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Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke (Review)

Mehrholz J, Pohl M, Platz T, Kugler J, Elsner B

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[Intervention Review]

Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

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ABSTRACT

Background

Electromechanical and robot-assisted arm training devices are used in rehabilitation, and may help to improve arm function after stroke.

Objectives

To assess the effectiveness of electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength in people after stroke. We also assessed the acceptability and safety of the therapy.

Search methods

We searched the Cochrane Stroke Group's Trials Register (last searched February 2015), the Cochrane Central Register of Controlled Trials (CENTRAL) (the Cochrane Library 2015, Issue 3), MEDLINE (1950 to March 2015), EMBASE (1980 to March 2015), CINAHL (1982 to March 2015), AMED (1985 to March 2015), SPORTDiscus (1949 to March 2015), PEDro (searched April 2015), Compendex (1972 to March 2015), and Inspec (1969 to March 2015). We also handsearched relevant conference proceedings, searched trials and research registers, checked reference lists, and contacted trialists, experts, and researchers in our field, as well as manufacturers of commercial devices.

Selection criteria

Randomised controlled trials comparing electromechanical and robot-assisted arm training for recovery of arm function with other rehabilitation or placebo interventions, or no treatment, for people after stroke.

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Data collection and analysis

Two review authors independently selected trials for inclusion, assessed trial quality and risk of bias, and extracted data. We contacted trialists for additional information. We analysed the results as standardised mean differences (SMDs) for continuous variables and risk differences (RDs) for dichotomous variables.

Main results

We included 34 trials (involving 1160 participants) in this update of our review. Electromechanical and robot-assisted arm training improved activities of daily living scores (SMD 0.37, 95% confidence interval (CI) 0.11 to 0.64, P = 0.005, I^2 = 62%), arm function (SMD 0.35, 95% CI 0.18 to 0.51, P < 0.0001, I^2 = 36%), and arm muscle strength (SMD 0.36, 95% CI 0.01 to 0.70, P = 0.04, I^2 = 72%), but the quality of the evidence was low to very low. Electromechanical and robot-assisted arm training did not increase the risk of participant drop-out (RD 0.00, 95% CI -0.02 to 0.03, P = 0.84, I^2 = 0%) with moderate-quality evidence, and adverse events were rare.

Authors' conclusions

People who receive electromechanical and robot-assisted arm and hand training after stroke might improve their activities of daily living, arm and hand function, and arm and hand muscle strength. However, the results must be interpreted with caution because the quality of the evidence was low to very low, and there were variations between the trials in the intensity, duration, and amount of training; type of treatment; and participant characteristics.

PLAIN LANGUAGE SUMMARY

Electromechanical-assisted training for improving arm function and disability after stroke

Review question

To assess the effects of electromechanical and robot-assisted arm and hand training for improving arm function in people who have had a stroke.

Background

More than two-thirds of people who have had a stroke have difficulties with reduced arm function, which can restrict a person's ability to perform everyday activities, reduce productivity, limit social activities, and lead to economic burden. Electromechanical and robot-assisted arm training uses specialised machines to assist rehabilitation in supporting shoulder, elbow, or hand movements. However, the role of electromechanical and robot-assisted arm training for improving arm function after stroke is unclear.

Study characteristics

We identified 34 trials (involving 1160 participants) up to March 2015 and included them in our review. Nineteen different electromechanical devices were described in the trials, which compared electromechanical and robot-assisted arm training with a variety of other interventions. Participants were between 21 to 80 years of age, the duration of the trials ranged from two to 12 weeks, the size of the trials was between eight and 127 participants, and the primary outcome differed between the included trials. Most of the trials were done in rehabilitation facilities in the USA.

Key results

Electromechanical and robot-assisted arm and hand training improved activities of daily living in people after stroke and function and muscle strength of the affected arm. As adverse events such as injuries and pain were seldom described, these devices can be applied as a rehabilitation tool, but we still do not know when or how often they should be used.

Quality of the evidence

The quality of the evidence was low to very low.

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SUMMARY OF FINDINGS FOR THE MAIN COMPARISON [Explanation]

Electromechanical and robotic-assisted training versus all other interventions for improving activities of daily living, arm function, and arm muscle strength after stroke

Patient or population: people after stroke
Settings: rehabilitation facilities
Intervention: electromechanical and robotic-assisted training versus all other interventions

Outcomes	Illustrative comparative risks* (95% CI)		No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Control	Electromechanical and robotic-assisted training versus all other interventions			
Activities of daily living at the end of intervention phase - all studies Measures of activities. Scale from: 0 to inf	The mean activities of daily living at the end of intervention phase - all studies in the control groups was **NA**	The mean activities of daily living at the end of intervention phase - all studies in the intervention groups was **0.37 SDs higher** (0.11 to 0.64 higher)	717 (18 studies)	⊕○○○ **very low**[1,2,3]	SMD 0.37 (0.11 to 0.64)
Activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - particpants treated in the acute and subacute phase of their stroke (within 3 months) Measures of activities. Scale from: 0 to inf	The mean activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - participants treated in the acute and subacute phase of their stroke (within 3 months) in the control groups was **NA**	The mean activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - participants treated in the acute and subacute phase of their stroke (within 3 month) in the intervention groups was **0.53 SDs higher** (0.09 to 0.96 higher)	320 (8 studies)	⊕⊕○○ **low**[2,3]	SMD 0.53 (0.09 to 0.96)

Activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - participants treated in the chronic phase (more than 3 months) Measures of activities. Scale from: 0 to inf	The mean activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - participants treated in the chronic phase (more than 3 months) in the control groups was **NA**	The mean activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase - participants treated in the chronic phase (more than 3 months) in the intervention groups was **0.66 SDs higher** (-0.17 lower to 1.49 higher)	397 (10 studies)	⊕⊕◯◯ **low**[1,2,3]	SMD 0.66 (-0.08 to 1.41)
Arm function at the end of intervention phase Measures of arm function. Scale from: 0 to inf	The mean arm function at the end of intervention phase in the control groups was **NA**	The mean arm function at the end of intervention phase in the intervention groups was **0.35 SDs higher** (0.18 to 0.51 higher)	1078 (31 studies)	⊕⊕◯◯ **low**[1,3]	SMD 0.35 (0.18 to 0.51)
Arm muscle strength at the end of intervention phase Measures of arm muscle strength. Scale from: 0 to inf	The mean arm muscle strength at the end of intervention phase in the control groups was **NA**	The mean arm muscle strength at the end of intervention phase in the intervention groups was **0.36 SDs higher** (0.01 to 0.7 higher)	568 (16 studies)	⊕◯◯◯ **very low**[1,2,3]	SMD 0.36 (0.01 to 0.7)
Acceptability: dropouts during intervention period Rate of dropouts and adverse events	**Study population**		1160 (34 studies)	⊕⊕⊕◯ **moderate**[1]	Risks were calculated from pooled risk differences
	42 per 1000	**45 per 1000** (22 to 72)			

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: Confidence interval; **NA:** Not applicable; **RR:** Risk ratio; **SD:** Standard deviation; **SMD:** Standardised mean difference

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GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[1] Downgraded due to several ratings with 'high risk of bias'.
[2] Downgraded due to considerable differences in effect sizes and unexplained heterogeneity.
[3] Upper or lower confidence limit crosses an effect size of 0.5 in either direction.

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BACKGROUND

A stroke is a sudden, non-convulsive loss of neurological function due to an ischaemic or haemorrhagic intracranial vascular event (WHO 2006). In general, strokes are classified by anatomic location in the brain, vascular distribution, aetiology, age of the affected individual, and haemorrhagic versus non-haemorrhagic nature (Adams 1993). The prevalence of stroke depends on age and gender, and is estimated to be 1% of the population (Feigin 2009; Vos 2015). Stroke, taken together with ischaemic heart disease, is one of the largest sources of disease burden; in low- and middle-income countries of Europe and Central Asia, these conditions account for more than a quarter of the total disease burden (Vos 2015).

Stroke is a major cause of chronic impaired arm function and may affect many activities of daily living. At hospital admission after stroke, more than two-thirds of people have arm paresis, resulting in reduced upper extremity function (Jørgensen 1999; Nakayama 1994), and six months after stroke the affected arm of approximately half of all people remains without function (Kwakkel 2003). Therefore, to reduce this burden, many people receive multidisciplinary rehabilitation soon after stroke. However, despite intensive rehabilitation efforts, only approximately 5% to 20% of people reach complete functional recovery (Nakayama 1994); in other words, four out of five people leave rehabilitation with restricted arm function. Thus, there still exists an urgent need for new inpatient and outpatient rehabilitation and training strategies that match the specific needs of stroke survivors and their relatives (Barker 2005).

In recent years, new electromechanical-assisted training strategies to improve arm function and activities of daily living have been developed for people after stroke. Examples of electromechanical and robot-assisted arm training devices found in this review are:

- Mirror Image Motion Enabler, MIME (Burgar 2000);
- InMotion robot (Massachusetts Institute of Technology, MIT-Manus) (Krebs 1998);
- Assisted Rehabilitation and Measurement (ARM) Guide (Reinkensmeyer 2000b);
- Robotic Rehabilitation System for upper limb motion therapy for the disabled, REHAROB (Fazekas 2007);
- Neuro-Rehabilitation-Robot, NeReBot (Fazekas 2007);
- Bi-Manu-Track (Hesse 2003);
- Robot-mediated therapy system, GENTLE/s (Coote 2003);
- Arm robot, ARMin (Riener 2005); and
- Amadeo (Hwang 2012).

Most of these devices provide passive movement of the person's arm. Other devices assist arm movements or provide resistance during training. Some devices may assist active movements of an isolated joint, like in continuous passive motion (Hesse 2003), while other devices are able to move multiple segments to perform reaching-like movements (Burgar 2000). The progression of therapy with electromechanical devices is possible by, for example, varying the force, decreasing assistance, increasing resistance, and expanding the movement amplitude. Moreover, some devices, such as the Bi-Manu-Track and the MIME, may be used to provide bimanual exercise: the device simultaneously moves (mirrors) the affected limb passively, steered by the non-paretic limb. Broadly considered, most robotic systems incorporate more than one modality into a single device.

Early studies and previous reviews suggested that an advantage of electromechanical and robotic devices, when compared with conventional therapies, may be an increase in repetitions during arm training due to an increase of motivation to train and also the opportunity for independent exercise (Kwakkel 2008; Prange 2006). Therefore, electromechanical-assistive training devices allow a therapy paradigm that is intensive, frequent and repetitive, and accords to principles of motor learning.

However, contrary to the remarkable number of publications about electromechanical technologies, scientific evidence for the benefits of these technologies, which could justify costs and effort, is still lacking. We summarised the evidence in our first Cochrane review about this topic in 2008 and in our last update in 2012 (Mehrholz 2008; Mehrholz 2012), but many new studies have emerged in recent years. Therefore there is a need for an updated and systematic evaluation of the available literature to assess the effectiveness and acceptability of these electromechanical-assisted training devices.

OBJECTIVES

To assess the effectiveness of electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength in people after stroke. We also assessed the acceptability and safety of the therapy.

METHODS

Criteria for considering studies for this review

Types of studies

We included randomised controlled trials (RCTs) and randomised controlled cross-over trials (we only analysed the first study period as a parallel-group trial).

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Types of participants

We included studies with participants of either gender over 18 years of age after stroke (using the World Health Organization (WHO) definition of stroke, or a clinical definition of stroke when the WHO definition was not specifically stated) (WHO 2006), regardless of the duration of illness or level of initial impairment. If we found RCTs with mixed populations (such as traumatic brain injury and stroke), we included only those RCTs with more than 50% of participants with stroke in our analysis.

Although we initially included all studies regardless of the duration of illness in our analysis, we later compared participants in the acute and subacute phase of their stroke (within three months) with participants in the chronic phase (more than three months) in a subgroup analysis.

Types of interventions

We compared electromechanical and robot-assisted arm training for recovery of arm function (such as robot-aided technologies or any other newly developed electromechanical device) with any other intervention for:

- improving activities of daily living (main analysis); and
- improving impairments (secondary analysis).

An example of an eligible robot-assisted intervention is the Mirror Image Motion Enabler, MIME (Burgar 2000). An example of an electromechanical-assisted intervention is the Bi-Manu-Track (Hesse 2003). Other interventions could include other devices, other rehabilitation or placebo interventions, or no treatment.

Types of outcome measures

Primary outcomes

The primary outcome was activities of daily living. We preferred the Barthel Index, Wade 1987, and the Functional Independence Measure, Hamilton 1994, (scales were regarded as continuous scaled, higher scores indicate a good outcome) as primary outcome measures, if they were available. However, we accepted other scales that measured activities of daily living.

Secondary outcomes

The secondary outcomes were impairments, such as motor function and muscle strength. We measured arm and hand motor function with the Fugl-Meyer score (regarded as continuous scaled, higher scores indicate a good outcome; Platz 2005) and measured arm and hand muscle strength with the Motricity Index Score (scales were regarded as continuous scaled, higher scores indicate a good outcome; Collin 1990; Demeurisse 1980). However, if these scales were not available we accepted other scales that measured arm and hand function and arm and hand muscle strength (in the following we will use the term 'arm function' instead of 'arm and hand function' and also 'arm muscle strength' instead of 'arm and hand muscle strength').

To measure the acceptance of electromechanical and robot-assisted arm training we used withdrawal or dropouts from the study due to any reason (including deaths) during the study period. We investigated the safety of electromechanical and robot-assisted arm training with the incidence of adverse outcomes, such as cardiovascular events, injuries and pain, and any other reported adverse events.

Depending on the aforementioned categories and the availability of variables used in the included trials, all review authors discussed and reached consensus on which outcome measures should be included in the analysis.

Search methods for identification of studies

See the 'Specialized register' section in the Cochrane Stroke Group module. We did not restrict our searches by language, publication status, or date, and we arranged for the translation of articles where necessary.

Electronic searches

We searched the Cochrane Stroke Group Trials Register (last searched in February 2015) and the following bibliographic databases:

- The Cochrane Central Register of Controlled Trials (CENTRAL) (the Cochrane Library 2015, Issue 3) (Appendix 1);
- MEDLINE (Ovid) (1950 to March 2015) (Appendix 2);
- EMBASE (Ovid) (1980 to March 2015) (Appendix 3);
- CINAHL (Ebsco) (1982 to March 2015) (Appendix 4);
- AMED (Allied and Complementary Medicine) (Ovid) (1985 to March 2015) (Appendix 5);
- SPORTDiscus (Ebsco) (1949 to March 2015) (Appendix 6);
- Physiotherapy Evidence Database (PEDro, http://www.pedro.org.au/) (searched April 2015);
- Compendex (1972 to March 2015) and Inspec (1969 to March 2015) (Engineering Village) (Appendix 7).

We developed the search strategy for MEDLINE with the help of the Cochrane Stroke Group Trials Search Co-ordinator and modified it for the other databases.

Searching other resources

In an effort to identify further published, unpublished, and ongoing trials not available in the major databases, we:

1. handsearched the following relevant conference proceedings:

i) World Congress for NeuroRehabilitation (WCNR, 1998, 2002, 2006, 2010, and 2014);

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ii) International Society of Physical and Rehabilitation Medicine World Congress (ISPRM 2001, 2003, 2005, 2007, 2009, and 2011);

iii) World Confederation for Physical Therapy (2003, 2007, 2011, and 2015);

iv) International Congress on Neurorehabilitation and Neural Repair (2015);

v) Deutsche Gesellschaft für Neurotraumatologie und Klinische Neurorehabilitation (2001 to 2015);

vi) Deutsche Gesellschaft für Neurologie (2000 to 2014);

vii) Deutsche Gesellschaft für Neurorehabilitation (1999 to 2014);

2. screened reference lists of all relevant articles;

3. identified and searched the following ongoing trials and research registers:

i) ISRCTN Registry (http://www.isrctn.com/) (searched June 2015);

ii) ClinicalTrials.gov (http://clinicaltrials.gov/) (searched June 2015);

iii) Stroke Trials Registry (www.strokecenter.org/trials) (searched June 2015);

4. contacted trialists, experts, and researchers in our field of study; and

5. contacted the following manufacturers of commercial devices:

i) Hocoma (last contact March 2015); and

ii) Reha-Stim (last contact May 2015).

Data collection and analysis

Selection of studies

Two review authors (JM and BE) independently read the titles and abstracts (if available) of identified publications and eliminated obviously irrelevant studies. We obtained the full text for the remaining studies, and the same two review authors independently examined potentially relevant studies using our predetermined criteria for including studies. Based on types of studies, participants, aims of interventions, and outcome measures, the review authors independently ranked these studies as relevant, irrelevant, or possibly relevant. We excluded all trials ranked initially as irrelevant, but included all other trials at that stage for further assessment. We excluded all trials of specific treatment components (such as electrical stimulation) as standalone treatment, and continuous passive motion treatment and continuous passive stretching. All review authors resolved disagreements through discussion. If further information was needed to reach consensus, we contacted the study authors.

Data extraction and management

Two review authors (JM and MP) independently extracted trial and outcome data from the selected trials. We used checklists to independently record details of the studies. If any review author was involved in any of the selected studies, another member of our review team not involved in the study was asked to handle the study information.

We established the characteristics of unpublished trials through correspondence with the trial co-ordinator or principal investigator. We used checklists to independently record details of the:

- methods of generating randomisation schedule;
- method of concealment of allocation;
- blinding of assessors;
- use of an intention-to-treat analysis (all participants initially randomised were included in the analyses as allocated to groups);
- adverse events and dropouts for all reasons;
- important imbalance in prognostic factors;
- participants (country, number of participants, age, gender, type of stroke, time from stroke onset to entry to the study, inclusion and exclusion criteria);
- comparison (details of the intervention in treatment and control groups, details of co-intervention(s) in both groups, duration of treatment); and
- outcomes and time points of measures (number of participants in each group and outcome, regardless of compliance).

We checked all of the extracted data for agreement between review authors, with another review author (JK or BE) arbitrating any disagreements. We contacted study authors to request more information, clarification, or missing data if necessary.

Assessment of risk of bias in included studies

All review authors independently assessed the methodological quality of the included trials using the Cochrane 'Risk of bias' tool, as described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011).

We checked all methodological quality assessments for agreement between review authors, resolving any disagreements by discussion. Two review authors (MP and JM) were coauthors of one included trial (Hesse 2005); two other review authors (BE and JK) conducted the quality assessment for this trial.

Measures of treatment effect

The primary outcome variables of interest were treated as continuous data and entered as mean and standard deviations (SDs). We calculated a pooled estimate of the mean differences (MDs) with 95% confidence intervals (CIs). If studies used different scales for an outcome variable, or if we obtained only full data of all included studies regarding changes from baseline to study end, we entered data as mean changes and SDs of changes and used the standardised mean difference (SMD) with 95% CI instead of MDs. For all

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binary outcomes (such as the secondary outcome 'dropouts from all causes'), we calculated risk ratios (RRs) with 95% CIs. If studies reported no events, we calculated risk differences (RDs) with 95% CIs, instead of RRs.

Assessment of heterogeneity

We used the I^2 statistic to assess heterogeneity. We used a random-effects model, regardless of the level of heterogeneity.

Data synthesis

We pooled the results of all eligible studies to present an overall estimate of the effect of electromechanical and robot-assisted arm training (meta-analysis). For all statistical analyses we used the latest version of the Cochrane Review Manager software, RevMan 5.3 (RevMan 2014). We calculated the overall effects using a random-effects model, regardless of the level of heterogeneity. To test the robustness of the results, we did a sensitivity analysis by leaving out studies that we assessed to be of lower or ambiguous methodological quality (with respect to randomisation procedure, allocation concealment, and blinding of assessors). Clinical diversity and heterogeneity did not contribute to the decision about when to pool trials, but we described clinical diversity, variability in participants, interventions, and outcomes studied in Table 1.

If studies had three or more intervention groups, for example two treatment groups and one control group, and the results of these intervention groups did not differ significantly, we combined the results of all intervention groups in one (collapsed) group and compared this with the results of the control group.

Subgroup analysis and investigation of heterogeneity

We conducted a formal subgroup analysis by splitting all participants into two subgroups: a subgroup of participants in the acute and subacute phase of their stroke (within three months) and a subgroup of participants treated in the chronic phase (more than three months after stroke). In this subgroup analysis, we did a formal comparison between the results of the primary outcome measure of participants treated in the acute and subacute phase of their stroke compared with the results of participants treated in the chronic phase (Deeks 2011).

We conducted another subgroup analysis by splitting all participants into two subgroups: a subgroup of participants who received mainly training for the distal arm and the hand (finger, hand, and radio-ulnar joints) and a subgroup of participants who received training mainly of the proximal arm (shoulder and elbow joints) and a subgroup of participants treated in the chronic phase (more than three months after stroke). In this subgroup analysis, we did a formal comparison between the results of the subgroups for the primary outcome measure (activities of daily living) and the secondary outcome measure (arm function). To quantify heterogeneity we used the I^2 statistic implemented in RevMan 5.3 for all comparisons (RevMan 2014).

Sensitivity analysis

In accordance with the description in the *Cochrane Handbook for Systematic Reviews of Interentions*, we used the methodological features randomisation procedure, concealed allocation, and blinding of assessors to test the robustness of the main results in a sensitivity analysis (Higgins 2011).

RESULTS

Description of studies

See: Characteristics of included studies, Characteristics of excluded studies, Characteristics of ongoing studies, Table 1 and Table 2.

Results of the search

Our updated searches of the electronic bibliographic databases identified 5308 citations (Figure 1). One review author (BE) carried out additional searches of trials registers, commercial websites, conference proceedings, and reference lists, and from these and the search of the Cochrane Stroke Group's Trials Register, we identified three further studies for inclusion. Hence the number of records identified was 5311. After the elimination of duplicates, two review authors (BE and JM) assessed 4471 relevant abstracts and eliminated obviously irrelevant studies from the titles and abstracts alone. We obtained the full text of 49 possibly relevant papers. The same review authors (BE and JM) independently reviewed the full papers and selected 15 studies (30 full texts) that met our inclusion criteria. If necessary due to disagreements or uncertainties, we held consensus discussions involving additional review authors. We carefully considered and discussed a further 10 studies, but did not deem them eligible; we have detailed them in Characteristics of excluded studies.

