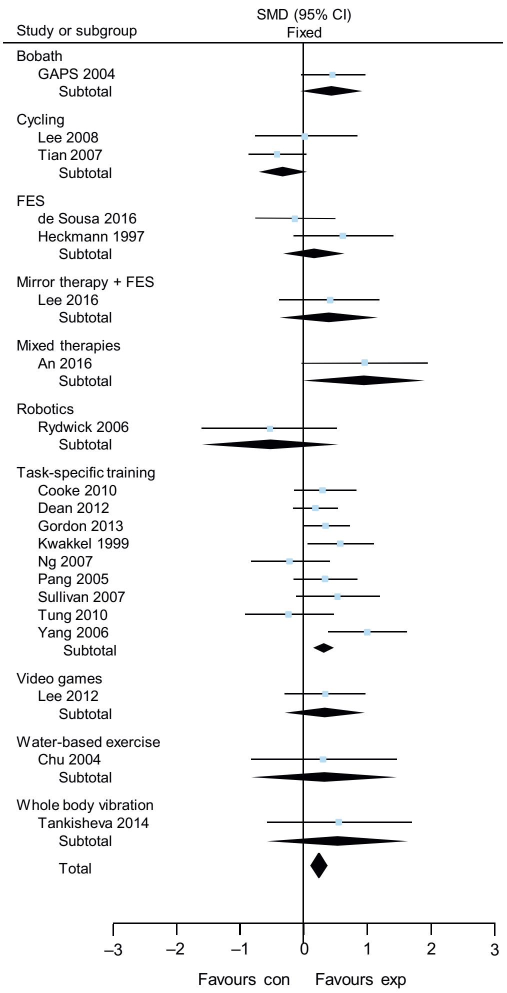

Figure 7. The effect of repetitive practice versus no intervention or sham on lower limb activity (n = 952).
Effects are expressed as SMD (95% CI).
A negative time score reflects improvement in walking speed on the 6-m and 10-m walk tests.

A subgroup analysis was planned for the effects of repetitive practice on strength in people who are weaker versus people who are stronger; however, because most studies recruited both weaker and stronger participants, this analysis was not possible.

Post-hoc analysis

When studies were grouped according to limbs that were trained and time since stroke, there were 13 studies with a total of 668 participants that investigated the effects of repetitive practice on upper limb strength early after stroke, and 12 studies with 305 participants that investigated the effects of repetitive practice on upper limb strength late after stroke. The SMD was 0.22 (95% CI –0.06 to 0.49, I^2 = 59%) in favour of repetitive practice on upper limb strength early after stroke and 0.23 (95% CI 0.00 to 0.46, I^2 = 29%) in favour of repetitive practice on upper limb strength late after stroke. There were eight studies with a total of 386 participants that investigated the effects of repetitive practice on lower limb strength early after stroke and 13 studies with a total of 569 participants that investigated the effects of repetitive practice on lower limb strength late after stroke. The SMD was 0.48 (95% CI 0.28 to 0.69, I^2 = 0%) in favour of repetitive practice on lower limb strength early after stroke and 0.25 (95% CI 0.08 to 0.42, I^2 = 45%) in favour of repetitive practice on lower limb strength late after stroke (see Appendix 4 on the eAddenda).

Sensitivity analysis

Sensitivity analyses were conducted on the primary meta-analysis for strength to explore the effects of various methodological aspects of the included studies. The only substantial difference on the estimate for strength was found in the analysis of eight studies with a total of 343 participants that were free from other bias. The SMD was 0.19 (95% CI –0.03 to 0.40) in favour of repetitive practice (see Appendix 5 on the eAddenda). This was a smaller and less precise estimate than the overall SMD on strength when the upper and lower limb studies were combined (0.25, 95% CI 0.16 to 0.34).