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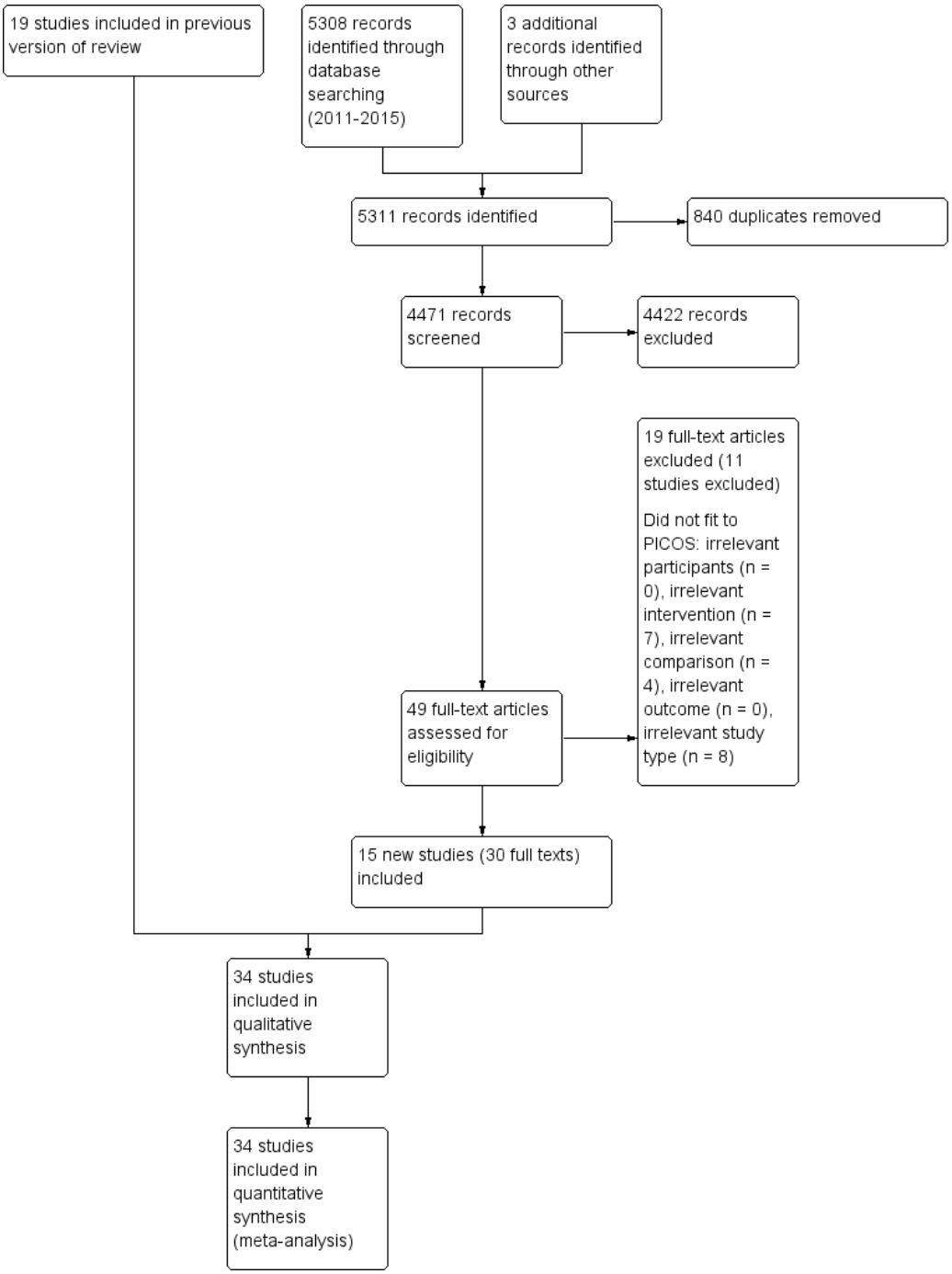
Figure 1. Study flow diagram. Please note that several studies have been published in multiple full-text articles. Hence the number of assessed full-text articles and the number of identified studies may differ.



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We thus identified 15 new studies (30 full texts), and together with 19 studies included in the original review, we have included a total of 34 studies in this update. Five studies are still awaiting classification; we have described these studies in detail in Characteristics of studies awaiting classification. In addition, we identified 24 ongoing studies, which we have listed in Characteristics of ongoing studies.

Included studies

Thirty-four trials, including a total of 1160 participants, met our inclusion criteria and have been included in the analysis (see Figure 1, Characteristics of included studies, Table 1, and Table 2).

Design

Two trials used a cross-over design with random allocation to the order of treatment sequences (Amirabdollahian 2007; Hollenstein 2011). For Amirabdollahian 2007, we could not obtain outcome data from the trialists of this study, therefore we could not pool the data for this trial together with the data from other studies. In the study of Hollenstein 2011, we used the data of the first period before cross-over. All other studies used a parallel-group design with true randomisation-to-group allocation.

Sample sizes

The sample sizes in the trials ranged from eight participants, in Mayr 2008, to 127 participants, in Lo 2010 (sample size median = 30 interquartile range = 25). We have provided a more detailed description of trial characteristics in Characteristics of included studies and in Table 1 and Table 2.

Setting

Most of the trials were done in rehabilitation facilities in the USA. We have provided a more detailed description of trial characteristics in Characteristics of included studies.

Participants

The mean age of participants in the included studies ranged from 21 years, in McCabe 2015, to 80 years, in Rabadi 2008. We have provided a detailed description of participant characteristics in Table 1. There were significantly more males than females (66% males with 95% CI 63 to 69), and slightly more participants with left-sided hemiparesis (53% left-sided with 95% CI 49 to 57) included in the studies.

Twenty-three studies provided information about baseline stroke severity (for example Functional Independence Measure, Barthel) or about the deficit of arm motor function (Fugl-Meyer) (Table 1; Table 2).

For inclusion and exclusion criteria of every included study, see Characteristics of included studies.

Interventions

The duration of the studies (time frame where experimental interventions were applied) was heterogeneous, ranging from two weeks, in Hollenstein 2011, and three weeks, in Amirabdollahian 2007; Burgar 2011, to 12 weeks (Brokaw 2014; Daly 2005; Lo 2010). Most studies (eight out of 34) used a two-, three-, four-, or six-week study period (Table 2). The studies described and used 19 different electromechanical devices (see Table 2 for an overview); the devices used most often were the Bi-Manu-Track (Hesse 2005; Hesse 2014; Hsieh 2011; Hsieh 2014; Liao 2011; Wu 2012), the InMotion (Conroy 2011; Daly 2005; McCabe 2015; Volpe 2008), and the MIT-Manus (Lo 2010; Rabadi 2008; Sale 2014; Volpe 2000).

Comparisons

The included trials compared electromechanical and robot-assisted arm training with a variety of other interventions. We only did a formal meta-analysis of studies that measured the same treatment effect. Thus we combined electromechanical and robot-assisted arm training versus placebo (or no additional therapy) (two studies) with electromechanical and robot-assisted arm training combined with physiotherapy versus physiotherapy alone (32 studies), as both estimate the effect of electromechanical and robot-assisted arm training compared with a different treatment. However, we did not combine electromechanical and robot-assisted arm training versus physiotherapy (or no treatment) with electromechanical and robot-assisted arm training A versus electromechanical and robot-assisted arm training B (Lum 2002), as these all measure entirely different treatment effects.

One study had four groups: three treatment (robot) groups and one control group (Lum 2006). Since the results of these experimental groups did not differ significantly, we combined the results of all experimental groups into one (collapsed, robot) group and compared this with the results of the control group. Nine other studies used three arms: two treatment (robot) groups and one control group or two control and one treatment group (Ang 2014; Burgar 2011; Conroy 2011; Hsieh 2011; Hsieh 2014; Lo 2010; McCabe 2015; Rabadi 2008; Wu 2012). As we were interested in the effects of robot therapy versus any other control intervention, we either combined the results of both experimental groups in one (collapsed) group and compared this with the results of the control group, or we combined the results of both control groups

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in one (collapsed) group and compared this with the results of the one treatment group.

For most trials the frequency of treatment was five times a week (see Table 2 for a detailed description of time and frequency for each single study).

The intensity of treatment (in terms of duration of experimental therapy provided) ranged from 20 minutes, in Masiero 2011, or 30 minutes, in Fazekas 2007, Hesse 2005, and Masiero 2007, to 90 minutes each working day, in Daly 2005 and Hsieh 2011, or even 90 to 105 minutes each day (Hsieh 2014). For some studies, the intensity of the experimental treatment is still unclear (Amirabdollahian 2007; Kahn 2006; Lo 2010). We have provided a detailed description for each single study in Table 2 and a more detailed description of the individual therapy in studies in Characteristics of included studies.

Outcomes

The primary outcomes of the included studies varied. See Characteristics of included studies for a detailed description of the primary outcomes for each trial.

In our pooled analysis for the primary outcome, activities of daily living, we used the Barthel Index score or the modified Barthel Index (Hesse 2005; Hesse 2014; Yoo 2013), the Functional Independence Measure (Burgar 2011; Fazekas 2007; Lum 2006; Masiero 2007; Volpe 2000), the ABILHAND (Hsieh 2011; Liao 2011), the Stroke Impact Scale 3.0 (motor function and social participation section) (Kutner 2010; Lo 2010; Wu 2012), the Stroke Impact Scale 2.0 (higher scores indicate a good outcome) (Volpe 2008), and the Frenchay Arm Test (Masiero 2011).

For our secondary outcome arm function, we used the Fugl-Meyer score or the Chedoke-McMaster Stroke Assessment (Abdullah 2011; Mayr 2008), and in one study the Wolf Motor Function Test for our pooled analysis and conducted a separate analysis for impaired arm function (Yoo 2013). For our secondary outcome arm strength, we accepted measures such as the Motricity Index score or Medical Research Council score (higher scores indicate a good outcome) or grip force.

Eighteen included studies assessed outcomes at the end of the study, but the follow-up assessment varied between three months and nine months after study end (see Table 2 for a detailed description of time points of assessment for each single study) (Lo 2010). As reporting data of follow-up measures were heterogeneous and limited mostly to our primary outcome, we did not conduct separate analyses for immediate data after study end and sustained data from follow-up after study end. We therefore undertook just one analysis (immediately after the end of the intervention).

Excluded studies

We excluded 22 trials (see Excluded studies). We have excluded 11 trials from the previous version of the review and another 11 trials (19 full texts) from the current update. See Characteristics of excluded studies for details of reasons for excluding these trials. If there was any doubt about whether or not a study should be excluded, we retrieved the full text of the article. Where the two review authors (BE and JM) disagreed, a third review author (JK) decided on inclusion or exclusion of a study.

Ongoing studies

We identified 24 ongoing studies (see Ongoing studies), which we have described in Characteristics of ongoing studies. Nine of these studies were listed as ongoing studies in the previous version of the review. After we retrieved further information, four of these ongoing studies became included studies; one became a study awaiting classification; and three remained ongoing studies.

Risk of bias in included studies

We have provided all details about the methodological quality of each included study in Characteristics of included studies.

We wrote to the trialists of all the included studies requesting clarification of some design features or missing information in order to complete the quality ratings. The correspondence was via email or letter, and we wrote reminders every month if we did not receive an answer. Most trialists provided some or all of the requested data, but for four trials we did not receive all requested data.

We used the 'Risk of bias' tool to assess the methodological quality of all the included trials for random allocation, concealment of allocation, and blinding of assessors. (See Characteristics of included studies and Figure 2).

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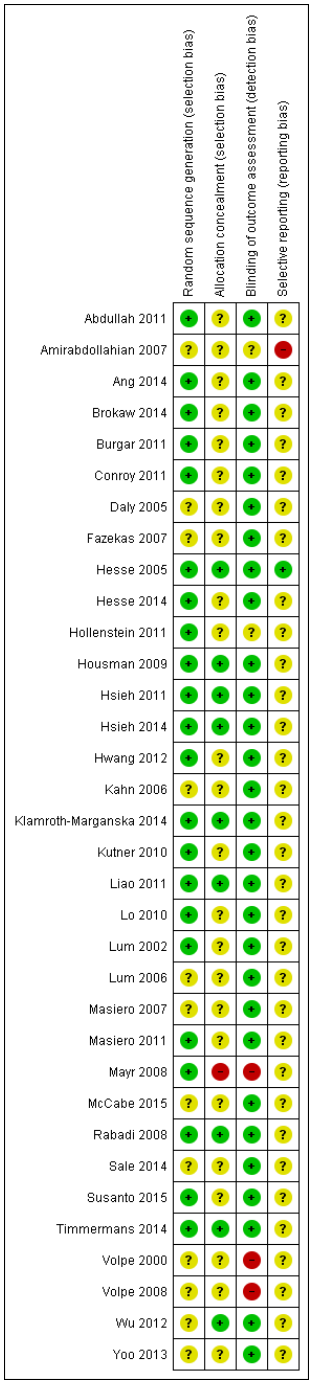
Figure 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



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Effects of interventions

See: **Summary of findings for the main comparison** Electromechanical and robotic-assisted training versus all other interventions for improving activities of daily living, arm function, and arm muscle strength after stroke

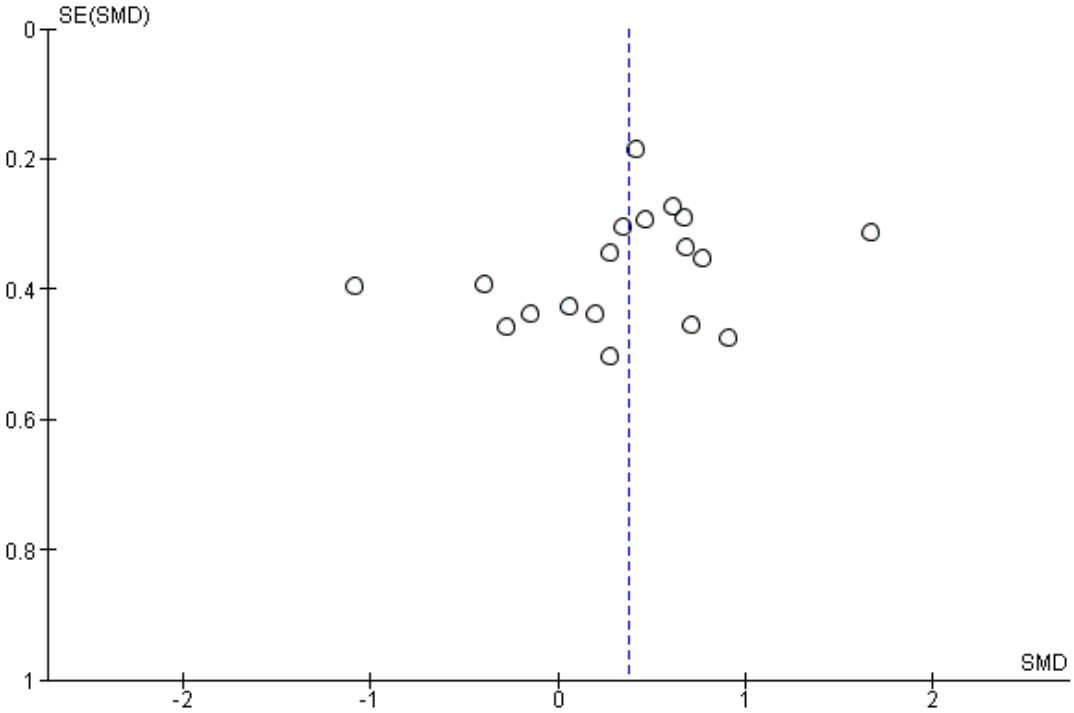
Electromechanical and robot-assisted arm training versus any other intervention

See Summary of findings for the main comparison.

Activities of daily living at the end of the intervention phase

Eighteen studies with a total of 717 participants compared electromechanical and robot-assisted arm training versus any other intervention and measured activities of daily living. Electromechanical and robot-assisted arm training improved activities of daily living scores. The pooled SMD (random-effects model) for activities of daily living was 0.37 (95% CI 0.11 to 0.64, P = 0.005, level of heterogeneity I^2 = 62%; Analysis 1.1). We did not find graphical evidence in a funnel plot for publication bias (Figure 3).

Figure 3. Funnel plot of comparison: 1 Electromechanical and robotic assisted training versus all other intervention, outcome: 1.1 Activities of daily living at the end of intervention phase.



Activities of daily living at the end of the intervention phase: subgroup analysis comparing the acute and chronic phase

We included eight trials with a total of 320 participants in the acute and subacute phase after stroke. Electromechanical and robot-assisted arm training improved activities of daily living scores in the acute phase after stroke; the SMD (random-effects model) was 0.53 (95% CI 0.09 to 0.96, P = 0.02, level of heterogeneity I^2 = 69%). We included 10 trials with a total of 397 participants in the chronic phase (more than three months after stroke). Electromechanical and robot-assisted arm training did not improve activities of daily living scores in the chronic phase after stroke; the SMD (random-effects model) was 0.66 (95% CI -0.17 to 1.49, P = 0.12, level of heterogeneity I^2 = 92%; Analysis 1.2). The test

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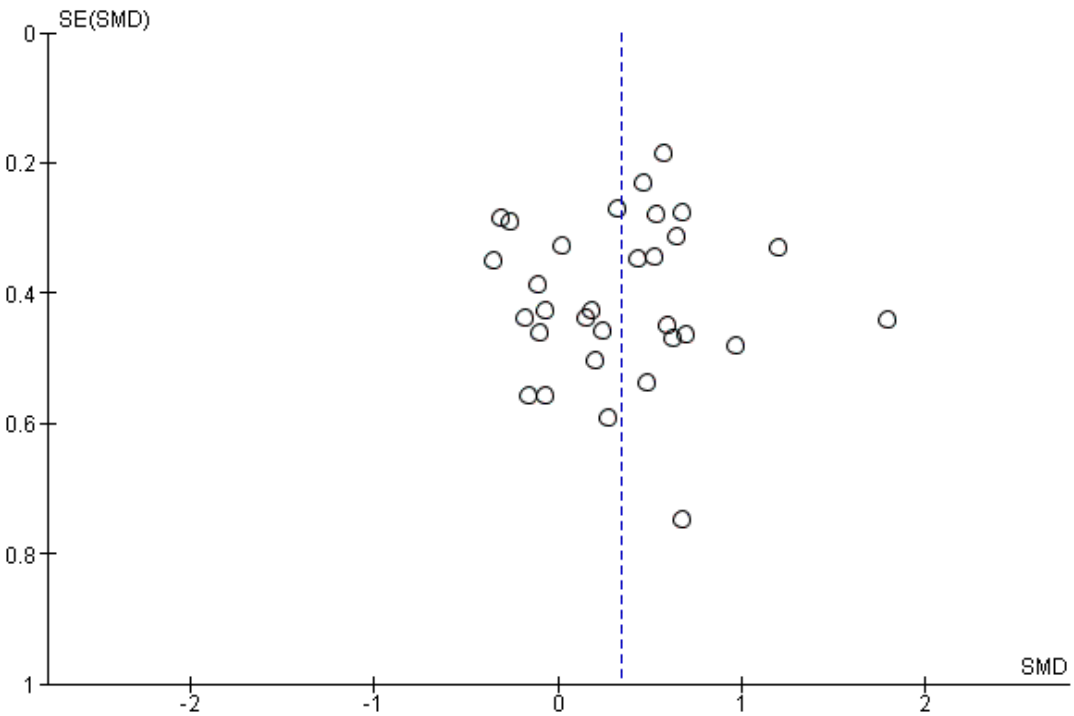
for subgroup differences (between acute and subacute phase after stroke versus chronic phase after stroke) revealed no significant difference (P = 0.78, level of heterogeneity I^2 = 0%).

Arm function at the end of the intervention phase

Thirty-one studies with a total of 1078 participants compared electromechanical and robot-assisted arm training versus any other intervention and measured arm function. Electromechanical and robot-assisted arm training improved arm function of the impaired arm. As we received the change data from baseline to study end for all trials that measured arm function, we used SMDs for this comparison. The pooled SMD (random-effects model) for arm function was 0.35 (95% CI 0.18 to 0.51, P < 0.0001, level of heterogeneity I^2 = 36%; Analysis 1.3). We did not find graphical evidence in a funnel plot for publication bias (Figure 4).

Figure 4. Funnel plot of comparison: 1 Electromechanical and robotic assisted training versus all other intervention, outcome: 1.3 Arm function at the end of intervention phase.



Arm muscle strength at the end of the intervention phase

Sixteen studies with a total of 568 participants compared electromechanical and robot-assisted arm training versus another intervention and measured strength of arm. Electromechanical and robot-assisted arm training improved arm muscle strength. The SMD (random-effects model) for muscle strength was 0.36 (95% CI 0.01 to 0.70, P = 0.04, level of heterogeneity I^2 = 72%; Analysis 1.4). We did not find graphical evidence in a funnel plot for publication bias (Figure 5).

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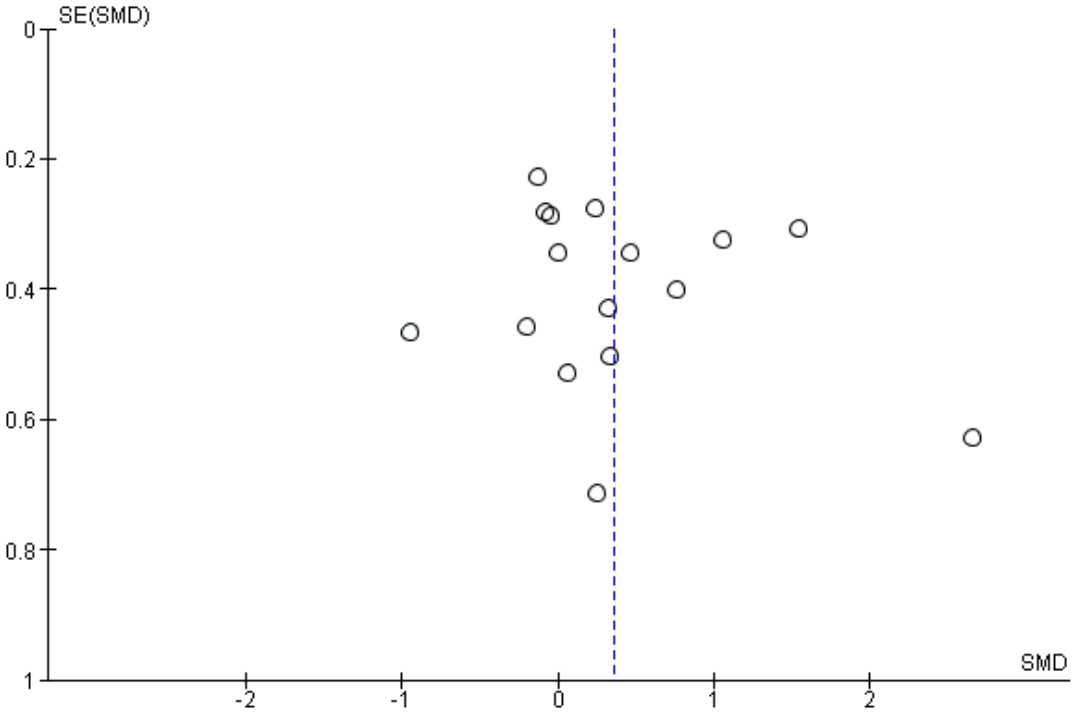
Figure 5. Funnel plot of comparison: 1 Electromechanical and robotic assisted training versus all other intervention, outcome: 1.4 Arm muscle strength at the end of intervention phase.



Acceptability: dropouts during the intervention period

We pooled all reported rates of participants who dropped out from all causes during the trial period. The use of electromechanical and robot-assisted arm training in people after stroke did not increase the risk of participants dropping out. The RD (random-effects model) for dropouts was 0.00 (95% CI -0.02 to 0.03, P = 0.84, level of heterogeneity I^2 = 0%; Analysis 1.5).

The drop-out rate for all reasons at the end of the treatment phase was relatively low (all included studies achieved a drop-out rate of less than 16%), but for one study this is still unclear (Amirabdollahian 2007). Twenty-one out of 34 included studies (62%) reported no dropouts at scheduled study end (Amirabdollahian 2007; Ang 2014; Burgar 2011; Fazekas 2007; Hollenstein 2011; Hsieh 2011; Hsieh 2014; Hwang 2012; Kahn 2006; Liao 2011; Lum 2006; Masiero 2011; Mayr 2008; McCabe 2015; Rabadi 2008; Sale 2014; Timmermans 2014; Volpe 2000; Volpe 2008; Wu 2012; Yoo 2013). The highest drop-out rate in the treatment group was 12% (five dropouts out of 41 participants; Conroy 2011). The highest drop-out rate in the control group was 14% (11 dropouts out of 78 participants; Lo 2010) and 16.7% (three dropouts out of 18 participants; Masiero 2011). Only one study in the early acute phase after stroke reported deaths during the treatment period (Masiero 2007). However, as explained by the authors via email correspondence, both deaths occurred in the control group. Other reasons for dropouts were:

- personal reasons (treatment group) (Daly 2005);
- personal reasons (control group) (Housman 2009);
- withdrew (treatment group) (Abdullah 2011; Klamroth-Marganska 2014);
- withdrew (control group) (Klamroth-Marganska 2014);
- injured arm in daily life (treatment group) (Housman 2009);
- depression (control group) (Housman 2009);
- refusing therapy (treatment group) (Hesse 2005Klamroth-Marganska 2014);
- medical complications (treatment group) (Conroy 2011; Lum 2002);
- medical reasons (control group) (Klamroth-Marganska 2014);
- exclusion (control group) (Lum 2002);
- lost to follow-up (control group) (Susanto 2015);
- unable to travel (Lo 2010) or transportation difficulties (treatment group) (Kutner 2010);

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- limited data (Conroy 2011; Hsieh 2014);
- moved (Conroy 2011; Housman 2009);
- did not met inclusion criteria after study commencement (Brokaw 2014).

Safety: adverse events during the intervention period

We did not carry out a pooled analysis because the reported rates of adverse events during the intervention period were rare and not related to the therapy (as described by the study authors). The reported adverse events were as described above: death in the control group, which was not related to the therapy (information as published by the study authors; Masiero 2007); and two participants experienced medical complications in the treatment group (information as published by the study authors; Lum 2002).

Sensitivity analysis: by trial methodology

Activities of daily living

To examine the robustness of the results, we specified variables in a sensitivity analysis that we believed could influence the size of effect observed (randomisation procedure, concealed allocation, and blinding of assessors) (Analysis 2.1). We did not investigate in this sensitivity analysis if selective reporting has an influence on the size of effect observed, because we did not find sufficient information to permit such a judgement.

All studies with description of randomisation procedure

We included 11 trials with a total of 481 participants with an adequate description of the randomisation procedure. Electromechanical and robot-assisted arm training improved activities of daily living. The SMD (random-effects model) for activities of daily living was 0.41 (95% CI 0.22 to 0.59, P < 0.0001, level of heterogeneity I^2 = 0%).

All studies with adequately concealed allocation

We included six trials with a total of 188 participants with adequate concealment of allocation. Electromechanical and robot-assisted arm training improved activities of daily living. The SMD (random-effects model) for activities of daily living was 0.34 (95% CI 0.01 to 0.67, P = 0.04, level of heterogeneity I^2 = 17%).

All studies with blinded assessors

Sixteen trials with a total of 640 participants had blinded assessors for the primary outcome. Electromechanical and robot-assisted arm training improved activities of daily living. The SMD (random-effects model) for activities of daily living was 0.31 (95% CI 0.07 to 0.54, P = 0.009, level of heterogeneity I^2 = 45%).

Arm function

To examine the robustness of the results, we specified variables in a sensitivity analysis that we believed could influence the size of effect observed (randomisation procedure, concealed allocation, and blinding of assessors) (Analysis 2.2).

All studies with description of randomisation procedure

We included 21 trials with a total of 737 participants with an adequate description of the randomisation procedure. Electromechanical and robot-assisted arm training improved impaired arm function. The SMD (random-effects model) for arm function was 0.33 (95% CI 0.15 to 0.52, P = 0.0005, level of heterogeneity I^2 = 28%).

All studies with adequately concealed allocation

We included nine trials with a total of 335 participants with adequate concealment of allocation. Electromechanical and robot-assisted arm training improved impaired arm function. The SMD (random-effects model) for arm function was 0.42 (95% CI 0.14 to 0.69, P = 0.003, level of heterogeneity I^2 = 30%).

All studies with blinded assessors

We included 28 trials with a total of 993 participants with blinded assessors. Electromechanical and robot-assisted arm training improved impaired arm function. The SMD (random-effects model) for arm function was 0.33 (95% CI 0.15 to 0.51, P = 0.0003, level of heterogeneity I^2 = 40%).

Subgroup analysis: by treatment approach

Activities of daily living at the end of intervention phase: subgroup analysis by treatment approach

The test for subgroup differences between a subgroup of participants who received mainly training for the distal arm and the hand (finger, hand, and radio-ulnar joints) and a subgroup of participants who received training mainly of the proximal arm (shoulder and elbow joints) revealed no significant difference (P = 0.47, level of heterogeneity I^2 = 0%; Analysis 3.1).

Arm function at the end of intervention phase: subgroup analysis by treatment approach

The test for subgroup differences between a subgroup of participants who received mainly training for the distal arm and the hand (finger, hand, and radio-ulnar joints) and a subgroup of participants who received training mainly of the proximal arm (shoulder and elbow joints) revealed no significant difference (P = 0.75, level of heterogeneity I^2 = 0%; Analysis 3.2).

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DISCUSSION

Summary of main results

We included 34 trials (involving 1160 participants) in this update of our systematic review of the effects of electromechanical and robot-assisted therapy for improving activities of daily living, arm function, and arm muscle strength. We found that the use of electromechanical-assistive devices in rehabilitation settings may improve activities of daily living, arm function, and arm strength, but the quality of evidence was rated as low to very low. Furthermore, adverse events and dropouts were uncommon and did not appear to be more frequent in those participants who received electromechanical and robot-assisted arm training, graded with moderate-quality evidence. This indicates that the use of electromechanical and robot-assisted arm training devices could be safe and acceptable to most participants included in the trials that this review analysed.

Although the quality of evidence was very limited, there seems to be at least a potential benefit of electromechanical and robot-assisted arm training.

When looking at certain groups of participants, we found significant improvements of activities of daily living in the subgroup of participants treated in the acute and subacute phase. We did not find such improvements for participants treated in the chronic phase. However, our statistical subgroup comparison does not indicate that people in the acute or subacute phase after stroke may improve more than people in the chronic phase with respect to activities of daily living. Participants who received mainly training for the distal arm and the hand (finger, hand, and radio-ulnar joints) and participants who received training mainly of the proximal arm (shoulder and elbow joints) did not differ significantly with regard to activities of daily living and arm function.

Electromechanical and robot-assisted therapy uses devices simply as 'vehicles' to apply an increased intensity in terms of many repetitions of arm training (Kwakkel 2008; Kwakkel 2015). It seems unlikely that motor therapy provided by robots will lead to better results than motor therapy provided by humans under the premise that intensity, amount, and frequency of therapy are exactly comparable. The potential advantage of electromechanical devices, when compared with conventional therapies, may be an increase in repetitions during arm training and an increase of motivation to train. Additionally, because people using electromechanical and robot-assistance therapy are able to practise without a therapist, this type of training has the potential to increase the number of repetitions of practise. However, in our analysis of the included studies in this review update, we were not able to compare different amounts of repetitions of arm training. The amount of repetitions and also the exact intensity, time, dose, amount, and frequency of applied therapies were not described in detail in most of the studies included here. However, almost all of the included studies (but not Yoo 2013) had an active control group, and most studies matched the time for therapy between in-treatment and control groups. One could therefore argue that robot-assisted arm therapy after stroke is more effective in improving activities of daily living, arm function, and arm strength than other interventions if the same time of practise is offered. Then again, as mentioned above, it could just be that more repetitions in the same time were applied by robotic-assisted arm training (higher dose). This appears to be an important issue that should be taken into account when discussing the effectiveness of electromechanical and robot-assisted therapy for improving activities of daily living, arm function, and arm muscle strength.

Overall completeness and applicability of evidence

The results of this review seem to be quite generalisable for settings in industrialised countries and especially for rehabilitation centres with available electromechanical and robot-assisted devices. However, the following factors produce uncertainty.

- Most of the studies included participants with first-ever stroke.
- The majority of participants suffered from ischaemic stroke.
- Nearly all of the participants were right-handed.
- The quality of evidence was rated as low to very low.
- The exclusion of certain patient groups, such as people with unstable cardiovascular conditions, cognitive and communication deficits, or with a limited range of motion in the arm joints at the start of the intervention (it is well known that limited range of motion is common after stroke).

Hence, the results may be of limited applicability for people with recurrent stroke, haemorrhagic stroke, and people who are left-handed. There is currently insufficient moderate- or high-quality evidence to make conclusions about the benefits of robot therapy for improving activities of daily living, arm function, and arm muscle strength. However, as we found no evidence of side effects or harm, further research into this type of therapy appears to be justified.

The relatively tight selection criteria that have been applied to many studies should be considered. For example, the relatively younger age of people who were studied should be recognised, and also many of the people studied had no limitations of passive range of motion or were free of shoulder pain. It is well known in clinical practice that people are older and that the prevalence of comorbidities, such as pain, spasticity, or limitations to range of motion, is expected to be higher than described in the studies included here.

Additionally, electromechanical and robot-assisted training could create additional costs of rehabilitation after stroke. The general applicability of robot therapy might therefore be limited simply due to lack of access of devices, for example in many low-income countries, and there also appears to be fewer opportunities for therapists and patients to access robots in outpatient than in in-

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patient settings. All these points taken together might limit the applicability of this type of therapy in day-to-day clinical routine.

Quality of the evidence

We found heterogeneity regarding trial design (parallel-group or cross-over design, two or three or more intervention groups), therapy variables (type of device, bilateral or unilateral assistance, proximal or distal assistance, dosage of therapy), and participant characteristics (age, time poststroke, and severity of arm paresis).
There were enough studies to perform our planned sensitivity analysis examining the effects of methodological quality on the effectiveness of the intervention. We found that the effects of electromechanical-assistive devices for improving activities of daily living and for improving arm function were quite stable and not affected by methodological quality (Analysis 2.1; Analysis 2.2).

Potential biases in the review process

The methodological rigour of Cochrane Reviews minimises bias in the process of conducting systematic reviews. A risk of publication bias, however, is present in all systematic reviews.
We searched extensively for relevant literature in databases and handsearched conference abstracts. Additionally, we contacted authors, trialists, and experts in the field for other unpublished and ongoing trials. We were unable to find graphical evidence for publication bias using funnel plots. There was heterogeneity between the trials in terms of trial design (two groups, four groups, parallel-group or cross-over trial, duration of study and follow-up, and selection criteria for participants), characteristics of the therapy interventions (especially device used), and participant characteristics (length of time since stroke onset). There were also methodological differences in the mechanism of randomisation and allocation concealment methods used and blinding of primary outcomes.
After examination of the influence of methodological quality on the observed effect on activities of daily living and arm function, we did not find a change of benefit when we removed trials with unclear randomisation or allocation concealment procedures or unclear blinding.
While the methodological quality of the included trials was in general good to very good, although heterogeneous (Figure 2), trials investigating electromechanical and robot-assisted arm training are subject to potential methodological limitations. These limitations include inability to blind the therapist and participants, so-called contamination (provision of the intervention to the control group), and co-intervention (when the same therapist unintentionally provides additional care to either treatment or comparison group). All these potential methodological limitations introduce the possibility of performance bias. However, as discussed above, our sensitivity analyses by methodological quality did not support this.
Some of the statistical analyses used in the review are based on parametric statistics. However, one could argue that it might not be appropriate to treat some scores for activities of daily living (for example Barthel Index score ranging from 0 to 100) and arm function (for example Fugl-Meyer score ranging from 0 to 66) included in this review with this approach. Most of these scores were used in the included trials as continuous scales, and by others as ordinal scaled scores. However, it is unclear how this has led to an over- or underestimation of our described treatment effects.
As is always the case in systematic reviews, a so-called publication bias could have potentially affected our results. The visual inspection of funnel plots for our main outcomes did not show evidence of publication bias (Figure 3; Figure 4; Figure 5), however this does not mean the complete absence of publication bias. Publication bias could therefore potentially be an issue, but it is unclear if this has led to an overestimation of our described treatment effects.

Agreements and disagreements with other studies or reviews

As far as we know, no other systematic reviews of RCTs about electromechanical and robot-assisted therapy for improving activities of daily living, arm function, and arm muscle strength have been conducted in the last three years. The most recent systematic review of this topic was done in 2008 (Kwakkel 2008). However, there are other systematic reviews within the context of our review.
A systematic review about the evidence of physiotherapy also searched for the effect of robotic training of different segments of the arm (Veerbeek 2014). The authors found 22 studies including a total of 648 participants investigating robotic arm training. Veerbeek and colleagues found small-to-moderate effect sizes for bilateral elbow-wrist robotic training (four studies) compared with studies with robotic training for the shoulder, elbow, wrist, and hand. The study authors classified robotic devices on the basis of the joints they target: 1) shoulder-elbow robots, 2) elbow-wrist robots, and 3) shoulder-elbow-wrist-hand robots, but they did not compare effect sizes (Veerbeek 2014). In our review, compared to Veerbeek 2014, the corresponding effect sizes and the differences in effect sizes between the different treatment approaches were lower. However, we were able to identify 34 trials including a total of 1160 participants. We therefore believe that our review has used a more sensitive search and hence shows a more comprehensive picture of the evidence.
Another up-to-date review also included trials using robotic training in combination with other interventions for people with stroke (Laver 2015). However, the authors specifically investigated the efficacy of virtual reality compared with an alternative intervention or no intervention on upper limb function and activity.

AUTHORS' CONCLUSIONS

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Implications for practice

We found that people after stroke who receive electromechanical or robot-assisted arm training are more likely to show improvement in their activities of daily living, arm function, and muscle strength of the paretic arm, but we rated the quality of evidence as low to very low.

In practice, electromechanical or robot-assisted arm training could increase the intensity of arm therapy. Perhaps more repetitions in the same time of therapy can be achieved if electromechanical and robot-assisted therapy is given. Electromechanical devices could therefore be used as an adjunct to conventional therapies.

However, it is still not clear if the difference between electromechanical or robot-assisted arm training and other interventions is clinically meaningful for most people. Perhaps one main difference between electromechanical or robot-assisted arm training and other interventions could be an improvement in motivation due to the feedback of the device, or the novelty of a robotic device, or both. However, we can only speculate about this.

Implications for research

There is still a need for well-designed, large-scale, multicentre studies to evaluate benefits and harms of electromechanical-assisted arm training after stroke. Further research should count the amount of repetitions in time and address specific questions about the type, timing, frequency, and duration of electromechanical and robot-assisted arm training. Further research should also investigate whether or not there is any benefit over and above the amount of practice, for example if it would be useful or not if a robot prevents 'incorrect learning or movements'. Additionally, improved reporting of trial methods and the use of published reporting guidelines for trials are essential.

It may be useful if future studies could use arm function-specific outcome measures and measures of repetitions during training to gain a better understanding of the explicit effects of this special form of training.

The heterogeneity of training dose could be seen as a limitation of this review. Future studies should therefore describe the total training time and dose and should also describe the personnel supervising participants during training.

Future studies should also investigate the most severely affected people and groups, who are not reflected so far in the existing trials.

We found a drop-out rate of less than 5%. Future studies could determine their sample size calculations based on this drop-out rate.

ACKNOWLEDGEMENTS

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* *Indicates the major publication for the study*

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CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Abdullah 2011

Methods	RCT
Participants	Country: Canada Sample size: 20 participants (9 in treatment group, 11 in control group) Inclusion criteria: first single, unilateral stroke; informed consent; age between 16 and 90 years; 2 to 8 weeks after stroke; motor arm impairment between stages 1 and 4 measured by CMSA Exclusion criteria: shoulder pain between 1 and 3 as measured by CMSA pain inventory scale; presence of other condition in the affected shoulder or elbow
Interventions	2 groups: 1. robotic-mediated therapy for 45 minutes, 3 times a week for 8 to 11 weeks 2. conventional arm therapy for 45 minutes, 3 times a week for 8 to 11 weeks
Outcomes	Outcome measures were assessed at baseline and at the end of intervention period Primary outcome measure: Chedoke Arm and Hand Activity Inventory (CAHAI-7) Secondary outcome measures: CMSA, client satisfaction using a 10-point Likert scale
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "A physiotherapist unrelated to the study randomized the participants into one of two groups using a random number table."
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "An occupational therapist blinded to patient allocation administered the CAHAI-7 and the CMSA at admission and discharge."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Amirabdollahian 2007

Methods	Cross-over RCT Method of randomisation: selecting a sealed envelope

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Amirabdollahian 2007 (*Continued*)

Participants	Countries: UK and Republic of Ireland Sample size: 31 participants (16 in treatment group, 15 in control group) Inclusion criteria: medically stable; first stroke; over 60 years of age; able to give informed consent; a score higher than 24 in the Short Orientation-Memory-Concentration Test Exclusion criteria: people with pacemakers
Interventions	2 groups: 1. group ABC: 3 weeks baseline (Phase A) then 3 weeks robot-mediated therapy (Phase B) then 3 weeks sling suspension (Phase C) 2. group ACB: 3 weeks baseline (Phase A) then 3 weeks sling suspension (Phase C) then 3 weeks robot-mediated therapy (Phase B)
Outcomes	Outcomes were recorded before and after baseline, after 3 weeks of therapy and again 3 weeks later (after each cross-over) Fugl-Meyer scale (0 to 66)
Notes	We planned to use Phase B data for group 1 (experimental) and Phase C data for group 2 (control) in the analysis

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Random sequence generation not exactly stated
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Blinding procedure not exactly stated
Selective reporting (reporting bias)	High risk	One or more outcomes are reported incompletely

Ang 2014

Methods	RCT
Participants	Country: Singapore Sample size: 21 participants (7 in treatment group brain computer interface with haptic knob device (BCI-HK); 8 in treatment group HK; 7 in control group) Inclusion criteria: first-ever stroke, confirmed by neuroimaging; age 21 to 80 years; time since stroke > 4 months; FMA-score 10 to 50 points (moderate to severe arm impairment) ; motor power grade 2 to 5 MRC shoulder abduction, grade 2 to 5 MRC elbow flexion, and grade 1 to 3 MRC in wrist dorsiflexion and finger flexion

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Ang 2014 (*Continued*)

	Exclusion criteria: medical instability; postural hypotension; terminal illness; severe aphasia; inattention; hemispatial neglect; severe visual impairment; epilepsy; severe depression; psychiatric disorders; recurrent stroke; skull defect; severe spasticity; fixed joint contractures; skin lesions
Interventions	3 groups: 1. robot-mediated therapy with the haptic knob robot and a brain computer interface for 60 minutes + therapist-assisted arm mobilisation for 30 minutes 2. robot-mediated therapy with the haptic knob robot alone for 60 minutes + therapist-assisted arm mobilisation for 30 minutes 3. standard arm therapy for 60 minutes + therapist-assisted arm mobilisation for 30 minutes
Outcomes	Outcomes were measured at baseline (week 0), at mid-intervention (week 3), at the end of intervention period (week 6), 6 weeks' follow-up (week 12), and 18 weeks' follow-up (week 24) Primary outcome: total FMA score
Notes	We combined the results of both HK groups in 1 (collapsed) group and compared this collapsed group with the results of the standard arm therapy group

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Quote: "The randomization block size was 3 and the allocation sequence was 1:1:1 generated using STATA software"
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "As subject blinding was not feasible, all outcome assessments for this study were performed by occupational therapist DXD who was blinded to allocation."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Brokaw 2014

Methods	Randomised cross-over trial
Participants	Country: USA Sample size: 12 participants Inclusion criteria: adult with ischaemic/haemorrhagic stroke at least 6 months before; persistent hemiparesis (score 1 to 2 on the National Institutes of Health Stroke Scale); voluntary wrist and finger extension; shoulder elevation Exclusion criteria: a score of less than 24 on the Mini-Mental State Examination; hemispatial neglect; severe sensory loss; excessive pain in any joint of the affected hemisphere or upper extremity injury

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Brokaw 2014 (*Continued*)

Interventions	2 groups: 1. group AB: 12 hours of robotic training within a month (A) and 12 hours of conventional therapy within a month (B), separated by a month of wash-out period 2. group BA: 12 hours of conventional therapy within a month (B) and 12 hours of robotic training within a month (A), separated by a month of wash-out period
Outcomes	FMA ARAT BBT
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Quote: "Randomization was done using a random number generator function in Matlab (MathWorks Inc, Natick, MA) that generated a list of numbers (1-10) randomly ordered"
Allocation concealment (selection bias)	Unclear risk	Quote: "The first 5 listed subject numbers received conventional therapy first and the second set received robot therapy first."
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "The OT performing recruitment and clinical evaluations was not aware of the randomization order, so was blinded to group assignment."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Burgar 2011

Methods	Prospective, single-blinded RCT Method of randomisation: stratified random number table
Participants	Country: USA Sample size: 54 participants (19 in the first treatment group, 17 in the second treatment group, and 18 in the control group) Inclusion criteria: primary diagnosis of stroke Exclusion criteria: people were excluded if they exhibited upper limb joint pain that restricted normal movement, had absent proprioception at the elbow or shoulder joints, or scored less than 22 on the Mini Mental State Examination. People with cardiovascular, orthopaedic, or neurological conditions that would have precluded exercise in short-duration, moderate-workload trials were also excluded

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Burgar 2011 (*Continued*)

Interventions	3 groups: 1. Robot-Lo: received up to 15 1-hour therapy sessions over a 3-week period with the MIME system 2. Robot-Hi: received up to 30 1-hour therapy sessions over a 3-week period with the MIME system 3. Control group: received up to 15 1-hour therapy sessions over a 3-week period
Outcomes	Outcomes were recorded at baseline, just after completion of training (after 3 weeks), and 6 months later (follow-up) • FMA (maximum 66 points) • FIM (upper limb, maximum 63 points) • Motor Power (maximum 70*) • Ashworth (MAS maximum 5 points) • WMFT Functional Ability Scale (maximum 5 and time in seconds) *The strength of 14 shoulder and elbow muscle groups was assessed by performing manual muscle testing of isolated joint actions and applying the MRC Motor Power grading scale (0 to 5) with a maximum possible score of 70 (scapular abduction/upward rotation, scapular elevation, adduction, adduction/depression, adduction/downward rotation, flexion, extension, abduction, horizontal adduction, horizontal abduction, external rotation, internal rotation, elbow flexion, elbow extension)
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Random-number table
Allocation concealment (selection bias)	Unclear risk	Unclear, not reported
Blinding of outcome assessment (detection bias) All outcomes	Low risk	A second therapist at each site, blinded to group assignment, performed a clinical assessment battery just before study initiation, just after completion of training, and again at the 6-month follow-up
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