Discussion

This systematic review provides evidence that interventions involving repetitive practice improve strength after stroke. The pooled mean treatment effects for upper and lower limbs are 1.28 kg and 5.75 Nm, respectively. This represents a 15% relative increase in strength in the upper limb, and a 28% relative increase in strength in the lower limb when compared to mean baseline strength. These estimates are reasonably precise with the 95% CI spanning from 0.24 to 2.32 kg (equivalent to a 3 to 26% relative increase) in the upper limb and 3.72 to 7.94 Nm (equivalent to an 18 to 39% relative increase) in the lower limb. These results suggest that the effect of repetitive practice on strength is greater in the lower limb (knee extension) than the upper limb (hand grip). These findings are similar in the post-hoc analyses that restricted studies to early after stroke. That is, the effects of repetitive practice on strength are greater in the lower limb (8.11 Nm, 95% CI 4.73 to 11.66) compared to the upper limb (1.76 kg, 95% CI –0.48 to 3.92).

These results suggest that small improvements in strength with repetitive practice translate into small improvements in activity of the upper (SMD 0.15, 95% CI 0.02 to 0.29) and lower limb (SMD 0.25, 95% CI 0.12 to 0.38) after stroke. The results for activity need to be interpreted with caution because the aim of this review was not to determine the effect of repetitive practice on activity. Instead, this was a secondary analysis used to determine whether improvements in strength were accompanied by improvements in activity. Therefore, it did not include studies that measured activity unless they measured strength. Other reviews provide the best evidence about the effects of repetitive practice on activity.[12,14,15,77] However, a unique feature of our review is that it provides insights into the possible mechanisms underlying the observed improvement in activity with repetitive practice. The accompanying improvement in activity with improvement in strength suggests that the observed improvement in activity may, at least in part, be due to improvement in strength.

Of course, not all of the observed improvements in activity can be attributed solely to improvements in strength. Repetitive practice typically involves practice of tasks, which demands the integration of strength, coordination and sensory input. Thus, improvements in strength with repetitive practice are more likely to translate into improvements in activity than interventions that involve isolated strength training of muscles (eg, progressive resistance training).

Our results suggest smaller improvements in strength with repetitive practice (SMD 0.25, 95% CI 0.16 to 0.34) than reviews of progressive resistance training (SMD 0.98, 95% CI 0.67 to 1.29)[10] and electrical stimulation (SMD 0.47, 95% CI 0.26 to 0.68).[22] However, we cannot conclude that these other interventions improve strength more than repetitive practice for two main reasons. Firstly, to answer questions about relative effectiveness, interventions need to be compared in a randomised controlled trial. Secondly, studies of progressive resistance training may not have included people who are very weak; therefore, the cohorts of the studies included in the review of progressive resistance training may be different to the cohorts of the studies in our review.

Some clinicians may disagree with our definition of repetitive practice. Repetitive practice was defined as voluntary contraction of muscles of the affected upper or lower limb, and could have included repetitive practice of a whole task or components of a task. This definition was intentionally broad because people after stroke may be too weak to practise a whole task (eg, reaching and manipulation of objects). Therefore, repetitive practice of components of a task (eg, elbow extension and finger flexion/extension) are needed prior to, and in combination with, whole task practice.

There is some indication that an increased dosage of repetitive practice improves strength after stroke. In studies where the total dosage was $\leq$ 24 hours, the SMD was 0.24 (95% CI 0.14 to 0.34) in favour of repetitive practice. When the total dosage of repetitive practice was > 24 hours, the SMD was slightly more, namely 0.31 (95% CI 0.10 to 0.53) in favour of repetitive practice. However, dosage was difficult to quantify in this review because most studies did not report actual duration of active practice, and only 16 studies reported total repetitions of active practice or specified the total amount of repetitions aimed for in each therapy session. For this reason, we were forced to rely on data about scheduled therapy time. Surprisingly, one study only provided 2.2 hours of active practice over 4 weeks (equivalent to 0.5 hour per week). At the other extreme, one study provided 60 hours of active practice over 2 weeks (equivalent to 30 hours per week). Clearly, the dose-response relationship of repetitive practice is complex and requires further investigation in large randomised controlled trials.