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Conroy 2011

Methods	Prospective, single-blinded RCT Method of randomisation: choosing a sealed envelope
Participants	Country: USA Sample size: 62 participants (41 in the treatment group and 21 in the control group) Inclusion criteria: diagnosis of clinically defined, unilateral hemiparetic stroke with radiologic exclusion of other possible diagnoses; onset of stroke 6 months before randomisation for ischaemic stroke, 12 months for haemorrhagic stroke; manual muscle testing of grade 3 or lower for at least 1 muscle of the affected arm; > 18 years of age Exclusion criteria: serious complicating medical illness or stroke occurring within the previous 6 months (or both); contractures or orthopaedic problems limiting the range of joint movement in the potential study arm; visual loss limiting the ability to see the test patterns on the robot monitor; Botox injection of the affected arm 3 months before study onset or during the study
Interventions	3 groups: 1. group A: received robot-assisted planar reaching tasks with the InMotion 2.0 shoulder/arm over 6 weeks, 3 sessions per week for 1 hour 2. group B: received robot-assisted planar and vertical reaching tasks with the InMotion Linear Robot over the same time and frequency 3. group C: participants received intensive conventional arm exercise, which includes, for example, 40 minutes of repetitive arm motion using an arm ergometer, or task specific and functional reaching tasks (cones), in addition to 10 minutes of passive and guided stretching and 10 minutes of repositioning and rest between activities
Outcomes	Outcomes were recorded 3 times at baseline and after 6 weeks and 3 months later (follow-up) • FMA • WMFT • SIS
Notes	We combined the results of both the planar group and the planar and vertical group in 1 (collapsed) group and compared this collapsed group with the results of the control group

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Stratified randomisation by a computer scheme
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Assessment was performed by a single experienced evaluator blinded to group assignment

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Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Daly 2005

Methods	RCT Method of randomisation: drawing of tickets from envelopes by a person not involved in or aware of the allocation process
Participants	Country: USA Sample size: 13 participants (7 in treatment group, 6 in control group) Inclusion criteria: > 12 months after stroke, at least grade 1 muscle contraction in wrist extensors, and a score of > 10 on the Fugl-Meyer upper-limb score (0 to 66) Exclusion criteria: not stated
Interventions	2 groups: 1. control group trained arms with functional neuromuscular stimulation 5 hours a day, 5 days a week for 12 weeks 2. experimental group (robotics and motor learning) had the same amount and frequency of treatment, but during 1.5 hours of the daily treatment session participants used the InMotion robot for practising shoulder/elbow movements
Outcomes	Outcomes were recorded at baseline and after 4 weeks and 3 months later • AMAT • FMA (0 to 66) • the motor control measures of target accuracy, smoothness of movement
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	The investigators describe a stratified randomisation, but there is insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Author stated that a blinded examiner scored the primary outcome measure from a videotape
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

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Fazekas 2007

Methods	RCT Method of randomisation: by a person not involved in the study
Participants	Country: Hungary Sample size: 30 participants (15 in treatment group, 15 in control group; 22 after stroke and 8 after traumatic brain injury) Inclusion criteria: hemiparesis after stroke or traumatic brain injury Exclusion criteria: not stated
Interventions	2 arms: 1. control group received 30 minutes of Bobath therapy sessions on 20 consecutive workdays 2. treatment group received same therapy as control group, but an additional 30 minutes of robot therapy
Outcomes	Outcomes were recorded at baseline and after the 10th session and at the end of the training • MAS of shoulder adductors and elbow flexors • range of motion of shoulder and elbow • FMA (shoulder and elbow subsection; 0 to 36) • Rivermead Motor Assessment, arm score • FIM, self care subsection
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Author stated that assessment was performed by a blinded physiotherapist
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

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Hesse 2005

Methods	RCT Method of randomisation: participant drew a lot out of the sealed envelope presented by an independent person
Participants	Country: Germany Sample size: 44 participants (22 in treatment group, 22 in control group) Inclusion criteria: first-time supratentorial stroke; stroke interval before study onset 4 to 8 weeks; severe arm paresis with no or only a palpable volitional activity of the wrist and finger extensors (i.e. MRC 0 or 1); an initial Fugl-Meyer arm motor score (0 to 66) of less then 18; absent or moderate elbow, wrist, and finger spasticity; able to understand the meaning of the study; and written informed consent to participate in the approved study Exclusion criteria: apraxia (i.e. 1 fault in the tasks waving goodbye, saluting, and making a fist with the non-affected hand after verbal instruction and demonstration, and using an eraser, comb, and screwdriver with the objects handed to the person and verbally instructed); shoulder pain insensitive to standard therapy; hand swelling sufficient to prevent fist formation; painful arthritis of the wrist or finger joints; and forearm skin ulcers
Interventions	2 groups: 1. control group received in addition to their standard inpatient rehabilitation programme 5 times a week for 6 weeks (if possible EMG-initiated) functional electrical stimulation for wrist extension 2. experimental group received in addition to their standard inpatient rehabilitation programme for the same time and frequency as the control group therapy with the Bi-Manu-Track robotic arm trainer
Outcomes	Outcomes were recorded at baseline and after 6 weeks and 3 months later • FMA (0 to 66) • MRC score (0 to 5) muscle strength of the shoulder abductors, flexors, and extensors of the elbow, the wrist, the fingers, and the thumb. A total MRC sum score (0 to 45) included a proximal (MRC proximal subscore) (0 to 15) and a MRC distal subscore (0 to 30) • MAS (0 to 5) assessed the tone of the shoulder adductors, the flexors of the elbow, wrist, fingers, and the thumb. A total MAS score (0 to 25), a proximal MAS score (0 to 10), and a distal MAS score (0 to 15) were calculated
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Sequence generation was done by shuffling envelopes
Allocation concealment (selection bias)	Low risk	Using sealed envelopes

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Hesse 2005 (*Continued*)

Blinding of outcome assessment (detection bias) All outcomes	Low risk	A blinded therapist rated the videos of all participants
Selective reporting (reporting bias)	Low risk	Study protocol is available and all of the study's prespecified (primary and secondary) outcomes that are of interest in the review have been reported in the prespecified way

Hesse 2014

Methods	RCT
Participants	Country: Germany Sample size: 50 (25 in the experimental group and 25 in the control group) Inclusion criteria: first-time supratentorial stroke; time since stroke more than 8 weeks; aged between 18 and 90 years; being able to get out of bed and mobilised in a wheelchair or being able to walk; Fugl-Meyer score < 35 Exlusion criteria: severe arm spasticity; hemiparetic shoulder pain; swollen hand impeding closing the fist
Interventions	2 groups: 1. robot-assisted group therapy for 30 minutes + individual arm therapy for 30 minutes, each workday for 4 weeks 2. individual arm therapy for 2 x 30 minutes each workday for 4 weeks
Outcomes	Outcomes were recorded at baseline, after 4 weeks at the end of intervention period, and at 3 months' follow-up Primary outcome: FMA Secondary outcomes: ARAT, BBT, MRC (upper limb muscles), MAS (upper limbs), Barthel Index
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Quote: "The allocation of patients to the two groups (robot-assisted group therapy or individual arm therapy) was conducted online by using a web-based randomization tool (http://www.randomizer.at)."
Allocation concealment (selection bias)	Unclear risk	Quote: "The allocation of patients to the two groups (robot-assisted group therapy or individual arm therapy) was conducted online by using a web-based randomization tool (http://www.randomizer.at)."

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Hesse 2014 (*Continued*)

Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "The test was videographed with a mirror placed behind the patient to ensure later blind rating by an external experienced therapist."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Hollenstein 2011

Methods	Cross-over RCT A cross-over design was used (only the first period before cross-over was used for data analysis) Methods of randomisation: described as follows: "subjects were randomly assigned by lottery of the supervising therapist"
Participants	Country: Germany Sample size: 13 participants (7 in treatment group, 6 in control group) Inclusion criteria: first-time stroke, affected arm and first rehabilitation Exclusion criteria: none described
Interventions	2 groups: 1. group A: received robot-mediated therapy with the Armeo device 5 times a week for 30 minutes over 2 weeks (10 times) 2. group B: received an arm group programme (without device) delivered by an occupational therapist for the same time and frequency as group A
Outcomes	Outcomes were recorded before and after 10 treatment sessions • FMA
Notes	This study was published in German

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Randomly assigned by lottery of the supervising therapist
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Insufficient information about the concealment of allocation
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

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Housman 2009

Methods	RCT Methods of randomisation: participants were randomly assigned by a supervising therapist
Participants	Country: USA Sample size: 34 participants (17 in treatment group, 17 in control group) Inclusion criteria: single ischaemic or haemorrhagic stroke at least 6 months prior to participation, moderate to severe upper extremity hemiparesis (characterised by arm motor Fugl-Meyer scores > 10 and < 30) Exclusion criteria: significant pain or shoulder instability, current enrolment in ongoing upper extremity therapy, severe cognitive dysfunction, aphasia, hemispatial neglect, or apraxia
Interventions	2 groups: 1. group A: received robot-mediated therapy with the T-WREX device 3 times a week for 1 hour over 8 to 9 weeks, over the first 3 sessions the participants received direct training with an occupational therapist, and after that the participants exercised with intermittent supervision 2. group B: received the same treatment programme for the same time and frequency but without the device
Outcomes	Outcomes were recorded before and after every treatment session and 6 months after treatment completion • FMA • Rancho Functional Test (functional use of the affected arm during activities of daily living) • MAL to evaluate the quality of movement and the amount of use of the affected arm during activities of daily living, used as a self report measurement • handheld dynamometer
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Randomly assigned by lottery of the supervising therapist
Allocation concealment (selection bias)	Low risk	The treating therapist and participants were blinded to assignment until each participant had consented and was enrolled in the project
Blinding of outcome assessment (detection bias) All outcomes	Low risk	A single-blinded rater performed the clinical assessments

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Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Hsieh 2011

Methods	Pilot RCT Methods of randomisation: by using a random-number table, a sealed envelope was given to the therapists after a new eligible participant was registered, to deliver therapy accordingly
Participants	Country: Taiwan Sample size: 18 participants (6 in higher-intensity robot-assisted group, 6 in lower-intensity robot-assisted group, 6 in conventional rehabilitation group) Inclusion criteria: unilateral stroke onset at least 6 months prior to study; an initial upper extremity subsection of the Fugl-Meyer Assessment score of 30 to 56, indicating moderate to mild motor impairment; no excessive spasticity in elbow and wrist finger joints of the affected upper extremity (MAS < 3); ability to follow study instructions and perform study tasks (Mini-Mental State Examination > 24); no upper limb fracture within 3 months; no participation in any experimental rehabilitation or drug studies during the study period; and written informed consent Exclusion criteria: painful arthritis of the elbow, wrist, or finger joints; severe neuropsychologic impairments; physician-determined major medical problems or poor physical condition that would interfere with participation; and cerebellar or brain stem lesions to limit potential interference of other symptoms or signs with task accomplishment
Interventions	3 groups: 1. higher-intensity RT group: Bi-Manu-Track used in this study for 20 training sessions for 90 to 105 minutes, 5 days per week for 4 weeks, within this group each participant practiced 600 to 800 repetitions of mode 1 (15 minutes), 600 to 800 repetitions of mode 2 (15 to 20 minutes), and 150 to 200 repetitions of mode 3 (5 minutes) for the forearm and wrist movement, after the RT participants received 15 to 20 minutes of functional activities training to help them transfer the acquired motor ability into ADL 2. lower-intensity RT group: with the Bi-Manu-Track the participants received over the same time a different frequency of 300 to 400 repetitions of mode 1 (15 minutes), 300 to 400 repetitions of mode 2 (15 to 20 minutes), and 70 to 100 repetitions of mode 3 (5 minutes) for the forearm and wrist movement, and after that they received the same treatment of functional abilities as the higher-intensity group 3. conventional rehabilitation group: these participants received a structured protocol using conventional occupational therapy techniques including passive range-of-motion exercises for 15 to 20 minutes, fine-motor dexterity training for 20 minutes, gross-motor training for 20 minutes, muscle strengthening of the affected upper limb for 15 to 20 minutes, activities of daily living for 15 to 20 minutes
Outcomes	Outcomes were recorded at baseline and post-treatment • FMA • MRC • MAL

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Hsieh 2011 (*Continued*)

	• ABILHAND scale to measure bimanual ability	
Notes	We combined the results of both the planar and the planar + vertical in 1 (collapsed) group and compared this collapsed group with the results of the control group	
Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	By random-number table
Allocation concealment (selection bias)	Low risk	Sealed envelopes to accordingly deliver the intervention to the registered participant
Blinding of outcome assessment (detection bias) All outcomes	Low risk	All clinical measures were administered to the participants by the same blinded rater
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Hsieh 2014

Methods	RCT Methods of randomisation: random-number table
Participants	Country: Taiwan Sample size: 48 Inclusion criteria: at least 6 months after onset of a unilateral stroke, an initial score of the FMA arm assessment of 20 to 50 (SD 25), minimal hand function (i.e. extension of the wrist $\geq$ 10°, extension of at least 2 fingers > 0° and > 10°, and abduction of thumb $\geq$ 10°, no excessive spasticity in any of the joints of the affected arm (MAS $\geq$ 4), no arm fracture within 3 months or painful arthritis of the joints, and able to follow study instructions and perform study tasks (Mini-Mental State Examination score $\geq$ 22) Exlusion criteria: none described
Interventions	3 groups: 1. RT + CIT group (robot-assisted arm therapy (Bi-Manu-Track) + constraint-induced therapy) 2. RT group (robot-assisted arm therapy (Bi-Manu-Track)) 3. CT group (received a therapist-mediated intervention using conventional occupational therapy techniques, including neurodevelopmental techniques, functional task practice, fine-motor training, arm exercises or gross-motor training, and muscle strengthening) Participants in each group received 20 training sessions of 90 to 105 min/day, 5 days/week for 4 weeks. In addition to the intervention provided in the clinics, all participants were encouraged to use their affected upper limb during activities in their daily life situations (e.g. at home)

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Hsieh 2014 (*Continued*)

Outcomes	Outcomes were recorded at baseline and post-treatment after 4 weeks • FMA • WMFT • MAL • accelerometers (actigraphy activity monitor)
Notes	We combined the results of both the RT + CIT group and the RT group (collapsed) group and compared this collapsed group with the results of the CT group

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Randomisation assignments were generated from a random-number table
Allocation concealment (selection bias)	Low risk	Sequentially numbered, sealed, and opaque envelopes and a blinded investigator assigned each participant to a treatment group
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Blinded assessor
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Hwang 2012

Methods	RCT Methods of randomisation: random allocation of participants to 2 groups was performed using a random-assignments generator (Wichmann-Hill random-number generator)
Participants	Country: Republic of Korea Sample size: 15 Inclusion criteria: ≥ 18 years old, more than 3 months after stroke, > 10° voluntary range of motion of the second metacarpophalangeal joint, a FMA arm motor scale of 2 to 20 for the wrist and hand subportion and requiring a > 25% longer time to finish the 9-hole pegboard test with the affected arm compared with the contralateral arm Exlusion criteria: apraxia (≤ 2 on the Alexander scale), impaired consciousness (≥ 1 for the NIH Stroke Scale question Ia-c), sensory impairment (< 75% of the contralateral score on the Nottingham Sensory Scale), increased spasticity (4 on the Ashworth scale), aphasia (≥ 2 for the NIH Stroke Scale question IX) or depression (≥ 8 on the Geriatric Depression Scale), with a combined disabling disease on the hemiparetic hand, or who refused to participate

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Hwang 2012 (*Continued*)

Interventions	2 groups: 1. 4 weeks (20 sessions) of active robot-assisted intervention (full-term intervention) group 2. 2 weeks (10 sessions) of early passive therapy, followed by 2 weeks (10 sessions) of active robot-assisted intervention (the half-term intervention) group The robot-assisted therapy included individual finger synchronisation (Amadeo, Tyromotion, Austria)
Outcomes	Outcomes were recorded at baseline and at 2, 4, and 8 weeks after starting therapy • FMA • Jebsen-Taylor test • MAS • 9-hole pegboard test • hand motor subscale of the SIS (involving 12 questions regarding hand function while activities of daily living, with a minimum score of 12 and maximum score of 60) • grasping force test • pinching force test • second metacarpophalangeal joint active range of motion
Notes	We used the data from the first 2 weeks of intervention

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Random allocation of participants into 2 groups was performed using a random-assignments generator (Wichmann-Hill random-number generator)
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Authors quote: "assessor-blinded"
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Kahn 2006

Methods	RCT Method of randomisation: not stated
Participants	Country: USA Sample size: 19 participants (10 in treatment group, 9 in control group) Inclusion criteria: unilateral stroke at least 1 year previously, CMSA 3 to 5 points scale Exclusion criteria: not stated

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Kahn 2006 (*Continued*)

Interventions	2 groups: 1. control group received "free reaching training" that involved unconstrained, unassisted repetitive voluntary reaching in an 8-week therapy programme involving a total of 24 exercise sessions. Each session lasted 45 minutes 2. treatment group used robot-guided active-assist training with the ARM Guide for the same time and frequency
Outcomes	Outcomes were recorded at baseline and after end of training • biomechanical examination of the impaired limb with the ARM Guide • CMSA • FMA • Rancho Los Amigos Functional Test for the hemiparetic upper extremity
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	By a blinded evaluator
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Klamroth-Marganska 2014

Methods	RCT Methods of randomisation: computer-generated list of random numbers was used that paired a unique sequential number with a treatment type (robotic or conventional). Pairs were sealed in tamper-evident envelopes by the study co-ordinator
Participants	Country: Switzerland Sample size: 77 Inclusion criteria: diagnosis of 1, first-ever cerebrovascular accident verified by brain imaging (magnetic resonance imaging or computed tomography); chronic impairment after stroke (minimum 6 months); moderate to severe arm paresis as indicated by a score of 8 to 38 on arm section of FMA (which has a maximum of 66 points); aged $\geq$ 18 years; stable recovery stage; able to sit in a chair without any additional support and without leaning on the back rest; passive range of motion in the shoulder as assessed with the neutral zero method: anteversion/retroversion 80°/0°/20°, abduction/adduction 60°/0°/

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	10°, inner and outer rotation 20°/0°/20°; passive range of motion in the elbow as assessed with the neutral zero method: flexion/extension 100°/40°/40° Exlusion criteria: excessive spasticity of the affected arm (MAS $\leq$ 3); serious medical or psychiatric disorder as assessed by their physician; participation in any clinical investigation within previous 4 weeks; participation in any therapeutic treatment (apart from assigned therapy) done with the paretic arm during the therapy phase of the study; anticipated need for any major surgery during the study; pregnancy or breastfeeding; orthopaedic, rheumatological, or other disease restricting movements of therapeutic arm; shoulder subluxation (palpation < 2 fingers); skin ulcerations at the paretic arm; not able to communicate effectively with the examiner such that the validity of the participant's data could not be compromised; cyber sickness (e.g. nausea when looking at a screen or playing computer games); pacemaker or other implanted electric devices; bodyweight above 120 kg; serious cognitive defects or aphasia preventing effective use of ARMin
Interventions	2 groups: 1. robotic therapy with ARMin, each of 3 therapy modes (mobilisation, games, and training for activities of daily living) had to be done for at least 10 minutes 2. conventional therapy: receiving common neurorehabilitation treatment given to participants after stroke in outpatient facilities, namely occupational therapy or physiotherapy. Therapists were asked to give regular therapy, usually including mobilisation, games, activities of daily living, or any combination of the 3 Therapy was given 3 times a week for a period of 8 weeks (sum of 24 sessions). Minimum session time (excluding time for preparation, diagnostics, and documentation) was 45 minutes
Outcomes	Outcomes were recorded at baseline and post-treatment every 2 weeks • FMA • WMFT • quality of movement section of the MAL • Stroke Impact Scale (SIS 2.0) • Goal Attainment Scale • MAS • grip strength (handheld dynamometer)
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Quote: "computer-generated list of random numbers was used, which paired a unique sequential number with a treatment type (robotic or conventional)"
Allocation concealment (selection bias)	Low risk	Quote: "Pairs were sealed in tamper-evident envelopes by the study co-ordinator."

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Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "Assessors were masked to treatment allocation"
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Kutner 2010

Methods	RCT Methods of randomisation: sealed envelope method
Participants	Country: USA Sample size: 21 participants (11 in experimental group and 10 in combined therapy group) Inclusion criteria: first clinical stroke diagnosis; time since stroke between 3 and 9 months; Mini-Mental State Examination score of > 24; being able to stand for 2 minutes; passive range of motion ≥ 45° for shoulder abduction, flexion, or external rotation and pronation of the forearm; active wrist extension ≥ 10°; active thumb extension and ≥ 10° of extension in at least 2 additional digits Exlusion criteria: not described
Interventions	2 groups: 1. 60 hours of repetitive task training over the course of 3 weeks 2. 30 hours of repetitive task training plus 30 hours of robotic-assisted training with the Hand Mentor device over the course of 3 weeks
Outcomes	Outcomes were recorded at baseline, at the end of intervention, and at 2 months postintervention Primary outcome measure: health-related quality of life (SIS)
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Quote: "participants were randomly assigned by the sealed envelope method"
Allocation concealment (selection bias)	Unclear risk	It was not described whether the sealed envelopes were opaque
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "Research staff blinded to treatment assignment conducted interview-based outcome assessments."

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Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Liao 2011

Methods	Prospective RCT Methods of randomisation: participants were randomly assigned to either the treatment or control group in accordance with a random-number table, then a sealed envelope was given to the therapists to deliver therapy accordingly
Participants	Country: Taiwan Sample size: 20 participants (10 in treatment group and 10 in control group) Inclusion criteria: clinical diagnosis of the first cortical or subcortical stroke, more than 6 months poststroke, initial upper limb FMA score of 28 to 56 (0 to 66), Mini-Mental State examination > 22, no excessive spasticity in elbow or wrist joints of the affected arm (MAS < 3) Exclusion criteria: stroke lesions in other than brain areas (cerebellum or brainstem) , comorbidity with other severe neurological diseases (epilepsy), severe shoulder pain or painful arthritis of the elbow, wrist, or finger joints, unable to follow treatment instructions
Interventions	2 groups: 1. group A: participants received robot-assisted therapy (with the Bi-Manu-Track) over 4 weeks, 5 days a week for 90 to 105 minutes per session, with 600 to 800 repetitions of mode 1 (passive-passive mode) and mode 2 (passive-active mode), and 150 to 200 repetitions of mode 3 (active-active or resistance mode). If the participants were able to perform actively forearm pronation-supination or wrist flexion-extension, then mode 2 was adjusted to mode 4 (active-passive mode, but the affected arm would actively execute the training cycle). After robot-training participants received 15 minutes of training in functional activities that were selected by participants and therapists, e.g. twisting a towel 2. group B: participants received active control therapy that senior occupational therapists designed for protocol-based occupational therapy techniques such as neurodevelopmental techniques with emphasis on functional training, e.g. muscle strengthening of the affected arm and ADL or functional task training. The control group received the same amount of therapy hours as the treatment group (dose-matched comparison group), after the active control therapy session the participants also received 15 minutes of training in functional activities that were selected by the participants and the therapists
Outcomes	Outcomes were recorded at baseline and immediately after the 4 weeks of intervention • arm activity ratio of the accelerometer data (ratio of activity between the affected and the unaffected limb) measured by the MicroMini-Motionlogger activity monitor (Ambulatory Monitoring, New York, NY, USA) • FMA • FIM • MAL • ABILHAND

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Liao 2011 (*Continued*)

Notes		
Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Random assignment in accordance with a number table to either treatment or control group
Allocation concealment (selection bias)	Low risk	By sealed opaque envelopes
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Blinded assessor
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Lo 2010

Methods	Multicentre RCT Method of randomisation: a permuted-block design that was stratified according to site
Participants	Country: USA Sample size: 127 participants (49 in intensive robot-assisted group, 50 in intensive comparison group, and 28 in usual-care group) Inclusion criteria: age 18 years and older; stroke that occurred at least 6 months prior to enrolment to the study; long-term, moderate to severe motor impairment of the upper limb (described as a score between 7 and 38 of the Fugl-Meyer score); and written informed consent from all participants Exclusion criteria: all patients with a baseline Fugl-Meyer score outside the required range of 7 to 38
Interventions	3 groups: 1. group A: the participants received intensive robot-assisted therapy for a maximum of 36 sessions over a period of 12 weeks 2. group B: the participants received intensive comparison therapy, which matched the robot-assisted therapy in schedule and in form of intensity of movements 3. group C: the participants received customary care (i.e. medical management, clinic visits needed, and in some cases rehabilitation services). After the final study visit the participants in the usual-care group were offered to choose between robot-assisted therapy or intensive comparison therapy
Outcomes	Outcomes were recorded at baseline, then 6 and 12 weeks after randomisation, then again 6 months and 9 months after treatment completion • FMA • WMFT

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Lo 2010 (*Continued*)

	• Stroke Impact Scale (SIS 3.0) • MAS • measure of pain with a scale from 0 to 10
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Random assignment with a permuted-block design that was according to participants stratified to 1 or the other site of intervention
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Trained blinded raters
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Lum 2002

Methods	RCT Method of randomisation: list of random numbers
Participants	Country: USA Sample size: 30 participants (15 in treatment group, 15 in control group) Inclusion criteria: diagnosis of a single stroke, more than 6 months post-stroke, obvious deficit in upper-limb motor function as a result of the stroke, had completed all formal outpatient therapy but continued with any home-based exercise regimen or community-based stroke programmes they were enrolled in at the time of intake into the study Exclusion criteria: upper-extremity joint pain or range-of-motion limitations that would affect their ability to complete the protocols; any unstable cardiovascular, orthopaedic, or neurologic conditions; cognitive impairments if people were unable to co-operate with the study tasks
Interventions	2 groups: 1. control group received 55 minutes of physiotherapy for the arm and 5 minutes of robot training for each of the 24 sessions over a 2-month period 2. experimental group received bimanual and passive robot therapy by the MIME robot for the same time and frequency

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Lum 2002 (*Continued*)

Outcomes	Outcomes were recorded at baseline and after 4 and 8 weeks (end of training) and 8 months after baseline • FMA • Barthel Index • FIM • strength • reach
Notes	Incorporates results of Burgar 2000

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Participants were randomly assigned to either group based on a list of random numbers
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	An occupational therapist blinded to group assignment tested all participants with a battery of clinical evaluations
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Lum 2006

Methods	RCT Method of randomisation: list of random numbers
Participants	Country: USA Sample size: 30 participants (9 in the robot-unilateral group, 10 in the robot-bilateral group, 5 in the robot-combined group, and 6 in the control group) Inclusion criteria: diagnosis of stroke, 1 to 5 months poststroke Exclusion criteria: any upper-limb joint pain or range-of-motion limitations that would affect their ability to complete the protocols; any unstable cardiovascular, orthopaedic, or neurological conditions; cognitive impairments (scored < 21 of the Folstein Mini-Mental State Examination)
Interventions	4 groups: 1. robot-unilateral group performed exercises with the MIME device that progressed from the easiest exercise modes (passive) to the most challenging (active-constrained); no bilateral exercise was performed 2. robot-bilateral group practised the same 12 reaching movements as in group 1, but only in bilateral mode with the MIME device

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	3. robot-combined group spent approximately half the treatment time in the unilateral mode (as in group 1) and the other half in the bilateral mode with the MIME device 4. control group received an equivalent intensity and duration of conventional therapy targeting proximal upper-limb function based on neurodevelopmental treatment Groups 1 to 3 were collapsed to 1 robot treatment group (pooled as 1 group) in our analysis
Outcomes	Outcomes were recorded immediately before treatment started, immediately post-treatment, and 6 months after treatment ended • FMA • Motor Status Score • FIM • Motor Power examination to assess arm strength • MAS
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	An occupational therapist blinded to group assignment tested all participants with a battery of clinical evaluations
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Masiero 2007

Methods	RCT Method of randomisation: not stated
Participants	Country: Italy Sample size: 35 participants (17 in treatment group, 18 in control group) Inclusion criteria: first, single unilateral ischaemic stroke using the World Health Organization definition of stroke Exclusion criteria: neurologic or cardiovascular instability contraindicating exercise (e.g. uncontrolled hypertension), early severe spasticity, multiple cerebrovascular lesions, severe neuropsychologic impairment (global aphasia, severe attention deficit or neglect), not able to follow instructions

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Masiero 2007 (*Continued*)

Interventions	2 groups: 1. treatment group received additional early sensorimotor robotic training with the NeReBot, robot training treatment twice a day, 5 days a week, for at least 5 weeks 2. control group received similar exposure to the robot (30 minutes twice per week) except that the exercises were performed with the unimpaired arm
Outcomes	Outcomes were recorded at baseline and after 1.5, 3, and 8 months • FMA • MRC score to measure the strength of shoulder abduction, elbow flexion, and wrist flexion • FIM (motor component) • Trunk Control Test • MAS
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Assessments were performed for all participants by the same blinded clinician
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Masiero 2011

Methods	RCT Method of randomisation: sequence of computer-generated random numbers
Participants	Country: Italy Sample size: 21 participants (11 in treatment group, 10 in control group) Inclusion criteria: (1) diagnosis of recent single-sided stroke (ischaemic or haemorrhagic) demonstrated by brain computerised axial tomography or nuclear magnetic resonance, (2) sufficient cognitive and language capacities to understand the operator's instructions (Modified Mini-Mental State Examination score > 18), (3) paralysis or paresis (Motor Power score between 8 and 12) with no ability for active movement against gravity or weak resistance Exclusion criteria: (1) cardiovascular instability (severe uncontrolled hypertension, severe coronary artery disease, etc.) or orthopaedic or neurological conditions, (2) mul-

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	tiple cerebrovascular lesions, (3) > 3 points Ashworth Scale, (4) upper-limb joint pain or limitations to range of motion that would have affected the participant's ability to complete the protocols, (5) severe neuropsychological impairment (global aphasia, severe attention deficit, or severe space inattention), (6) age > 85 years or < 18 years
Interventions	2 groups: 1. treatment group received robotic training with the NeReBot, robot training twice a day for 20 minutes, and 40 minutes conventional training, 5 days a week, for at least 5 weeks 2. control group received conventional functional rehabilitation for 80 minutes a day (including proprioceptive exercises, functional re-education, gait training, occupational therapy, and passive and active-assisted mobilisation of the hand and wrist) but without specifically exercising the proximal paretic arm
Outcomes	Outcomes were recorded at baseline, 5 weeks after treatment onset, and after 3-month follow-up: • MRC • FMA • Motor subsection of Functional Independence Measure (m-FIM) • MAS • Frenchay Arm Test • BBT • Tolerability of treatment: evaluated by noting the number of medical complications in the 2 groups (shoulder-hand syndrome, shoulder pains) and the degree of acceptance of the robotic training rated on a visual analogue scale (0 = poor acceptance and 10 = maximum acceptance)
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Randomisation was achieved with use of a sequence of computer-generated random numbers
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	All participant assessments were performed by the same blinded clinician, who had previously attended a training course qualifying him or her to use the scales, was not directly involved in the delivery of either robot-aided or standard rehabilitation therapy within the study, and did not know which participants had been enrolled in the EG and the CG

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Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Mayr 2008

Methods	Cross-over RCT Method of randomisation: not stated
Participants	Country: Austria Sample size: 8 (4 in treatment group, 4 in control group) Inclusion criteria: < 3 months poststroke with severe to moderate upper-limb paresis, sufficient communication abilities to complete the study, and written informed consent Exclusion criteria: painful arthritis of the wrist and finger or physician-determined major medical problems
Interventions	2 groups: 1. group AB: the participants received over 2 weeks, 5 times per week robot-assisted therapy with the ARMOR device, then 2 weeks with no intervention, and then over 2 weeks, 5 times per week EMG-initiated functional electrical stimulation 2. group BA: the participants received 5 times per week over 2 weeks EMG-initiated functional electrical stimulation, then 2 weeks no intervention, and then 5 times per week over 2 weeks robot-assisted therapy
Outcomes	Outcomes were recorded at baseline and then after each cross-over (after 2, 4, and 6 weeks since baseline) • CMSA • MAS • Jamar dynamometer to measure hand-force • Functional Dexterity Test
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	High risk	No concealment of allocation was provided (information provided by the investigator)
Blinding of outcome assessment (detection bias) All outcomes	High risk	Assessors were not blinded (information provided by the investigator)

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Mayr 2008 (*Continued*)

Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

McCabe 2015

Methods	RCT Method of randomisation: not described
Participants	Country: USA Sample size: 39 participants (12 in the experimental and 27 in the control group) Inclusion criteria: single unilateral stroke; > 1 year upper extremity impairment; a trace muscle contraction in the wrist extensors; mobility and function sufficient for independent performance of activities; stable medical condition; not other neurologic condition; ability to follow 2-step commands; informed consent Exlusion criteria: not explicitly stated
Interventions	3 groups: 1. Motor Learning Programme in a 1:3 group paradigm for 5 hours per day for 12 weeks 2. Motor Learning Programme 1:3 group paradigm for 3.5 hours per day + functional electric stimulation for 1.5 hours per day for 12 weeks 3. Motor Learning Programme 1:3 group paradigm for 3.5 hours per day + robotic-assisted arm training with the InMotion2 Shoulder-Elbow Robot 1.5 hours per day for 12 weeks
Outcomes	Outcomes were recorded at baseline and post-treatment every 2 weeks Primary outcome: AMAT Secondary outcomes: AMAT subscale wrist/hand; AMAT subscale shoulder/elbow; FMA (shoulder/elbow and wrist/hand subscales); AMAT (function scale)
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "There was 1 assessor, who was blinded to the group assignment of the subject."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

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Rabadi 2008

Methods	RCT Method of randomisation: sealed, opaque envelopes
Participants	Country: USA Sample size: 30 participants (10 in experimental group and 20 in control groups) Inclusion criteria: First acute stroke; time since stroke < 4 weeks; admission to an inpatient rehabilitation facility; arm weakness as defined by Medical Research Council grade < 2 in the shoulder joint; informed consent Exlusion criteria: Anterior or severe inferior shoulder subluxation ($\geq$ 3 cm) of the affected arm; shoulder pain on passive range of 60° forward flexion and 60° abduction of the weak arm; trophic skin changes and significant oedema (shoulder-hand syndrome); prior rotator cuff surgery; bursitis or biceps tendonitis; recent cardiac event; medications enhancing motor recovery such as Botox or d-amphetamine
Interventions	3 groups: 1. standard occupational and physical therapy for 3 hours per day + 12 additional sessions of 40 minutes of occupational therapy 5 days per week 2. standard occupational and physical therapy for 3 hours per day + 12 additional sessions of 40 minutes of arm ergometry 5 days per week 3. standard occupational and physical therapy for 3 hours per day + 12 additional sessions of 40 minutes of robotic-assisted arm training with the MIT-Manus 5 days per week
Outcomes	Outcomes were recorded at baseline and at discharge Primary outcomes: • Shoulder/elbow subscales of FMA wrist/hand subscales • Motor Status Scale • FIM (including motor and cognition subscale) Secondary outcomes: • Motor Power Scale for muscle strength • ARAT • MAS
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "Patients who consented were randomized by sealed, opaque envelopes in blocks of six (two patients in each group) at a time."
Allocation concealment (selection bias)	Low risk	Quote: "Envelopes were identical for the three groups of patients. These sealed envelopes were kept in a locked place. Participants were assigned to one of the three groups by a designated nurse on the unit not associated with the study."

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Rabadi 2008 (*Continued*)

Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "The outcome measures were recorded at baseline and on discharge by an evaluator (LD) blinded to treatment allocation."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Sale 2014

Methods	RCT Method of randomisation: Lehmer's algorithm
Participants	Country: Italy Sample size: 53 Inclusion criteria: subacute first-ever stroke, unilateral paresis, ability to understand and follow simple instructions, ability to remain in a sitting posture Exlusion criteria: bilateral impairment, severe sensory deficits in the paretic upper limb, cognitive impairment or behavioural dysfunction that would influence the ability to comprehend or perform the experiment, refusal or inability to provide informed consent, other current severe medical problems
Interventions	2 groups: 1. performed 30 sessions of robot-assisted therapy (5 days a week for 6 weeks, goal-directed, planar reaching tasks, which emphasised shoulder and elbow movements, moving from the centre target to each of the 8 peripheral targets MIT-Manus/ InMotion2 robot) 2. 30 sessions (5 days a week for 6 weeks) of conventional rehabilitative treatment, matching robot-assisted therapy of the same duration, such as assisted stretching, shoulder and arm exercises, and functional reaching tasks provided by experienced physiotherapists Experimental and control therapies were applied in addition to usual rehabilitation
Outcomes	Outcomes were recorded at baseline, after 3 weeks and post-treatment after 6 weeks • FMA • MAS-Shoulder and Elbow • passive range of motion • Motricity Index
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	Quote: "A Lehemer algorithm was applied to achieve a balanced allocation in the EG and CG groups. Therapists were randomly

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Sale 2014 (*Continued*)

		assigned to patients within each group using the same algorithm."
Allocation concealment (selection bias)	Unclear risk	Quote: "The random allocation to treatment was concealed and based upon dedicated software."
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "The clinical assessments were carried out by blinded assessors..."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Susanto 2015

Methods	RCT Method of randomisation: random-number generator
Participants	Country: China Sample size: 19 Inclusion criteria: primary stroke 6 to 24 months prior to the beginning of the intervention, moderate stroke condition (50 > FMA score > 20), ability to understand simple commands (Mini-Mental State Examination score > 21), and ability to differentiate sensation on 1 finger from the other fingers Exclusion criteria: recurrent stroke; other neurological, neuromuscular, or orthopaedic disease; or shoulder or arm contracture/pain
Interventions	2 groups: 1. hand exoskeleton robot-assisted group 2. control group (non-assisted group)
Outcomes	Outcomes were recorded at baseline (within 2 weeks from the first training session, within 1 week from the first session), within 3 days after the last session, and at 6 months' follow-up • ARAT • WMFT • FMA
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Low risk	Random-number generator
Allocation concealment (selection bias)	Unclear risk	Not described

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Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "single-blinded so the assessors were of no knowledge of the grouping."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Timmermans 2014

Methods	RCT Method of randomisation: blocked randomisation, using opaque envelopes
Participants	Country: the Netherlands Sample size: 22 Inclusion criteria: first-ever stroke, age between 18 and 85 years, clinically diagnosed with a central paresis of the arm/hand (strength: MRC grade 2 to 4 at entry into study) , poststroke time ≥ 12 months, fair to good cognitive level (Mini-Mental State Examination score ≥ 26), able to read and understand the Dutch language, unable to fully perform at least 2 of the following skills: drinking from a cup, eating with knife and fork, taking money from a purse and using a tray, motivated to train at least 2 of the above-mentioned skills (At the start of the last 6 months of the inclusion period, inclusion criteria were adjusted to poststroke time ≥ 8 months, to facilitate participant inclusion) Exclusion criteria: severe neglect (Bell Test, Letter Cancellation Test: minimum omission score of 15%), hemianopsia, severe spasticity (MAS total arm > 3, severe additional neurological, orthopaedic, or rheumatoid impairments prior to stroke that could interfere with task performance, Broca's aphasia, Wernicke's aphasia, global aphasia (determined by the Akense Afasie Test), apraxia (apraxia test of Van Heugten), and attending another study or therapy to improve arm-hand function
Interventions	2 groups: 1. robotic-assisted training with the end-effector robot HapticMaster 2. arm-hand training program (control group) Training was provided during 8 weeks, 4 times/week, twice a day for 30 minutes (separated by 0.5 hour to 1 hour of rest)
Outcomes	Outcomes were recorded at baseline and post-treatment every 2 weeks • FMA • ARAT • MAL (quality of use (QU) and amount of use (AU)) • EuroQol-5D (visual analogue scale) • SF-36
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**

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Random sequence generation (selection bias)	Low risk	Quote: "participants were randomly allocated to ... using blocked randomization (block size = 2). The randomization procedure was performed by an independent researcher using 2 opaque envelopes with in each envelope a training condition code. "
Allocation concealment (selection bias)	Low risk	Quote: "The randomization procedure was performed by an independent researcher using 2 opaque envelopes within each envelope a training condition code."
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "Persons involved in data collection were blinded for group allocation."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Volpe 2000

Methods	RCT Method of randomisation: not stated
Participants	Country: USA Sample size: 56 participants (30 in treatment group, 26 in control group) Ambulatory at study onset Inclusion criteria: first, single stroke, hemiparesis or hemiplegia of the upper and lower extremity, to be able to follow simple instructions, written informed consent Exclusion criteria: not stated
Interventions	2 groups: 1. treatment group used the MIT-Manus device for arm training for 1 hour per day, 5 days a week (for at least 25 sessions) 2. control group had similar initial exposure to the robot with the exception that half the tasks were performed with the unimpaired arm, and when the participant could not perform the task with the affected limb, the unimpaired limb was used to complete the task or the technician assisted the movement. The robot never actively moved the limbs of participants in the control group. Participants were exposed to the robot 1 hour per week
Outcomes	Outcomes were recorded before and after end of treatment • FMA • Motor Power Score (0 to 20) • Motor Status Score for shoulder and elbow (0 to 40) • Motor Status Score for wrist and hand (0 to 42) • FIM (motor and cognition score)

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Volpe 2000 (*Continued*)

Notes		
Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	High risk	Participants and the medical and rehabilitation team providing the clinical care were "masked" to the group assignment
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Volpe 2008

Methods	RCT Method of randomisation: not stated
Participants	Country: USA Sample size: 21 participants (11 in treatment group, 10 in control group) Inclusion criteria: people after stroke with impaired arm and hand mobility for at least 6 months Exclusion criteria: not able to follow simple instructions, minimally impaired (Fugl-Meyer shoulder-elbow section > 33 points), neurosurgical procedure, second stroke, fixed contracture
Interventions	2 groups: 1. control group: intensive movement protocol with a trained physiotherapist 2. treatment group: robotic training with the InMotion2 robot (the commercial version of MIT-Manus) All participants had an identical number of treatment sessions, and the sessions were of the same duration (1 hour per session, 3 times a week for 6 weeks)
Outcomes	Outcomes were recorded at 3 preliminary evaluations (Pre1, Pre2, Pre3), at midpoint, at discharge, and at 3-month follow-up • FMA • Motor Power Scale for shoulder/elbow (0 to 70) • MAS • Stroke Impact Scale (SIS 2.0) • ARAT • shoulder dislocation (joint stability; maximum cm of displacement = 9) • pain scale from the FMA (0 to 24)

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Volpe 2008 (*Continued*)

	• Beck Depression Scale (maximum = 63)
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Insufficient information about the sequence generation process
Allocation concealment (selection bias)	Unclear risk	Insufficient information about the concealment of allocation
Blinding of outcome assessment (detection bias) All outcomes	High risk	No blinding of outcome assessment was done
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Wu 2012

Methods	RCT Method of randomisation: not described
Participants	Country: Taiwan Sample size: 42 Inclusion criteria: unilateral stroke at least 6 months previously, mild to moderate motor impairment (total score of 26 to 66 on the upper extremity part of the FMA, no severe spasticity in the paretic arm (MAS score of 2 in any joint), no serious cognitive deficits (Mini-Mental State Examination score of 22), no other neurologic, neuromuscular, or orthopaedic disease and no participation within the previous 3 months in any experimental rehabilitation or drug studies Exlusion criteria: none described
Interventions	3 groups: 1. therapist-mediated bilateral arm training (TBAT Group) 2. robot-assisted (Bi-Manu-Track) arm trainer (RBAT Group) 3. CT involved weight bearing, stretching, strengthening of the paretic arms, coordination, unilateral and bilateral fine-motor tasks, balance, and compensatory practice on functional tasks Each group received treatment for 90 to 105 minutes per session, 5 sessions on weekdays, for 4 weeks
Outcomes	Outcomes were recorded at baseline and post-treatment after 4 weeks • Kinematic analysis • FMA • MAL (Quality of use and Amount of use)

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Wu 2012 (*Continued*)

	• SIS
Notes	We combined the results of both the TBAT and the CT Group (collapsed) group and compared this collapsed group with the results of the RBAT group

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Exact method not described
Allocation concealment (selection bias)	Low risk	Quote: "The allocation to group was concealed from the investigators"
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "the participants were blinded to the study hypotheses." and "Clinical outcome measures were administered ... by ... therapists blinded to the participant group. "
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

Yoo 2013

Methods	RCT Method of randomisation: not clearly described
Participants	Country: South Korea Sample size: 22 Inclusion criteria: no visual neglect or impaired cognitive function (Mini-Mental State Examination score > 24 points), written informed consent Exlusion criteria: none
Interventions	2 groups: 1. 3-dimensional robot-assisted therapy (RAT) and conventional rehabilitation therapy (CRT) for a total of 90 minutes (RAT: 30 minutes, CRT: 60 minutes) a day with 10 minutes rest halfway through the session, received training 3 days a week for 6 weeks 2. the control group received only CRT for 60 minutes a day on the same days as the first group
Outcomes	Outcomes were recorded at baseline and post-treatment after 6 weeks • WMFT • BBT • modified Barthel Index
Notes	

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Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
Random sequence generation (selection bias)	Unclear risk	Quote: "Subjects were randomly assigned to..." The method of randomisation is not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Quote: "Patients and investigators were blind to the test results and intervention grouping because this study used a double-blinded design."
Selective reporting (reporting bias)	Unclear risk	Insufficient information to permit judgement