This review is unique because it included all randomised trials that investigated the effects of repetitive practice on strength after stroke. This review also provides individual estimates of improvements in strength for 12 different types of interventions involving repetitive practice. No other systematic review has investigated these issues. This review provides meta-analyses of the effects of repetitive practice in the upper limb both early and late after stroke, and in the lower limb both early and late after stroke. These analyses are useful because there may be differences in the way the upper and lower limbs respond to repetitive practice at different times after stroke.

The main limitation of this review was that a minimum worthwhile treatment effect for strength was not defined a priori, making it difficult to determine if a statistically significant result was clinically worthwhile. However, data were converted to relative improvements in strength to help clinicians interpret the results (see Appendices 6 and 7 on the eAddenda). Another limitation was that post-intervention data were used instead of change data. Change data may have provided a more precise estimate of effect of repetitive practice on strength. Post-intervention data were used in preference to change data because these were the most commonly provided data in studies.

The loss of strength is a common and important impairment after stroke. In addition, repetitive practice is widely used and recommended in rehabilitation after stroke to improve activity. However, prior to this review it was not known whether improvements in activity with repetitive practice are accompanied by improvements in strength. This systematic review provides evidence that interventions involving repetitive practice do improve strength after stroke, and these improvements are accompanied by improvements in activity. This suggests that repetitive practice should be prioritised as an intervention that can improve both strength and activity in people after stroke.

What was already known on this topic: Loss of strength after stroke is common, and causes profound limitations in activity and participation. Progressive resistance training can be used to increase strength after stroke but it can be time-consuming to set up and monitor.
What this study adds: Interventions involving repetitive practice improve strength after stroke, and the improvement in strength is accompanied by improvements in activity. Repetitive practice should be prioritised as an intervention that can improve both strength and activity in people after stroke.

Footnote: [a] Review Manager Version 5.3, The Nordic Cochrane Centre, Copenhagen.

eAddenda: Figures 4, 6, 8, 9 and 10, and Appendices 1, 2, 3, 4, 5, 6 and 7 can be found online at https://doi.org/10.1016/j.jphys.2018.08.004

Competing interest: Nil.

Source of support: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements: Nil.

Provenance: Not invited. Peer reviewed.

Correspondence: Davide G de Sousa, Graythwaite Rehabilitation Centre, Ryde Hospital, Sydney, Australia. Email: davidedesousa@gmail.com

References

1. Andrews AW, Bohannon RW. Short-term recovery of limb muscle strength after acute stroke. *Arch Phys Med Rehabil.* 2003;84:125–130.
2. Andrews AW, Bohannon RW. Distribution of muscle strength impairments following stroke. *Clin Rehabil.* 2000;14:79–87.
3. Neckel N, Pelliccio M, Nichols D, Hidler J. Quantification of functional weakness and abnormal synergy patterns in the lower limb of individuals with chronic stroke. *J Neuroeng Rehabil.* 2006;3:17.
4. Horstman AM, Beltman MJ, Gerrits KH, Koppe P, Janssen TW, Elich P, et al. Intrinsic muscle strength and voluntary activation of both lower limbs and functional performance after stroke. *Clin Physiol Funct Imaging.* 2008;28:251–261.
5. Faria-Fortini I, Michaelsen SM, Cassiano JG, Teixeira-Salmela LF. Upper extremity function in stroke subjects: relationships between the international classification of functioning, disability, and health domains. *J Hand Ther.* 2011;24:257–265.
6. Canning CG, Ada L, Adams R, O'Dwyer NJ. Loss of strength contributes more to physical disability after stroke than loss of dexterity. *Clin Rehabil.* 2004;18:300–308.
7. Ada L, O'Dwyer N, O'Neill E. Relation between spasticity, weakness and contracture of the elbow flexors and upper limb activity after stroke: an observational study. *Disabil Rehabil.* 2006;28:891–897.
8. Faria-Fortini I, Basílio ML, Polese JC, Faria CD, Teixeira-Salmela LF. Strength deficits of the paretic lower extremity muscles were the impairment variables that best explained restrictions in participation after stroke. *Disabil Rehabil.* 2017;39:2158–2163.
9. American College of Sports Medicine. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc.* 2009;41:687–708.
10. Dorsch S, Ada L, Alloggia D. Progressive resistance training increases strength after stroke but this may not carry over to activity: a systematic review. *J Physiother.* 2018;64:84–90.
11. Hendrey G, Holland AE, Mentiplay BF, Clark RA, Williams G. Do trials of resistance training to improve mobility after stroke adhere to the American College of Sports Medicine Guidelines? A Systematic Review. *Arch Phys Med Rehabil.* 2018;99:584–597.
12. Corbetta D, Sirtori V, Castellini G, Moja L, Gatti R. Constraint-induced movement therapy for upper extremities in people with stroke. *Cochrane Database Syst Rev.* 2015;10:CD004433.
13. Veerbeek JM, van Wegen E, van Peppen R, van der Wees PJ, Hendriks E, Rietberg M, et al. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. *PLoS One.* 2014;9:e87987.
14. French B, Thomas LH, Coupe J, McMahon NE, Connell L, Harrison J, et al. Repetitive task training for improving functional ability after stroke. *Cochrane Database Syst Rev.* 2016;11:CD006073.
15. Mehrholz J, Pohl M, Platz T, Kugler J, Elsner B. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database Syst Rev.* 2015;11:CD006876.
16. Ada L, Dorsch S, Canning CG. Strengthening interventions increase strength and improve activity after stroke: a systematic review. *Aust J Physiother.* 2006;52:241–248.
17. Harris JE, Eng JJ. Strength training improves upper-limb function in individuals with stroke: a meta-analysis. *Stroke.* 2010;41:136–140.
18. Wist S, Clivaz J, Sattelmayer M. Muscle strengthening for hemiparesis after stroke: A meta-analysis. *Ann Phys Rehabil Med.* 2016;59:114–124.
19. Salter K, Musovic A, Taylor NF. In the first 3 months after stroke is progressive resistance training safe and does it improve activity? A systematic review. *Top Stroke Rehabil.* 2016;23:366–375.
20. Saunders DH, Sanderson M, Hayes S, Kilrane M, Greig CA, Brazzelli M, et al. Physical fitness training for stroke patients. *Cochrane Database Syst Rev.* 2016;3:CD003316.
21. Pomeroy VM, King L, Pollock A, Baily-Hallam A, Langhorne P. Electrostimulation for promoting recovery of movement or functional ability after stroke. *Cochrane Database Syst Rev.* 2006;2:CD003241.
22. Nascimento LR, Michaelsen SM, Ada L, Polese JC, Teixeira-Salmela LF. Cyclical electrical stimulation increases strength and improves activity after stroke: a systematic review. *J Physiother.* 2014;60:22–30.
23. Stroke Foundation. *Clinical Guidelines for Stroke Management 2017.* Melbourne, Australia.
24. Kwakkel G, Lannin NA, Borschmann K, English C, Ali M, Churilov L, et al. Standardized measurement of sensorimotor recovery in stroke trials: Consensus-based core recommendations from the Stroke Recovery and Rehabilitation Roundtable. *Int J Stroke.* 2017;12:451–461.
25. Alberts JL, Butler AJ, Wolf SL. The effects of constraint-induced therapy on precision grip: A preliminary study. *Neurorehabil Neural Repair.* 2004;18:250–258.