ADL: activities of daily living
AMAT: Arm Motor Ability Test
ARAT: Action Research Arm Test
BBT: Box and Block Test
CG: control group
CMSA: Chedoke-McMaster Stroke Assessment
EG: experimental group
EMG: electromyography
FIM: Functional Independence Measure
FMA: Fugl-Meyer Assessment
MAL: Motor Activity Log
MAS: Modified Ashworth Scale
MIME: mirror image motion enabler
MRC: Medical Research Council
NIH: National Institutes of Health
RCT: randomised controlled trial
RT: robot training
SD: standard deviation
SIS: Stroke Impact Scale
WMFT: Wolf Motor Function Test

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Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Abdollahi 2014	Compared 2 different approaches of robotic training
Aisen 1997	Not an RCT; participants were allocated by stratification not by randomisation; inclusion criteria not fulfilled
Dodakian 2013	Not an RCT; participants were allocated using an approach that kept age and baseline motor deficits matched across the 2 groups
Fasoli 2003	All included participants received a kind of robotic therapy
Fluet 2012	Irrelevant comparison: 2 different approaches of robotic training tested
Hesse 2007	All participants received the same robotic therapy
Hill 2011	Not an electromechanical-assistive device; used functional electrical stimulation only
Hu 2015	Irrelevant comparison: 2 different approaches of robotic training tested
Jackson 2013	Not an RCT; description of a project/plan for RCT
Krebs 2000	Not an RCT
Luft 2004	Inclusion criteria of robot-aided or electromechanical-assisted technology not fulfilled; device used is a mechanical device without robot aid and without an electromechanical-assisted technology
Lum 2004a	Not an RCT
Lum 2004b	This trial was excluded after correspondence with the study authors because it overlaps with another trial included in the analysis
Page 2012	Not an electromechanical-assistive device; used functional electrical stimulation only
Prange 2015	Not an electromechanical-assistive device; used sling support and feedback only
Reinkensmeyer 2000a	Not an RCT
Takahashi 2008	No strict randomisation process; inclusion criteria not fulfilled
Takebayashi 2013	Not a genuine RCT
Thorsen 2013	Investigated myoelectrically controlled functional electrical stimulation
Tropea 2013	Irrelevant comparison: 2 different approaches of robotic training were tested
Volpe 1999	Not an RCT

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(*Continued*)

Whitall 2000	Inclusion criteria of robot-aided or electromechanical-assisted technology not fulfilled; device used is a mechanical device without robot aid and without an electromechanical-assisted technology

RCT: randomised controlled trial

Characteristics of studies awaiting assessment *[ordered by study ID]*

AIAS

Methods	RCT
Participants	Country: UK Participants: estimated enrolment n = 18 Inclusion criteria: age above 18 years; clinical diagnosis of stroke; Medical Research Council Scale for arm impairment between 1 and 4; medically stable; informed consent; ability to understand and follow simple instructions; sitting balance sufficient to use Armeo arm orthosis safely Exclusion criteria: orthosis cannot be fitted to affected limb; bone instability of hemiparetic upper limb; pre-existing upper limb deficits; pronounced, fixed contractures of hemiparetic upper limb; shoulder instability or excessive pain; severe spasticity; severe spontaneous movements; confused; non-co-operative; requiring isolation due to infection; severe visual, perceptual, or cognitive problems precluding participation in study protocol; involved in any other intervention study
Interventions	Experimental group 1: standard care + ArmeoSpring arm orthosis intervention for 60 minutes per day, 5 days a week for 2 weeks or discharge (whichever is sooner) Experimental group 2: standard care + ArmeoSpring arm orthosis intervention for 40 minutes per day, 3 days a week for 2 weeks or discharge (whichever is sooner) Control group (active): standard care, provided by physiotherapists or occupational therapists
Outcomes	Outcomes will be collected at the end of intervention period and at 3-month follow-up Primary outcome measure: feasibility of experimental intervention (number of per-protocol interventions recorded at the end of intervention period; reasons for non-compliance recorded at end of intervention period); acceptability/ satisfaction of experimental intervention: informal interviews with participants completed at the end of intervention period Secondary outcome measures: arm pain (5-point scale); shoulder subluxation (clinical report); fatigue (Borg Scale of Perceived Exertion); all adverse events; ARAT; FMA; disability (Barthel Index)
Notes	

Chisari 2014

Methods	RCT
Participants	Country: Italy Sample size: 18 Inclusion criteria: chronic stroke Exclusion criteria: not described

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Chisari 2014 (*Continued*)

Interventions	2 groups: 1. robotic therapy delivered with a robotic exoskeleton 2. manual physical therapy The treatments were matched in terms of intensity, duration, and tasks
Outcomes	• FMA • Modified Ashworth Scale • Bimanual Activity Test • execution time and smoothness index
Notes	

Faran 2008

Methods	RCT
Participants	Countries: USA, Germany 20 participants between 3 weeks and 3 months poststroke
Interventions	2 groups, 20 sessions of either Reo-Therapy system (Motorika USA Inc, NJ) or air splint therapy
Outcomes	• FMA • ARAT • Motor Power Score • Motor Status Score
Notes	

NCT00435617

Methods	RCT
Participants	Country: USA Inclusion criteria: 3 to 12 months post-stroke; able to extend wrist and fingers at least 10°; functional hearing and vision; able to follow instructions; lives at home, not institution; stable medications for 3 months Exclusion criteria: excessive cognitive impairments; taking/receiving medicines/shots to make arm/hand less stiff; severe pain in the impaired arm; stroke was more than 12 months ago
Interventions	Experimental group: electromechanical-assisted hand therapy at home for 6 weeks (device: Hand Mentor) Control group: not described
Outcomes	Primary outcome: WMFT Secondary outcomes: compliance with recommended use, FMA, SIS
Notes	Estimated enrolment: 70 participants

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Reinkensmeyer 2012

Methods	RCT
Participants	Country: USA Sample size: 27 Inclusion criteria: single ischaemic or haemorrhagic stroke; time since stroke at least 3 months; upper extremity FMA between 10 to 35 out of 66; written informed consent Exclusion criteria: significant pain; instability or subluxation of the affected shoulder; cognitive dysfunction interfering with the study tasks; visual deficits; severe neglect or apraxia; current other upper extremity therapy
Interventions	Experimental group: 24 x 1-hour treatment sessions with the Pneu-WREX device, 3 times a week for 8 to 9 weeks Control group (active): conventional exercises typical of home exercise programs, including self range-of-motion stretches, active range-of-motion strengthening exercises, and ADL tasks plus 30 minutes training on the Pneu-WREX per week
Outcomes	Outcomes were collected at baseline, at the end of intervention phase, and at 3-month follow-up Primary outcome measures: FMA Other outcome measures: Rancho Functional Test for the Hemiplegic/Paretic Upper Extremity; MAL; BBT; Nottingham Sensory Assessment
Notes	

ADL: activities of daily living
ARAT: Action Research Arm Test
BBT: Box and Block Test
FMA: Fugl-Meyer Assessment
MAL: Motor Activity Log
RCT: randomised controlled trial
SIS: Stroke Impact Scale
WMFT: Wolf Motor Function Test

Characteristics of ongoing studies *[ordered by study ID]*

Krebs 2007

Trial name or title	Robot-aided neurorehabilitation: a robot for wrist rehabilitation
Methods	RCT
Participants	Country: USA Inclusion criteria: first, single focal unilateral lesion with diagnosis verified by brain imaging (MRI or CT scans) that occurred at least 6 months prior; cognitive function sufficient to understand the experiments and follow instructions (Mini-Mental State score of 22 or higher or interview for aphasic participants), Motor Power Score 1/5 and 4/5 (neither hemiplegic nor fully recovered motor function in the muscles of the shoulder and elbow and wrist), never experienced robot-assisted therapy, given informed written consent to participate in the study Exclusion criteria: fixed contraction deformity in the affected limb

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Krebs 2007 (*Continued*)

Interventions	4 groups: 1. 6 weeks of robot-delivered wrist therapy followed by 6 weeks of robot-delivered shoulder-and-elbow training (3 times per week; 36 sessions in total) 2. 6 weeks of shoulder-and-elbow training followed by 6 weeks of wrist training (3 times per week; 36 sessions in total) 3. 12 weeks of alternating days of shoulder-and-elbow and wrist training (with at least 24 hours between alternations) using the planar and wrist robots in stand-alone mode (3 times per week; 36 sessions in total) 4. 12 weeks of training with half of the day's session focusing on shoulder-and-elbow training and half of the session focusing on wrist training (3 times per week; 36 sessions in total) using the planar and wrist robots in stand-alone mode
Outcomes	Primary outcomes: FMA (shoulder/elbow and wrist/hand subsections); motor power
Starting date	Not described
Contact information	Principal Investigator: Hermano Igo Krebs, PhD, Principal Research Scientist & Lecturer, Massachusetts Institute of Technology, Mechanical Engineering Department, 77 Massachusetts Ave, 3-137 Cambridge, MA 02139 USA, Tel: +1 617 253 8112, Fax: +1 617 258 7018, hikrebs@mit.edu
Notes	Estimated enrolment: 160 participants

Linder 2013

Trial name or title	The home stroke rehabilitation and monitoring system trial
Methods	RCT Method of randomisation: adaptive, stratified, computer-driven minimisation procedure
Participants	Country: USA Sample size: 96 Inclusion criteria: age $\geq$ 18, unilateral ischaemic or haemorrhagic stroke within 6 months confirmed with neuroimaging, persistent hemiparesis with UE voluntary activity as indicated by a score of 11-55 on the FMA, limited access to an organised stroke rehabilitation programme, preserved cognitive function as indicated by a score of $\leq$ 3 on the Short Portable Mental Status Questionnaire, and no UE injury or condition that limited function of the more-affected side before the stroke Exlusion criteria: inability to provide informed consent, not independent before the stroke as determined by a score of > 1 on the Modified Rankin Scale, sensory loss $\geq$ 2 on the sensory item of the NIHSS, hemispatial neglect as determined by asymmetry > 3 errors on the Star Cancellation Test, spastic hypertonus of hemiparetic hand or wrist musculature $\geq$ 3 on MAS, Botox injection in hemiparetic upper extremity within 6 months of enrolment, and life expectancy $\leq$ 1 year
Interventions	2 groups: 1. Robotic-assisted therapy with Hand Mentor Pro and home exercise program (HEP) 2. HEP only
Outcomes	Outcomes were recorded at baseline and post-treatment every 2 weeks • ARAT • WMFT

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	• FMA • SIS
Starting date	Not described
Contact information	Jay L Alberts: albertj@ccf.org
Notes	

NCT00272259

Trial name or title	Robots for stroke survivors
Methods	RCT
Participants	Country: USA Inclusion criteria: 1 year poststroke and difficulties with picking up small objects Exclusion criteria: not described
Interventions	Not described
Outcomes	Primary outcomes: not described
Starting date	Not described
Contact information	Bambi Brewer, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA, Tel: +1 412-241-9423, bambi@andrew.cmu.edu Study chairs or principal investigators: • Yoky Matsuoka, PhD, Principal Investigator, Carnegie Mellon University • Roberta Klatzky, PhD, Study Director, Carnegie Mellon University
Notes	Assessed on 27 May 2015

NCT00343304

Trial name or title	Pilot study - Comparison of upper body ergometer versus robot in upper extremity motor recovery post-stroke
Methods	RCT
Participants	Country: USA Participants: estimated enrolment n = 30 Inclusion criteria: age between 19 and 90 years; stroke in the last 4 weeks; UE plegia (MRC grade $\leq$ 2 at the shoulder joint); written informed consent; being able to follow simple directions Exclusion criteria: anterior or severe inferior shoulder subluxation ($\geq$ 3 cms) of the plegic arm; no shoulder pain on passive range of 75° forward flexion and 75° abduction of the plegic arm; trophic skin changes and significant oedema; prior rotator cuff surgery; people with bursitis or biceps tendonitis, or both; recent cardiac events

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NCT00343304 (*Continued*)

Interventions	Experimental group: unilateral arm training with a robot Control group: bilateral arm training with upper body ergometer
Outcomes	Not described
Starting date	
Contact information	
Notes	This study has been completed. No study results posted

NCT00453843

Trial name or title	The effect of proximal and distal training on stroke recovery
Methods	RCT
Participants	Country: USA Estimated enrolment: 160 participants Inclusion criteria: never experienced robot-assisted therapy; first, single focal unilateral lesion with diagnosis verified by brain imaging (MRI or CT scans) that occurred at least 6 months prior; cognitive function sufficient to understand the experiments and follow instructions (Mini-Mental State score of 22 and higher or interview for aphasic participants); average Motor Power score $\geq$ 1/5 or $\leq$ 3/5 (neither hemiplegic nor fully recovered motor function in 6 muscles of the shoulder, elbow, and wrist); informed written consent to participate in the study Exclusion criteria: fixed contraction deformity in the affected limb
Interventions	Robotic arm training; no further description
Outcomes	Primary outcome measures: FMA, Motor Power Secondary outcomes: WMFT, SIS
Starting date	June 2004
Contact information	Principal Investigator: Hermano Igo Krebs, PhD, Principal Research Scientist & Lecturer, Massachusetts Institute of Technology, Mechanical Engineering Department, 77 Massachusetts Ave, 3-137 Cambridge, MA 02139, USA, Tel: +1 617 253 8112, Fax: +1 617 258 7018, hikrebs@mit.edu
Notes	

NCT00785343

Trial name or title	Effectiveness of adding robotic therapy to conventional therapy for acute stroke patients with upper extremity paresis
Methods	RCT

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NCT00785343 (*Continued*)

Participants	Country: USA Participants: estimated enrolment n = 40 Inclusion criteria: age between 65 and 84 years; right-hemispheric unilateral ischaemic stroke; time since stroke < 15 days; arm weakness; right-handedness; MRC grade ≥ 2; being able to follow 2-3 step commands; head, neck, and trunk control; maintain upright posture for at least 45 minutes; some synergistic movements at shoulder flexion or abduction > 30°; ≥ 45° elbow flexion Exclusion criteria: previous stroke; haemorrhagic, cerebellar stroke or subarachnoid haemorrhage; contractures in the involved upper extremity; moderate to severe muscle tone in the involved upper extremity; full, active isolated movement of the involved upper extremity; corrected visual acuity worse than 20/50 for distance; cognitive or other deficits that would negatively affect their ability to follow directions or track visual targets; unstable cardiovascular, orthopaedic, or neurological conditions that would preclude exercise in short-duration, high-workload trials
Interventions	Experimental group: ReoGo robotic arm trainer additional to conventional therapy Control group: conventional therapy
Outcomes	Outcomes will be collected at baseline and at study end Primary outcomes: FMA Secondary outcomes: EMG - muscle activation and co-contraction index
Starting date	September 2008
Contact information	Lauren McDonagh, PT; lmcdonagh@KESSLER-REHAB.com Christine Post, OT; CHPost@selectmedicalcorp.com
Notes	

NCT00878085

Trial name or title	fMRI and robot-assisted practice of activities of daily living
Methods	RCT
Participants	Country: USA Participants: estimated enrolment n = 61 Inclusion criteria: age between 30 to 85 years; right-handedness; unilateral ischaemic stroke in the motor control area with resulting hemiparesis in the arm; time since stroke at least 6 months; residual movement of at least 15° shoulder flexion or adduction and 15° active elbow flexion and extension; no claustrophobia; not depressed; passes the fMRI scanner; being able to understand the instructions and complete the tracking tasks; no history of neurological disorders Exclusion criteria: brainstem stroke; spasticity > 3 at elbow or fingers on Ashworth Scale; visuospatial, language, or attention deficits of a severity that prevents understanding of the task; shoulder pain or joint pain during movements; decline to participate; will not comply with full protocol; pregnant; allergic to Gore-Tex and conductivity gel
Interventions	Experimental group: robot therapy with ADLs 3 times a week for 4 weeks Control group: occupational therapy 3 times a week for 4 weeks

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NCT00878085 (*Continued*)

Outcomes	Outcomes will be collected at baseline, at the end of study, and at follow-up Primary outcomes: • FMA • functional hand evaluation (ADL) • Jebsen-Taylor • movement time • grasp aperture • movement smoothness • BOLD response (activation) • laterality index • fractional anisotropy • fiber density index • secondary outcomes • joint range of motion • manual muscle test • spasticity • pain • exertion
Starting date	November 2008
Contact information	Michel Torbey, MD; Medical College of Wisconsin
Notes	This study has been completed. No study results posted

NCT01117194

Trial name or title	Rehabilitation robot for upper limbs, component project 5: effect on shoulder training using rehabilitation robot for stroke patients
Methods	RCT
Participants	Country: Taiwan Participants: estimated enrolment n = 12 Inclusion criteria: not described Exclusion criteria: not described
Interventions	2 groups: 1. Experimental group: shoulder training with the (self developed) NTUH Model One device 2. Control group: no intervention
Outcomes	Outcomes will be measured at 1-year follow-up Primary outcomes: 1. Barthel Index 2. MAS 3. Stroke Rehabilitation Assessment of Movement Measure 4. Postural Assessment Scale for Stroke Patients 5. secondary outcomes

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NCT01117194 (*Continued*)

	6. shoulder range of motion 7. visual analogue scale
Starting date	January 2010
Contact information	Wen-Shiang Chen, MD, PhD; wenshiang@gmail.com
Notes	

NCT01253018

Trial name or title	Evaluation of robot assisted neuro-rehabilitation (SRT3)
Methods	RCT
Participants	Country: USA Participants: estimated enrolment n = 75 Inclusion criteria: age over 21 years; clinically defined unilateral hemiparetic stroke (radiologically confirmed) ; adequate language and cognitive function to participate in training, testing, and informed consent; FMA score with a range of 7 to 38 in the study arm; stroke onset at least 6 months for ischaemic and at least 1 year for haemorrhagic stroke Exclusion criteria: seizures or treatment with anticonvulsants in the past 10 years (for transcranial magnetic stimulation testing); any medication known to interfere with brain stimulation; serious complicating medical conditions, contractures, or orthopaedic problems in the study arm limiting the range of motion for study positions; serious visual loss; Botox injection 3 months prior to enrolment; any change in the exercise regimen involving the study arm
Interventions	Experimental group: 12 weeks of robot therapy consisting of a progression through 3 robot modules: wrist, planar, and alternating wrist and planar robot. The progression will be sequential, with 4 weeks of training on each robotic device Control group: 12 weeks of task-specific practise of functional activities using the hemiparetic arm
Outcomes	Outcomes will be collected at baseline and at the end of study Primary outcomes: FMA Secondary outcomes: motor cortex excitability via transcranial magnetic stimulation
Starting date	April 2011
Contact information	Christopher Bever, MD; Baltimore VA Medical Center VA Maryland Health Care System, Baltimore, MD
Notes	

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NCT01552733

Trial name or title	Robotic therapy early after stroke events
Methods	RCT
Participants	Country: UK Participants: estimated enrolment n = 80 Inclusion criteria: age above 18 years; confirmed diagnosis of stroke; randomisation by 7 days; upper limb impairment (FMA score < 50 at randomisation); being able to comply with requirements of the protocol Exclusion criteria: other significant upper limb impairment; diagnosis likely to interfere with rehabilitation or outcome assessments; participation in other stroke rehabilitation trial
Interventions	Experimental group: robotic therapy using InMotion device plus standard care for up to 12 1-hourly sessions Control group: rehabilitation therapy according to local guidelines
Outcomes	Primary outcomes will be collected at 1-month follow-up, and secondary outcomes will be collected at 3-month follow-up Primary outcomes: • FMA • feasibility Secondary outcomes: • FMA • Modified Rankin Scale score • BI • SIS • NIHSS • ARAT
Starting date	March 2012
Contact information	Jesse Dawson, MD; jesse.dawson@glasgow.ac.uk
Notes	

NCT01655446

Trial name or title	Randomized trial of robotic rehabilitation, mirror therapy, and dose-matched control intervention for upper-limb rehabilitation in patients with chronic stroke: comparative efficacy and clinimetric study
Methods	RCT with factorial assignment
Participants	Country: Taiwan Participants: estimated enrolment n = 100 Inclusion criteria: unilateral stroke; onset more than 6 months; written informed consent; initial scores on the upper extremity FMA score of 25 to 56 or 18 to 50; Mini-Mental State Examination $\geq$ 24 points; no upper limb fracture in the last 3 months Exclusion criteria: recurrent stroke or seizures during the intervention; serious or continuous pain on affected upper extremity; history of other neurological disease or severe orthopaedic condition

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NCT01655446 (*Continued*)

Interventions	Experimental group 1: robotic rehabilitation combined functional electrical stimulation (5 to 10 minutes of warm-up, 1 hour of robotic rehabilitation with combined functional electrical stimulation, and 15 to 20 minutes of functional-activities training 5 days a week for 4 weeks) Experimental group 2: mirror therapy (1 hour mirror therapy and 0.5 hour functional training per day, 5 days a week for 4 weeks); focuses on symmetrical bimanual movements and simultaneously observing the mirror visual feedback reflected by the unaffected upper extremity Experimental group 3: robotic rehabilitation (5 to 10 minutes of warm-up, 1 hour of robotic rehabilitation, and 15 to 20 minutes of functional-activities training 5 days a week for 4 weeks) Control group 1 (active): conventional rehabilitation (participants in this group received a structured protocol based on occupational therapy such as neurodevelopmental techniques and task-oriented approach for 1.5 hours per day, 5 days a week for 4 weeks) Control group 2 (placebo): like experimental group 1 but without any electrical current applied for 1.5 hours per day, 5 days a week for 4 weeks
Outcomes	Outcomes will be collected at baseline and at 4, 8, 16, and 28 weeks Primary outcomes: • FMA • MAS • FIM • movement smoothness (movement units) • trajectory smoothness (total displacement) • pre-motor planning ability (percentage of peak velocity) • speed of motor planning (reaction time) • ARAT • MRC • Muscle tone (Myoton-3) • amount of the impaired arm movement outside the laboratory (accelerometer) • produced force (peak velocity) • trunk-related kinematic variables Secondary outcomes: • MAL • ABILHAND questionnaire • SIS 3.0 • Nottingham Extended Activities of Daily Living Scale • revised Nottingham Sensory Assessment • FMA Sensory • oxidative stress • Multidimensional Fatigue Symptom Inventory
Starting date	August 2011
Contact information	Keh-chung Lin, ScD; kehchunglin@ntu.edu.tw
Notes	