26. Almhdawi KA, Mathiowetz VG, White M, del Mas RC. Efficacy of occupational therapy task-oriented approach in upper extremity post-stroke rehabilitation. *Occup Ther Int.* 2016;23:444–456.
27. Burgar C, Lum P, Scremin E, Garber SL, Van der Loos HF, Kenney D, et al. Robot-assisted upper-limb therapy in acute rehabilitation setting following stroke: Department of Veterans Affairs multisite clinical trial. *J Rehabil Res Dev.* 2011;48:445–448.
28. Chan B, Ng S, Ng G. A home-based program of transcutaneous electrical nerve stimulation and, task-related trunk training improves trunk control in patients with stroke: A randomized controlled clinical trial. *Neurorehabil Neural Repair.* 2015;29:70–79.
29. Cooke E, Tallis R, Clark A, Pomeroy V. Efficacy of functional strength training on restoration of lower-limb motor function early after stroke: Phase 1 randomized controlled trial. *Neurorehabil Neural Repair.* 2010;24:88–96.
30. Donaldson C, Tallis R, Miller S, Sunderland A, Lemon R, Pomeroy V. Effects of conventional physical therapy and functional strength training on upper limb motor recovery after stroke: A randomized phase II study. *Neurorehabil Neural Repair.* 2009;23:389–397.
31. Hsieh YW, Wu CY, Lin KC, Yao G, Wu KY, Chang YJ. Dose-response relationship of robot-assisted stroke motor rehabilitation: the impact of initial motor status. *Stroke.* 2012;43:2729–2734.
32. Kwakkel G, Wagenaar RC, Twisk JW, Lankhorst GJ, Koetsier JC. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet.* 1999;354:191–196.
33. Masiero S, Celia A, Rosati G, Armani M. Robotic-assisted rehabilitation of the upper limb after acute stroke. *Arch Phys Med Rehabil.* 2007;88:142–149.
34. Pang M, Eng J, Dawson A, McKay H, Harris J. A community-based fitness and mobility exercise program for older adults with chronic stroke: a randomized, controlled trial. *J Am Geriatr Soc.* 2005;53:1667–1674.
35. Sullivan KJ, Brown DA, Klassen T, Mulroy S, Ge T, Azen SP, et al. Effects of task-specific locomotor and strength training in adults who were ambulatory after stroke: results of the STEPS randomized clinical trial. *Phys Ther.* 2007;87:1580–1607.
36. Sunderland A, Tinson DJ, Bradley EL, Fletcher D, Langton Hewer R, Wade DT. Enhanced physical therapy improves recovery of arm function after stroke. A randomised controlled trial. *J Neurol Neurosurg Psychiatry.* 1992;55:530–535.
37. Tung FL, Yang YR, Lee CC, Wang RY. Balance outcomes after additional sit-to-stand training in subjects with stroke: a randomized controlled trial. *Clin Rehabil.* 2010;24:533–542.
38. Tyson S, Wilkinson J, Thomas N, Selles R, McCabe C, Tyrrell P, et al. Phase II pragmatic randomized controlled trial of patient-led therapies (mirror therapy and lower-limb exercises) during inpatient stroke rehabilitation. *Neurorehabil Neural Repair.* 2015;29:818–826.
39. Winstein C, Rose D, Tan S, Lewthwaite R, Chui H, Azen S. A randomized controlled comparison of upper-extremity rehabilitation strategies in acute stroke: A pilot study of immediate and long-term outcomes. *Arch Phys Med Rehabil.* 2004;85:620–628.
40. Bowman BR, Baker LL, Waters RL. Positional feedback and electrical stimulation: an automated treatment for the hemiplegic wrist. *Arch Phys Med Rehabil.* 1979;60:497–502.
41. Bi S. *Treatment of upper limb paresis by transcutanenous electrical nerve stimulation and task-related training during chronic stroke*. [PhD Thesis], Hong Kong: Hong Kong Polytechnic University; 2008.
42. Cowles T, Clark A, Mares K, Peryer G, Stuck R, Pomeroy V. Observation-to-imitate plus practice could add little to physical therapy benefits within 31 days of stroke: Translational randomized controlled trial. *Neurorehabil Neural Repair.* 2013;27:173–182.
43. Dean C, Richards C, Malouin F. Task-related circuit training improves performance of locomotor tasks in chronic stroke: a randomized, controlled pilot trial. *Arch Phys Med Rehabil.* 2000;81:409–417.
44. Dean CM, Rissel C, Sherrington C, Sharkey M, Cumming RG, Lord SR, et al. Exercise to enhance mobility and prevent falls after stroke: the community stroke club randomized trial. *Neurorehabil Neural Repair.* 2012;26:1046–1057.
45. Gordon CD, Wilks R, McCaw-Binns A. Effect of aerobic exercise (walking) training on functional status and health-related quality of life in chronic stroke survivors: A randomized controlled trial. *Stroke.* 2013;44:1179–1181.
46. Harris JE, Eng JJ, Miller WC, Dawson AS. A self-administered graded repetitive arm supplementary program (GRASP) improves arm function during inpatient stroke rehabilitation: A multi-site randomized controlled trial. *Stroke.* 2009;40:2123–2128.
47. Higgins J, Salbach N, Wood-Dauphinee S, Richards C, Cote R, Mayo N. The effect of a task-oriented intervention on arm function in people with stroke: a randomized controlled trial. *Clin Rehabil.* 2006;20:296–310.
48. So RC, Ng JK, Ng GY. Effect of transcutaneous electrical acupoint stimulation on fatigue recovery of the quadriceps. *Eur J Appl Physiol.* 2007;100:693–700.
49. Ross L, Harvey L, Lannin N. Do people with acquired brain impairment benefit from additional therapy specifically directed at the hand? A randomized controlled trial. *Clin Rehabil.* 2009;23:492–503.
50. Sanchez-Sanchez ML, Ruescas-Nicolau MA, Perez-Miralles JA, Marques-Sule E, Espi-Lopez GV. Pilot randomized controlled trial to assess a physical therapy program on upper extremity function to counteract inactivity in chronic stroke. *Top Stroke Rehabil.* 2017;24:183–193.
51. Yang Y, Wang R, Lin K, Chu M, Chan R. Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. *Clin Rehabil.* 2006;20:860–870.
52. de Sousa DG, Harvey LA, Dorsch S, Leung J, Harris W. Functional electrical stimulation cycling does not improve mobility in people with acquired brain injury and its effects on strength are unclear: a randomised trial. *J Physiother.* 2016;62:203–208.
53. Dorsch S, Ada L, Canning CG. EMG-triggered electrical stimulation is a feasible intervention to apply to multiple arm muscles in people early after stroke, but does not improve strength and activity more than usual therapy: a randomized feasibility trial with consumer summary. *Clin Rehabil.* 2014;28:482–490.
54. Heckmann J, Mokrusch T, Krockel A, Warnke S, von Stockert T, Neundorfer B. EMG-triggered electrical muscle stimulation in the treatment of central hemiparesis after a stroke. *Eur J Phys Med Rehabil.* 1997;7:138–141.
55. Shin HK, Cho SH, Jeon HS, Lee YH, Song JC, Jang SH, et al. Cortical effect and functional recovery by the electromyography-triggered neuromuscular stimulation in chronic stroke patients. *Neurosci Lett.* 2008;442:174–179.
56. Winchester P, Montgomery J, Bowman B, Hislop H. Effects of feedback stimulation training and cyclical electrical stimulation on knee extension in hemiparetic patients. *Phys Ther.* 1983;63:1096–1103.
57. Hsieh Y, Wu C, Liao W, Lin K, Wu K, Lee C. Effects of treatment intensity in upper limb robot-assisted therapy for chronic stroke: A pilot randomized controlled trial. *Neurorehabil Neural Repair.* 2011;25:503–511.
58. Hwang CH, Seong JW, Son DS. Individual finger synchronized robot-assisted hand rehabilitation in subacute to chronic stroke: a prospective randomized clinical trial of efficacy. *Clin Rehabil.* 2012;26:696–704.
59. Rydwik E, Eliasson S, Akner G. The effect of exercise of the affected foot in stroke patients – A randomized controlled pilot trial. *Clin Rehabil.* 2006;20:645–655.
60. Atteya AA. Effects of modified constraint induced therapy on upper limb function in subacute stroke patients. *Neurosci.* 2004;9:24–29.