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NCT01767480

Trial name or title	Effects and mechanisms of intensive robot-assisted therapy in patients with subacute stroke: outcomes in brain/movement reorganization, sensorimotor and daily functions, and physiological markers
Methods	RCT
Participants	Country: Taiwan Participants: estimated enrolment n = 90 Inclusion criteria: age between 20 and 75 years; first-ever unilateral stroke; time since stroke < 3 months; initial motor part of upper limb FMA score ranging from 10 to 40; Mini-Mental State Examination score > 23) Exclusion criteria: pregnant or breastfeeding; aphasia interfering with understanding of instructions; major health problems or poor physical condition; current participation in other research; contraindications to fMRI
Interventions	Experimental group 1 (higher-intensity robotic training group; 1200 to 1800 repetitions during robot-assisted functional rehabilitation with the Bi-Manu-Track device): 90 to 120 minutes per day for 5 days a week for 4 consecutive weeks Experimental group 2 (lower-intensity robotic training group; 600 to 900 repetitions during robot-assisted functional rehabilitation with the Bi-Manu-Track device): 90 to 120 minutes per day for 5 days a week for 4 consecutive weeks Control group (active): Neurodevelopmental techniques with emphasis on functional tasks
Outcomes	Outcomes will be measured at baseline and at the end of study Primary outcomes: • FMA • Motor Status Scale • MAS • MyotonPRO • Muscle metabolism (near-infrared spectroscopy) • BBT • Revised Nottingham Sensory Assessment • FIM • MAL • ABILHAND questionnaire • Adelaide Activites Profile • EQ-5D-5L • accelerometers • fMRI • kinematic analysis • inflammatory markers • oxidative stress markers • erythrocyte deformability • blood glucose indicators
Starting date	January 2013
Contact information	Ching-Yi Wu, ScD; cywu@mail.cgu.edu.tw
Notes	

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NCT01907139

Trial name or title	Comparative efficacy research of robot-assisted therapy with and without constraint-induced therapy in stroke rehabilitation: does the combined therapy improve outcomes compared with monotherapy?
Methods	RCT with factorial assignment
Participants	Country: Taiwan Participants: estimated enrolment n = 80 Inclusion criteria: aged between 20 to 80 years; unilateral first-ever stroke; 6 months from onset; initial upper extremity FMA score of 20 to 56; minimal motor criteria to receive constraint-induced therapy (i.e. $\geq$ 100 wrist extension and $\geq$ 100 extension at the thumb and any other 2 digits); MAS $\leq$ 3 of the affected upper extremity; no upper limb fracture within the last 3 months; Mini-Mental State Examination $\geq$ 24 points; written informed consent Exclusion criteria: major medical problems or poor physical condition that would interfere with participation; excessive pain in any joint that might limit participation
Interventions	Experimental group 1: distributed constraint-induced therapy (placement of the hand in a mitt for 6 hours/day and intensive training of the affected upper limb in functional tasks for 1.5 hours/weekday over 4 weeks) Control group (active): dose-matched control therapy for 1.5 hours/weekday over 4 weeks Experimental group 2: robot-assisted therapy (ArmeoSpring) for 1.5 hours/weekday over 4 weeks Experimental group 3: robot-assisted therapy (ArmeoSpring) for 1.5 hours/weekday over 2 weeks plus distributed constraint-induced therapy for 1.5 hours/weekday over 2 weeks
Outcomes	Outcomes will be collected at baseline and at 2 and 4 weeks Primary outcomes: • FMA • WMFT • FIM • MAL • SIS 3.0 Secondary outcomes: • MRC • MAS • Revised Nottingham Sensory Assessment • muscle tone (MyotonPRO) • activity (actigraphy) • visual analogue scale for assessing postexertional fatigue and pain • urinary 8-hydroxydeoxyguanosine • kinematic analysis
Starting date	August 2013
Contact information	Keh-chung Lin, ScD; School of Occupational Therapy, College of Medicine, National Taiwan University, Taiwan Yi-shiung Horng, PhD; Buddhist Tzu Chi General Hospital Taipei Branch
Notes	

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NCT01939041

Trial name or title	Efficacy of unilateral versus bilateral approach to robot-assisted rehabilitation on motor control/performance, daily functions, and physiological responses in patients with subacute stroke
Methods	RCT
Participants	Country: Taiwan Participants: estimated enrolment n = 84 Inclusion criteria: first stroke; time since stroke less than 6 months and more than 2 weeks; initial motor impairment between 24 to 52 points on the upper extremity FMA; Mini-Mental State Examination $\geq$ 24 points Exclusion criteria: aphasia that might limit ability to understand instructions; chronic inflammatory, autoimmune, or haematological disorders; intake of anti-inflammatory drugs; major health problems or poor physical condition that might interfere with participation; current enrolment in other research
Interventions	Experimental group 1: robot-assisted therapy with InMotion3 for 90 minutes per day, 5 days a week for 4 weeks Experimental group 2: robot-assisted therapy with Bi-Manu-Track for 90 minutes per day, 5 days a week for 4 weeks Control group (active): control intervention for 90 minutes per day, 5 days a week for 4 weeks
Outcomes	Outcomes will be collected at baseline, at study end, and at 6-month follow-up Primary outcomes: • change of kinematic analysis • FMA • MAS • MyotonPRO • MRC • grip strength (Jamar dynamometer) • ARAT • MAL • ABILHAND questionnaire • Accelerometer • Adelaide Activities Profile Secondary outcomes: • inflammatory markers • oxidative stress markers • erythrocyte deformability • blood glucose indicators
Starting date	August 2013
Contact information	Ching-Yi Wu, ScD; cywu@mail.cgu.edu.tw Chia-Ling Chen, PhD, MD; clingchen@gmail.com
Notes	

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NCT02077439

Trial name or title	Interactive intention-driven upper-limb training robotic system
Methods	RCT
Participants	Country: China Participants: estimated enrolment n = 70 Inclusion criteria: age above 18 years; pure unilateral motor paresis after ischaemic or haemorrhagic stroke; sufficient cognition to understand instructions; being able to sit upright for 1 hour Exclusion criteria: excessive spasticity of the affected arm; involvement in any other therapy
Interventions	Experimental group 1: hand robotic training for 20 1-hourly sessions, 3 to 5 times per week Experimental group 2: hand and arm robotic training for 20 1-hourly sessions, 3 to 5 times per week Control therapy (active): conventional therapy for 20 1-hourly sessions, 3 to 5 times per week
Outcomes	Outcomes will be measured at baseline, at the end of study, and at 3- and 6-months follow-up Primary outcomes: • FMA • ARAT Secondary outcomes: • WMFT • MAS
Starting date	January 2014
Contact information	Raymond KY Tong, PhD; k.y.tong@polyu.edu.hk
Notes	

NCT02079779

Trial name or title	Efficacy study of an interactive robot for the rehabilitation of the upper limb in acute stroke patients
Methods	RCT
Participants	Country: Belgium Inclusion criteria: • first stroke • acute stroke (less than 1 month) • unilateral localisation of the stroke • moderate to severe upper limb impairments (7 < FMA score < 50/66) Exclusion criteria: • brainstem or cerebellum stroke • an unstable clinical condition contraindicating the upper limb rehabilitation treatments • cognitive disorders preventing understanding of the instructions • other neurological or orthopaedic pathology affecting the upper limb
Interventions	2 groups: 1. robotic-assisted therapy 2. classical therapy

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NCT02079779 (*Continued*)

Outcomes	Outcomes were recorded at baseline and post-treatment every 2 weeks • kinematic • FMA • Stroke Impairment Assessment Set • BBT • MRC • MAS • Bells Test • WMFT • ABILHAND • ACTIVLIM • SIS
Starting date	Not described
Contact information	Thierry Lejeune, Professor: thierry.lejeune@uclouvain.be
Notes	

NCT02096445

Trial name or title	Neurocognitive robot-assisted rehabilitation of hand function after stroke
Methods	RCT
Participants	Country: Switzerland Participants: estimated enrolment n = 20 Inclusion criteria: aged between 18 and 90 years; first stroke with resulting hemiparesis; time since stroke less than 6 weeks Exclusion criteria: insufficient state of consciousness; severe aphasia; severe cognitive deficits; severe pathologies of the upper extremity of traumatic or rheumatic nature; severe pain in the affected arm; people with metal implants
Interventions	Experimental group: robot-assisted neurocognitive therapy (ReHapticKnob) for 45 minutes 4 times per week Control group: conventional neurocognitive therapy (Perfetti) for 45 minutes 4 times per week
Outcomes	Outcomes will be collected at baseline, at 4 and 8 weeks, and at 6 months Primary outcomes: • FMA Secondary outcomes: • FMA • BBT • MAS • tactile and proprioceptive sensory function of the upper limb (Erasmus Medical Center Nottingham Sensory Assessment) • neglect (Albert's test of neglect) • cognitive impairment (Mini-Mental State Examination) • frontal lobe function (Frontal Assessment Battery)

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NCT02096445 (*Continued*)

	• aphasia (Aachen Aphasia Test) • attention
Starting date	April 2013
Contact information	Daria Dinacci, MD; d.dinacci@clinica-hildebrand.ch
Notes	

NCT02188628

Trial name or title	Refinement and clinical evaluation of the H-Man: a novel, portable, inexpensive planar robot for arm rehabilitation after stroke
Methods	RCT
Participants	Country: Singapore Participants: estimated enrolment n = 60 Inclusion criteria: age between 21 and 85 years; first-ever clinical stroke confirmed by imaging; time since stroke between 3 and 24 months; hemiplegic pattern of motor impairment with MRC motor power of shoulder and elbow flexion grade $\geq$ 3; FMA score of the affected upper limb between 20 and 50 points; motor inco-ordination or motor ataxia Exclusion criteria: other causes of arm motor impairment; severe medical conditions; palliative care; severe arm pain; inability to sit for 90 minutes; local fractures; spasticity of MAS grades 3 to 4; skin wounds; shoulder pain > 5/10 visual analogue scale; severe sensory impairment of affected limb; severe visual impairment; hemispatial neglect or homonymous hemianopia; cognitive impairments or uncontrolled behaviour; Mini-Mental State Examination < 26/28
Interventions	Experimental group: H-Man (end-effector upper limb robot; dosage not stated) Control group: additional conventional therapy (repetitive goals-based arm therapy; dosage not stated)
Outcomes	Outcomes will be collected at baseline and at 3, 6, 12, and 24 weeks after start of the intervention Primary outcomes: • FMA Secondary outcomes: • ARAT
Starting date	July 2014
Contact information	Chua SG Sui Geok; karen_chua@ttsh.com.sg
Notes	

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NCT02228863

Trial name or title	Upper extremity rehabilitation using robot and botulinum toxin
Methods	RCT
Participants	Country: Republic of Korea Participants: estimated enrolment n = 348 Inclusion criteria: first-ever stroke; shoulder or elbow flexor spasticity ≥ MAS 1+; being able to follow instructions from the investigator Exclusion criteria: history of surgery or fracture of affected upper limb; Botox injection within the last 6 months
Interventions	Experimental group: early InMotion and Botox (robotic rehabilitation with the InMotion device and Botox for 8 weeks; dosage not stated) Control group 1: Botox, then InMotion (robotic rehabilitation 4 weeks after botulinum toxin injection; dosage not stated) Control group 2: InMotion, then Botox (robotic rehabilitation from the baseline, then Botox injection at 4 weeks after baseline; dosage not stated) Control group 3: late Inmotion and Botox (no intervention, then robotic rehabilitation and Botox injection at 4 weeks after baseline; dosage not stated)
Outcomes	Outcomes will be collected at baseline and 4, 8, and 12 weeks from baseline Primary outcomes: • FMA Secondary outcomes: • kinematic data (InMotion) • spasticity of elbow and shoulder joint (Modified Tardieu Scale) • MRC of elbow and shoulder joint strength • painless range of motion of elbow and shoulder joint • numeric rating scale of pain of elbow and shoulder joint • associated reaction rating scale • surface electromyography data from bilateral upper extremities • behavioural activation system/behavioral inhibition system scale • Controlled Oral Word Association Test • FMA • SIS • Beck Depression Inventory • satisfaction about the intervention • adverse events • digit span test
Starting date	March 2014
Contact information	Joon-Ho Shin, MS; asfreelyas@gmail.com
Notes	

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NCT02254343

Trial name or title	Effects of proximal and distal robot-assisted therapy combined with functional training on stroke rehabilitation
Methods	RCT
Participants	Country: Taiwan Participants: estimated enrolment n = 92 Inclusion criteria: unilateral stroke, radiologically confirmed; time since onset more than 6 months; upper extremity FMA score between 10 and 50; Mini-Mental State Examination > 24 points; being able to follow commands Exclusion criteria: serious visual or visual perception problems; orthopaedic or other neurological problems in the last 6 months prior to enrolment; participation in other studies in the last 3 months
Interventions	Experimental group 1: proximal robot-assisted therapy (InMotion2 device); dosage not described Experimental group 2: distal robot-assisted therapy (InMotion3 device); dosage not described Experimental group 3: combined robot-assisted therapy (InMotion2 and InMotion3 devices); dosage not described Control group (active): dose-matched, individualised intensive therapy; dosage not described
Outcomes	Outcomes will be collected at baseline, 2 weeks, and 4 weeks Primary outcomes: • FMA Secondary outcomes: • BBT • ARAT • MRC • MAS • Myoton • WMFT • Chedoke Arm and Hand Activity Inventory • FIM • SIS 3.0 • EuroQol Quality of Life Scale (EQ-5D) • hand strength • MAL • ABILHAND questionnaire • 10-meter walking test • Nottingham Extended ADL Questionnaire • Adelaide Activities Profile • Montreal Cognitive Assessment • Number Stroop test • accelerometer • Revised Nottingham Sensory Assessmen • algometer • kinematic analysis • adverse effects
Starting date	September 2014
Contact information	Ching-Yi Wu, ScD; cywu@mail.cgu.edu.tw

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NCT02254343 (*Continued*)

Notes	

NCT02319785

Trial name or title	Effects of robot-assisted combined therapy in upper limb rehabilitation in stroke patients
Methods	Randomised cross-over trial
Participants	Country: Taiwan Participants: estimated enrolment n = 120 Inclusion criteria: age 18 to 80 years; first-ever unilateral stroke > 3 months after onset; upper extremity FMA score between 18 to 56 points; no excessive spasticity in the affected upper extremity; being able to follow study instructions and to perform study tasks; written informed consent Exclusion criteria: neural or psychological problems that may interfere with study; severe joint pain; upper limb fracture within the last 3 months; participation in any other research
Interventions	Experimental group 1: robot-assisted therapy and neuromuscular electrical stimulation for 1.5 hours per day, 5 days a week for 4 weeks Experimental group 2: robot-assisted therapy and mirror therapy for 1.5 hours per day, 5 days a week for 4 weeks Experimental group 3: mirror therapy for 1.5 hours per day, 5 days a week for 4 weeks Experimental group 4: unilateral robot-assisted therapy (InMotion device) for 1.5 hours per day, 5 days a week for 4 weeks Experimental group 5: bilateral robot-assisted therapy (Bi-Manu-Track) for 1.5 hours per day, 5 days a week for 4 weeks Control group (active): conventional rehabilitation for 1.5 hours per day, 5 days a week for 4 weeks
Outcomes	Outcomes will be collected at baseline and at the end of study at 4 weeks Primary outcomes: • kinematic analyses • FMA Secondary outcomes: • 10-meter walk test • WMFT • FIM • ARAT Other outcome measures: • MRC • Functional Ambulation Categories • MAS • MAL • ABILHAND questionnaire • SIS 3.0
Starting date	August 2014
Contact information	Keh-Chung Lin; kehchunglin@ntu.edu.tw Chung-Shan Hung; f00429003@ntu.edu.tw

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NCT02319785 (*Continued*)

Notes	

NCT02323061

Trial name or title	Brain Computer Interface (BCI) System for stroke rehabilitation
Methods	RCT
Participants	Country: China Participants: estimated enrolment n = 60 Inclusion criteria: age above 18 years; hemiparesis resulting from a single unilateral lesion of the brain; at least 6 months after onset; subcortical ischaemic lesion within the territory of the middle cerebral artery; being able to follow simple instructions; understand purpose and content of the experiment; moderate to severe motor disability in the paretic upper limb Exclusion criteria: severe hand spasticity; open hand wound or hand deformity; visual-field defects; aphasia; neglect; apraxia; participation in any therapeutic treatment outside the study; history of substance abuse; bilateral infarctions; uncontrolled medical problems; serious cognitive deficits; other MRI contraindications
Interventions	Experimental group 1: EEG-guided robotic training based on ipsilesional EEG signals for 30 sessions Experimental group 2: EEG-guided training based on both ipsilesional and contralesional EEG signals for 30 sessions Control group: placebo comparator robot for 30 sessions
Outcomes	Outcomes will be collected at 3-month follow-up Primary outcomes: • FMA Secondary outcomes: • ARAT • MAS • MRI
Starting date	May 2015
Contact information	Raymond Tong, PhD; +852 3943 8454
Notes	

NTR3669

Trial name or title	Feasibility of supervised care and rehabilitation involving personal telerobotics for arm/hand function of chronic stroke patients
Methods	RCT
Participants	Country: the Netherlands Participants: estimated enrolment n = 20 Inclusion criteria: age between 18 and 80 years; unilateral and ischaemic or haemorrhagic stroke; time since stroke between 6 and 12 months; clinical diagnosis of central paresis of arm or hand with 15° active elbow

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NTR3669 (*Continued*)

	flexion; 1/4 range of active finger flexion; ability to complete measurements and training sessions; discharged from medical centre; living at home and having Internet access; having a carer who is co-resident or closely involved in care; ability to read, understand, and follow instructions; device fits to the person; written informed consent Exclusion criteria: receiving additional therapy to the affected upper extremity during the study; not eligible to join normal rehabilitation; other severe comorbidities; severe sensory impairments; severe neglect; visual impairments; cognitive impairment
Interventions	Experimental group: 60 minutes of technology-assisted arm/hand training for 18 sessions during 6 weeks (consisting of computerised gaming wearing the SCRIPT hand device to support hand opening and the SaeboMAS for gravity compensation) Control group: 60 minutes of technology-assisted arm/hand training for 18 sessions during 6 weeks of conventional home training (standard arm and hand exercises)
Outcomes	Primary outcomes: • user acceptance (usability, satisfaction, motivation, compliance) Secondary outcomes: • ARAT • FMA • BBT • MAL • SIS • kinematics • EMG
Starting date	January 2013
Contact information	Sharon Nijenhuis, MSc; s.nijenhuis@rrd.nl
Notes	

RATULS

Trial name or title	Robot Assisted Training for the Upper Limb after Stroke (RATULS)
Methods	Multicentre RCT
Participants	Country: UK Inclusion criteria: adults with acute or chronic stroke causing moderate to severe upper limb functional limitation
Interventions	3 groups: 1. robot-assisted training using the InMotion robotic gym system 2. enhanced upper limb therapy 3. usual care
Outcomes	Primary outcome: upper limb function measured by ARAT at 3 months' postrandomisation Secondary outcomes: upper limb impairment, activities of daily living, quality of life, resource use, and adverse events measured at 3 and 6 months' postrandomisation

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RATULS (*Continued*)

Starting date	April 2014
Contact information	https://research.ncl.ac.uk/ratuls/contact%20us/
Notes	Sample size: 720 participants Study duration: 57 months

ADL: activities of daily living
ARAT: Action Research Arm Test
BBT: Box and Block Test
BOLD: blood oxygenation level dependent
BI: Barthel Index
CT: computerised tomography
EEG: electroencephalogram
EMG: electromyography
FIM: Functional Independence Measure
FMA: Fugl-Meyer Assessment
fMRI: functional magnetic resonance imaging
MAL: Motor Activity Log
MAS: Modified Ashworth Scale
MRC: Medical Research Council
MRI: magnetic resonance imaging
NIHSS: National Institutes of Health Stroke Scale
RCT: randomised controlled trial
SIS: Stroke Impact Scale
UE: upper extremity
WMFT: Wolf Motor Function Test

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DATA AND ANALYSES

Comparison 1. Electromechanical and robotic assisted training versus all other intervention

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Activities of daily living at the end of intervention phase	18	717	Std. Mean Difference (IV, Random, 95% CI)	0.37 [0.11, 0.64]
2 Activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase	18		Std. Mean Difference (IV, Random, 95% CI)	Subtotals only
2.1 Participants treated in the acute and subacute phase of their stroke (within 3 months)	8	320	Std. Mean Difference (IV, Random, 95% CI)	0.53 [0.09, 0.96]
2.2 Participants treated in the chronic phase (more than 3 months)	10	397	Std. Mean Difference (IV, Random, 95% CI)	0.66 [-0.17, 1.49]
3 Arm function at the end of intervention phase	31	1078	Std. Mean Difference (IV, Random, 95% CI)	0.35 [0.18, 0.51]
4 Arm muscle strength at the end of intervention phase	16	568	Std. Mean Difference (IV, Random, 95% CI)	0.36 [0.01, 0.70]
5 Acceptability: drop-outs during intervention period	34	1160	Risk Difference (M-H, Random, 95% CI)	0.00 [-0.02, 0.03]

Comparison 2. Sensitivity analysis: by trial methodology

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Activities of daily living	16		Std. Mean Difference (IV, Random, 95% CI)	Subtotals only
1.1 All studies with description of randomisation procedure	11	481	Std. Mean Difference (IV, Random, 95% CI)	0.41 [0.22, 0.59]
1.2 All studies with adequate concealed allocation	6	188	Std. Mean Difference (IV, Random, 95% CI)	0.34 [0.01, 0.67]
1.3 All studies with blinded assessors	16	640	Std. Mean Difference (IV, Random, 95% CI)	0.31 [0.07, 0.54]
2 Arm function	29		Std. Mean Difference (IV, Random, 95% CI)	Subtotals only
2.1 All studies with description of randomisation procedure	21	737	Std. Mean Difference (IV, Random, 95% CI)	0.33 [0.15, 0.52]
2.2 All studies with adequate concealed allocation	9	335	Std. Mean Difference (IV, Random, 95% CI)	0.42 [0.14, 0.69]

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2.3 All studies with blinded assessors	28	993	Std. Mean Difference (IV, Random, 95% CI)	0.33 [0.15, 0.51]

Comparison 3. Subgroup analysis by treatment approach

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Activities of daily living at the end of intervention phase: subgroup analysis comparing different device groups	18		Std. Mean Difference (IV, Random, 95% CI)	Subtotals only
1.1 distal training (finger, hand and radio-ulnar joints)	6	195	Std. Mean Difference (IV, Random, 95% CI)	0.49 [0.20, 0.78]
1.2 proximal training (shoulder and elbow joints)	12	522	Std. Mean Difference (IV, Random, 95% CI)	0.32 [-0.05, 0.68]
2 Arm function at the end of intervention phase: subgroup analysis comparing different device groups	31		Std. Mean Difference (IV, Random, 95% CI)	Subtotals only
2.1 distal training (finger, hand and radio-ulnar joints)	10	299	Std. Mean Difference (IV, Random, 95% CI)	0.39 [0.06, 0.72]
2.2 proximal training (shoulder and elbow joints)	21	779	Std. Mean Difference (IV, Random, 95% CI)	0.33 [0.14, 0.52]

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Analysis 1.1. Comparison 1 Electromechanical and robotic assisted training versus all other intervention, Outcome 1 Activities of daily living at the end of intervention phase.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 1 Electromechanical and robotic assisted training versus all other intervention