61. Yoon JA, Koo BI, Shin MJ, Shin YB, Ko HY, Shin YI. Effect of constraint-induced movement therapy and mirror therapy for patients with subacute stroke. *Ann Rehabil Med.* 2014;38:458–466.
62. Glasgow Augmented Physiotherapy Study. Can augmented physiotherapy input enhance recovery of mobility after stroke? A randomized controlled trial. *Clin Rehabil.* 2004;18:529–537.
63. Lincoln NB, Parry RH, Vass CD. Randomized, controlled trial to evaluate increased intensity of physiotherapy treatment of arm function after stroke. *Stroke.* 1999;30:573–579.
64. Rodgers H, Mackintosh J, Price C, Wood R, McNamee P, Fearon T, et al. Does an early increased-intensity interdisciplinary upper limb therapy programme following acute stroke improve outcome? *Clin Rehabil.* 2003;17:579–589.
65. Lee M, Kilbreath SL, Singh MF, Zeman B, Lord SR, Raymond J, et al. Comparison of effect of aerobic cycle training and progressive resistance training on walking ability after stroke: a randomized sham exercise-controlled study. *J Am Geriatr Soc.* 2008;56:976–985.
66. Tian Y, Shi L, Jing L, Li L, Chen B, Zhao K. Effects of active and passive training apparatus combined with rehabilitation training on lower limb function of stroke patients during recovery period. *Neural Regen Res.* 2007;2:636–640.
67. An C-M, Won J-I. Effects of ankle joint mobilization with movement and weight-bearing exercise on knee strength, ankle range of motion, and gait velocity in patients with stroke: a pilot study. *J Phys Ther Sci.* 2016;28:689–694.
68. Barker RN, Brauer SG, Carson RG. Training of reaching in stroke survivors with severe and chronic upper limb paresis using a novel nonrobotic device: A randomized clinical trial. *Stroke.* 2008;39:1800–1807.
69. Lannin NA, Cusick A, Hills C. Upper limb motor training using a Saebo™ orthosis is feasible for increasing task-specific practice in hospital after stroke. *Aust Occup Ther J.* 2016;63:364–372.
70. Lee G. Effects of training using video games on the muscle strength, muscle tone, and activities of daily living of chronic stroke patients. *J Phys Ther Sci.* 2013;25:595–597.
71. Lee SH, Byun SD, Kim CH, Go JY, Nam HU, Huh JS, et al. Feasibility and effects of newly developed balance control trainer for mobility and balance in chronic stroke patients: a randomized controlled trial. *Ann Rehabil Med.* 2012;36:521–529.
72. Tankisheva E, Bogaerts A, Boonen S, Feys H, Verschueren S. Effects of intensive whole-body vibration training on muscle strength and balance in adults with chronic stroke: A randomized controlled pilot study. *Arch Phys Med Rehabil.* 2014;95:439–446.
73. Tihanyi J, Di Giminiani R, Tihanyi T, Gyulai G, Trzaskoma L, Horvath M. Low resonance frequency vibration affects strength of paretic and non-paretic leg differently in patients with stroke. *Acta Physiol Hung.* 2010;97:172–182.
74. Kim JH, Lee BH. Mirror therapy combined with biofeedback functional electrical stimulation for motor recovery of upper extremities after stroke: a pilot randomized controlled trial. *Occup Ther Int.* 2015;22:51–60.
75. Lee DG, Lee GC, Jeong JS. Mirror therapy with neuromuscular electrical stimulation for improving motor function of stroke survivors: a pilot randomized clinical study. *Technol Health Care.* 2016;24:503–511.
76. Chu K, Eng J, Dawson A, Harris J, Ozkaplan A, Gylfadottir S. Water-based exercise for cardiovascular fitness in people with chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil.* 2004;85:870–874.
77. Mehrholz J, Thomas S, Werner C, Kugler J, Pohl M, Elsner B. Electromechanical-assisted training for walking after stroke: a major update of the evidence. *Stroke.* 2017.
78. Cooke EV, Mares K, Clark A, Tallis RC, Pomeroy VM. The effects of increased dose of exercise-based therapies to enhance motor recovery after stroke: a systematic review and meta-analysis. *BMC Med.* 2010;8:60.

Websites

PEDro www.pedro.org.au