Outcome: 1 Activities of daily living at the end of intervention phase

Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
Burgar 2011	36	19.6 (8.47)	18	15.9 (6.36)		6.5 %	0.46 [-0.11, 1.04]
Conroy 2011	41	3.98 (11.94)	21	-3.19 (10.72)		6.8 %	0.61 [0.08, 1.15]
Fazekas 2007	15	12.07 (9.26)	15	25.53 (14.32)		5.2 %	-1.09 [-1.86, -0.31]
Hesse 2005	22	22.45 (15.14)	22	17.27 (13.95)		6.4 %	0.35 [-0.25, 0.95]
Hesse 2014	25	25.2 (11)	25	16 (15.7)		6.5 %	0.67 [0.10, 1.24]
Housman 2009	17	0.2 (0.4)	17	0.1 (0.3)		5.8 %	0.28 [-0.40, 0.95]
Hsieh 2011	12	0.13 (0.19)	6	0.06 (0.32)		4.0 %	0.28 [-0.71, 1.27]
Kutner 2010	11	6.89 (9.995)	10	8.49 (11.33)		4.7 %	-0.14 [-1.00, 0.71]
Liao 2011	10	0.25 (0.17)	10	0.03 (0.28)		4.3 %	0.91 [-0.02, 1.84]
Lo 2010	49	6.31 (11.76)	78	1.37 (12.1)		8.1 %	0.41 [0.05, 0.77]
Lum 2006	24	2.85 (1.21)	6	3.2 (1.4)		4.5 %	-0.27 [-1.17, 0.62]
Masiero 2007	17	32.6 (7.2)	18	25.5 (10.5)		5.7 %	0.77 [0.08, 1.46]
Masiero 2011	11	1.83 (1.4)	10	1 (0.7)		4.5 %	0.71 [-0.18, 1.60]
Rabadi 2008	10	25.49 (7.23)	20	28.29 (6.72)		5.2 %	-0.40 [-1.16, 0.37]
Volpe 2000	30	9.1 (3.3)	26	4.4 (2)		6.2 %	1.67 [1.05, 2.29]
Volpe 2008	11	67.1 (7.96)	10	65.5 (7.59)		4.7 %	0.20 [-0.66, 1.06]
Wu 2012	14	3.26 (7.16)	28	-2.88 (9.56)		5.9 %	0.68 [0.02, 1.34]
Yoo 2013	11	0.4 (6.1)	11	0.1 (3.2)		4.8 %	0.06 [-0.78, 0.90]
Total (95% CI)	**366**		**351**			**100.0 %**	**0.37 [0.11, 0.64]**

Heterogeneity: $Tau^2 = 0.19$; $Chi^2 = 44.26$, df = 17 (P = 0.00031); $I^2 = 62\%$

Test for overall effect: Z = 2.81 (P = 0.0049)

Test for subgroup differences: Not applicable

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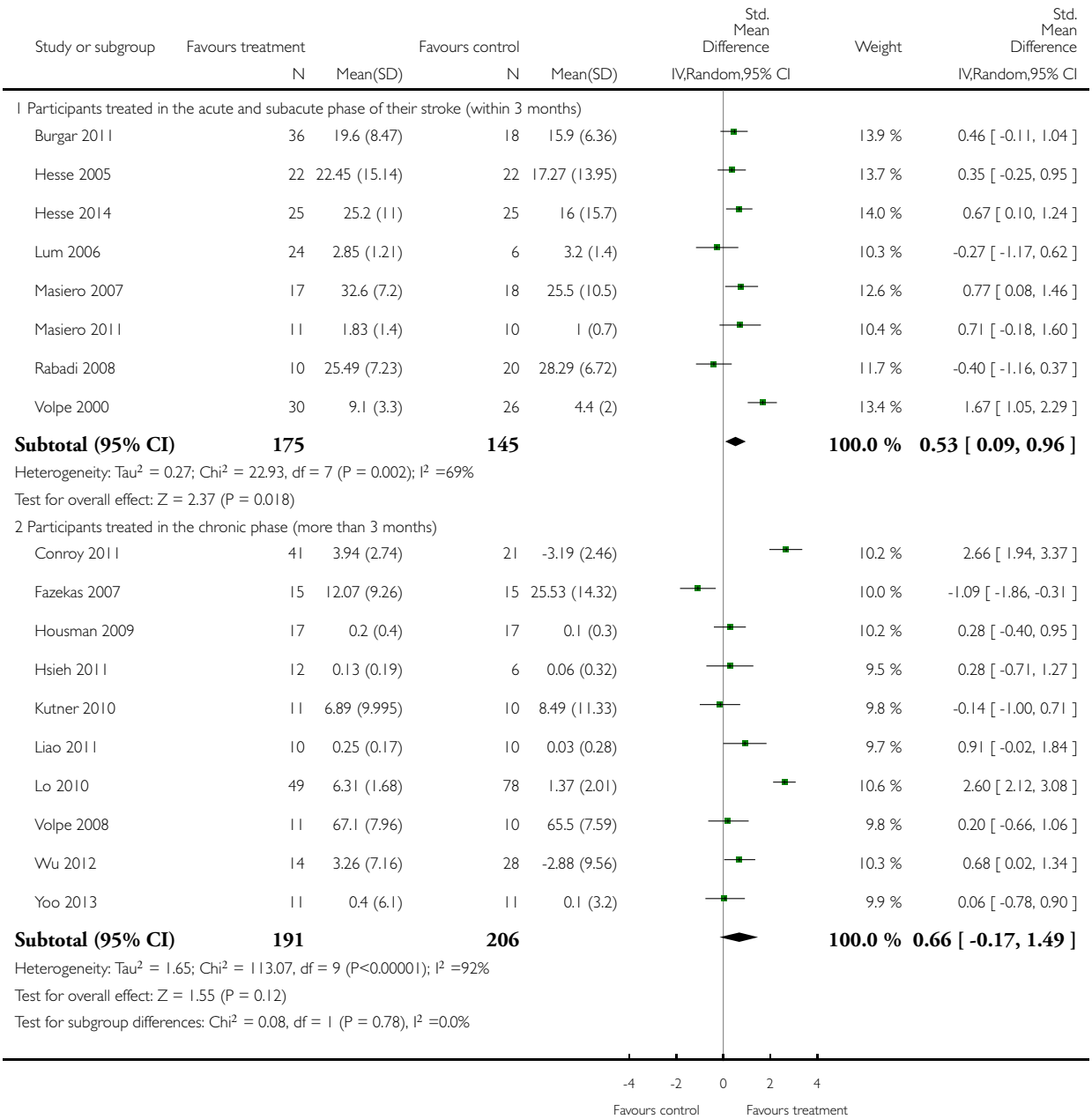
Analysis 1.2. Comparison 1 Electromechanical and robotic assisted training versus all other intervention, Outcome 2 Activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 1 Electromechanical and robotic assisted training versus all other intervention

Outcome: 2 Activities of daily living at the end of intervention phase: subgroup analysis comparing acute and chronic phase



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Analysis 1.3. Comparison 1 Electromechanical and robotic assisted training versus all other intervention, Outcome 3 Arm function at the end of intervention phase.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 1 Electromechanical and robotic assisted training versus all other intervention

Outcome: 3 Arm function at the end of intervention phase

Study or subgroup	Treatment		Control		Std. Mean Difference	Weight	Std. Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
Abdullah 2011	9	2.75 (1.8)	11	1 (1.69)		2.3 %	0.96 [0.02, 1.91]
Ang 2014	15	7.3 (3.5)	7	4.9 (4.1)		2.4 %	0.63 [-0.29, 1.55]
Brokaw 2014	7	1.8 (2)	5	1.2 (2)		1.7 %	0.28 [-0.88, 1.43]
Burgar 2011	36	10.6 (11.56)	18	14 (15.27)		4.5 %	-0.26 [-0.83, 0.31]
Conroy 2011	41	2.32 (3.42)	21	1.19 (3.4)		4.8 %	0.33 [-0.20, 0.86]
Daly 2005	7	8.17 (7.31)	6	9.5 (8.02)		1.8 %	-0.16 [-1.25, 0.93]
Fazekas 2007	15	5.53 (1.38)	15	2.6 (1.77)		2.6 %	1.80 [0.93, 2.66]
Hesse 2005	22	20.5 (19.85)	22	2.82 (4.98)		3.9 %	1.20 [0.55, 1.85]
Hesse 2014	25	11.1 (10.6)	25	14.6 (11.2)		4.6 %	-0.32 [-0.87, 0.24]
Hollenstein 2011	7	3.4 (3.9)	6	3.7 (4.1)		1.8 %	-0.07 [-1.16, 1.02]
Housman 2009	17	3.3 (2.4)	17	2.2 (2.6)		3.6 %	0.43 [-0.25, 1.11]
Hsieh 2011	12	4.17 (5.85)	6	2.83 (7.44)		2.2 %	0.20 [-0.78, 1.18]
Hsieh 2014	32	7.31 (5.53)	16	3.81 (5.02)		4.1 %	0.64 [0.03, 1.26]
Hwang 2012	9	3.5 (4.19)	6	1.3 (4.32)		1.9 %	0.49 [-0.56, 1.54]
Klamroth-Marganska 2014	39	3.25 (1.68)	38	2.47 (1.67)		5.6 %	0.46 [0.01, 0.91]
Kutner 2010	11	26.47 (17.54)	10	14.85 (19.86)		2.6 %	0.60 [-0.28, 1.48]
Liao 2011	10	6.3 (5.64)	10	1.3 (7.92)		2.4 %	0.70 [-0.21, 1.61]
Lo 2010	49	3.87 (7.35)	78	-0.03 (6.39)		6.6 %	0.57 [0.21, 0.94]
Lum 2006	24	6.98 (1.8)	6	6.5 (2.5)		2.5 %	0.24 [-0.66, 1.14]
Masiero 2007	17	15.8 (8.1)	18	10.3 (12.1)		3.7 %	0.52 [-0.16, 1.19]
Masiero 2011	11	12.16 (8.3)	10	13.87 (10.2)		2.7 %	-0.18 [-1.04, 0.68]
Mayr 2008	4	3 (2.94)	4	1.25 (1.26)		1.1 %	0.67 [-0.79, 2.13]

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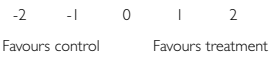
Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
McCabe 2015	12	7.7 (3.84)	27	9.35 (4.87)		3.6 %	-0.35 [-1.04, 0.33]
Rabadi 2008	10	3.05 (8.12)	20	3.88 (6.94)		3.1 %	-0.11 [-0.87, 0.65]
Sale 2014	26	8.65 (7.52)	27	3.63 (10.7)		4.7 %	0.53 [-0.02, 1.08]
Susanto 2015	9	5.11 (6.55)	10	5.7 (4.35)		2.5 %	-0.10 [-1.00, 0.80]
Timmermans 2014	11	1.6 (10.8)	11	3.5 (32.7)		2.8 %	-0.08 [-0.91, 0.76]
Volpe 2000	30	6 (3.5)	26	4 (2)		4.7 %	0.68 [0.14, 1.22]
Volpe 2008	11	19.46 (13.27)	10	17.7 (8.22)		2.7 %	0.15 [-0.71, 1.01]
Wu 2012	14	3.85 (6.71)	28	3.71 (7.08)		3.9 %	0.02 [-0.62, 0.66]
Yoo 2013	11	1.7 (9.94)	11	0.3 (3.93)		2.7 %	0.18 [-0.66, 1.02]
Total (95% CI)	**553**		**525**			**100.0 %**	**0.35 [0.18, 0.51]**

Heterogeneity: $Tau^2 = 0.07$; $Chi^2 = 46.81$, df = 30 (P = 0.03); $I^2 = 36\%$

Test for overall effect: Z = 4.13 (P = 0.000036)

Test for subgroup differences: Not applicable



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Analysis 1.4. Comparison 1 Electromechanical and robotic assisted training versus all other intervention, Outcome 4 Arm muscle strength at the end of intervention phase.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 1 Electromechanical and robotic assisted training versus all other intervention

Outcome: 4 Arm muscle strength at the end of intervention phase

Study or subgroup	Treatment		Control		Std. Mean Difference	Weight	Std. Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
Burgar 2011	36	14.85 (11.2)	18	15.4 (15.7)		7.4 %	-0.04 [-0.61, 0.52]
Hesse 2005	22	12.09 (8.35)	22	4.27 (6.17)		7.1 %	1.05 [0.41, 1.68]
Hesse 2014	25	7.5 (7.1)	25	8.1 (6.4)		7.5 %	-0.09 [-0.64, 0.47]
Housman 2009	17	0.8 (3)	17	0.8 (2.3)		6.8 %	0.0 [-0.67, 0.67]
Hsieh 2011	12	3.53 (0.53)	6	3.33 (0.69)		5.2 %	0.33 [-0.66, 1.31]
Hwang 2012	9	1.7 (7.04)	6	1.3 (6.3)		5.0 %	0.06 [-0.98, 1.09]
Klamroth-Marganska 2014	39	1.4 (8)	38	2.6 (9.5)		8.0 %	-0.14 [-0.58, 0.31]
Lum 2006	24	7.87 (7.47)	6	9.3 (3.18)		5.7 %	-0.20 [-1.10, 0.69]
Masiero 2007	17	1.73 (1.23)	18	1.2 (1.03)		6.8 %	0.46 [-0.21, 1.13]
Masiero 2011	11	0.77 (0.64)	10	1.54 (0.92)		5.6 %	-0.94 [-1.85, -0.03]
Mayr 2008	4	3.63 (4.39)	4	2.38 (4.23)		3.6 %	0.25 [-1.14, 1.65]
Rabadi 2008	10	8.33 (7.86)	20	1.24 (9.57)		6.2 %	0.76 [-0.02, 1.55]
Sale 2014	26	13.89 (15.5)	27	9.26 (21.72)		7.5 %	0.24 [-0.30, 0.78]
Volpe 2000	30	4.1 (1.4)	26	1.7 (1.7)		7.2 %	1.53 [0.93, 2.13]
Volpe 2008	11	4.82 (0.66)	10	3.37 (0.32)		4.2 %	2.64 [1.41, 3.87]
Yoo 2013	11	1 (3.61)	11	0.1 (1.49)		5.9 %	0.31 [-0.53, 1.16]
Total (95% CI)	**304**		**264**			**100.0 %**	**0.36 [0.01, 0.70]**

Heterogeneity: $Tau^2 = 0.33$; $Chi^2 = 53.04$, df = 15 (P<0.00001); $I^2 = 72\%$

Test for overall effect: Z = 2.04 (P = 0.041)

Test for subgroup differences: Not applicable

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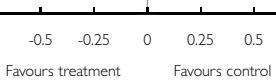
Analysis 1.5. Comparison 1 Electromechanical and robotic assisted training versus all other intervention, Outcome 5 Acceptability: drop-outs during intervention period.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 1 Electromechanical and robotic assisted training versus all other intervention

Outcome: 5 Acceptability: drop-outs during intervention period

Study or subgroup	Treatment n/N	Control n/N	Risk Difference M-H,Random,95% CI	Weight	Risk Difference M-H,Random,95% CI
Abdullah 2011	1/9	0/11		0.9 %	0.11 [-0.14, 0.36]
Amirabdollahian 2007	0/16	0/15		3.8 %	0.0 [-0.12, 0.12]
Ang 2014	0/15	0/7		1.5 %	0.0 [-0.19, 0.19]
Brokaw 2014	0/7	2/5		0.3 %	-0.40 [-0.83, 0.03]
Burgar 2011	0/36	0/18		8.0 %	0.0 [-0.08, 0.08]
Conroy 2011	5/41	2/21		2.0 %	0.03 [-0.13, 0.19]
Daly 2005	1/7	0/6		0.5 %	0.14 [-0.19, 0.47]
Fazekas 2007	0/15	0/15		3.6 %	0.0 [-0.12, 0.12]
Hesse 2005	1/22	0/22		3.8 %	0.05 [-0.07, 0.16]
Hesse 2014	1/25	0/25		4.9 %	0.04 [-0.06, 0.14]
Hollenstein 2011	0/7	0/6		0.8 %	0.0 [-0.25, 0.25]
Housman 2009	2/17	1/17		1.5 %	0.06 [-0.13, 0.25]
Hsieh 2011	0/12	0/6		1.1 %	0.0 [-0.22, 0.22]
Hsieh 2014	0/32	0/16		6.4 %	0.0 [-0.09, 0.09]
Hwang 2012	0/9	0/8		1.3 %	0.0 [-0.20, 0.20]
Kahn 2006	0/10	0/9		1.6 %	0.0 [-0.18, 0.18]
Klamroth-Marganska 2014	1/39	3/38		5.4 %	-0.05 [-0.15, 0.05]
Kutner 2010	3/10	0/11		0.6 %	0.30 [0.00, 0.60]
Liao 2011	0/10	0/10		1.7 %	0.0 [-0.17, 0.17]
Lo 2010	5/49	11/78		4.0 %	-0.04 [-0.15, 0.08]
Lum 2002	2/15	1/15		1.2 %	0.07 [-0.15, 0.28]
Lum 2006	0/24	0/6		1.3 %	0.0 [-0.20, 0.20]
Masiero 2007	2/17	3/18		1.0 %	-0.05 [-0.28, 0.18]
Masiero 2011	0/11	0/10		1.9 %	0.0 [-0.17, 0.17]



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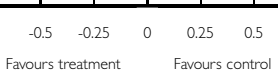
Study or subgroup	Treatment n/N	Control n/N	Risk Difference M-H,Random,95% CI	Weight	Risk Difference M-H,Random,95% CI
Mayr 2008	0/4	0/4		0.4 %	0.0 [-0.37, 0.37]
McCabe 2015	0/12	0/27		3.9 %	0.0 [-0.12, 0.12]
Rabadi 2008	0/10	0/20		2.7 %	0.0 [-0.14, 0.14]
Sale 2014	0/26	0/27		10.5 %	0.0 [-0.07, 0.07]
Susanto 2015	0/9	1/10		0.9 %	-0.10 [-0.34, 0.14]
Timmermans 2014	0/11	0/11		2.1 %	0.0 [-0.16, 0.16]
Volpe 2000	0/30	0/26		11.5 %	0.0 [-0.07, 0.07]
Volpe 2008	0/11	0/10		1.9 %	0.0 [-0.17, 0.17]
Wu 2012	0/14	0/28		5.0 %	0.0 [-0.10, 0.10]
Yoo 2013	0/11	0/11		2.1 %	0.0 [-0.16, 0.16]
Total (95% CI)	**593**	**567**		**100.0 %**	**0.00 [-0.02, 0.03]**

Total events: 24 (Treatment), 24 (Control)

Heterogeneity: $Tau^2 = 0.0$; $Chi^2 = 13.07$, df = 33 (P = 1.00); $I^2 = 0.0\%$

Test for overall effect: Z = 0.20 (P = 0.84)

Test for subgroup differences: Not applicable



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Analysis 2.1. Comparison 2 Sensitivity analysis: by trial methodology, Outcome 1 Activities of daily living.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 2 Sensitivity analysis: by trial methodology

Outcome: 1 Activities of daily living

Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
1 All studies with description of randomisation procedure							
Burgar 2011	36	19.6 (8.47)	18	15.9 (6.36)		10.6 %	0.46 [-0.11, 1.04]
Conroy 2011	41	3.98 (11.94)	21	-3.19 (10.72)		12.0 %	0.61 [0.08, 1.15]
Hesse 2005	22	22.45 (15.14)	22	17.27 (13.95)		9.8 %	0.35 [-0.25, 0.95]
Hesse 2014	25	25.2 (11)	25	16 (15.7)		10.7 %	0.67 [0.10, 1.24]
Housman 2009	17	0.2 (0.4)	17	0.1 (0.3)		7.6 %	0.28 [-0.40, 0.95]
Hsieh 2011	12	0.13 (0.19)	6	0.06 (0.32)		3.6 %	0.28 [-0.71, 1.27]
Kutner 2010	11	6.89 (9.995)	10	8.49 (11.33)		4.7 %	-0.14 [-1.00, 0.71]
Liao 2011	10	0.25 (0.17)	10	0.03 (0.28)		4.0 %	0.91 [-0.02, 1.84]
Lo 2010	49	6.31 (11.76)	78	1.37 (12.1)		26.7 %	0.41 [0.05, 0.77]
Masiero 2011	11	1.83 (1.4)	10	1 (0.7)		4.4 %	0.71 [-0.18, 1.60]
Rabadi 2008	10	25.49 (7.23)	20	28.29 (6.72)		5.9 %	-0.40 [-1.16, 0.37]
Subtotal (95% CI)	**244**		**237**			**100.0 %**	**0.41 [0.22, 0.59]**
Heterogeneity: Tau^2 = 0.0; Chi^2 = 9.01, df = 10 (P = 0.53); I^2 =0.0%							
Test for overall effect: Z = 4.27 (P = 0.000019)							
2 All studies with adequate concealed allocation							
Hesse 2005	22	22.45 (15.14)	22	17.27 (13.95)		23.5 %	0.35 [-0.25, 0.95]
Housman 2009	17	0.2 (0.4)	17	0.1 (0.3)		19.3 %	0.28 [-0.40, 0.95]
Hsieh 2011	12	0.13 (0.19)	6	0.06 (0.32)		10.2 %	0.28 [-0.71, 1.27]
Liao 2011	10	0.25 (0.17)	10	0.03 (0.28)		11.2 %	0.91 [-0.02, 1.84]
Rabadi 2008	10	25.49 (7.23)	20	28.29 (6.72)		15.7 %	-0.40 [-1.16, 0.37]
Wu 2012	14	3.26 (7.16)	28	-2.88 (9.56)		20.1 %	0.68 [0.02, 1.34]
Subtotal (95% CI)	**85**		**103**			**100.0 %**	**0.34 [0.01, 0.67]**
Heterogeneity: Tau^2 = 0.03; Chi^2 = 6.05, df = 5 (P = 0.30); I^2 =17%							
Test for overall effect: Z = 2.01 (P = 0.045)							
3 All studies with blinded assessors							
Burgar 2011	36	19.6 (8.47)	18	15.9 (6.36)		7.7 %	0.46 [-0.11, 1.04]

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Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
Conroy 2011	41	3.98 (11.94)	21	-3.19 (10.72)		8.2 %	0.61 [0.08, 1.15]
Fazekas 2007	15	12.07 (9.26)	15	25.53 (14.32)		5.5 %	-1.09 [-1.86, -0.31]
Hesse 2005	22	22.45 (15.14)	22	17.27 (13.95)		7.4 %	0.35 [-0.25, 0.95]
Hesse 2014	25	25.2 (11)	25	16 (15.7)		7.7 %	0.67 [0.10, 1.24]
Housman 2009	17	0.2 (0.4)	17	0.1 (0.3)		6.5 %	0.28 [-0.40, 0.95]
Hsieh 2011	12	0.13 (0.19)	6	0.06 (0.32)		4.0 %	0.28 [-0.71, 1.27]
Kutner 2010	11	6.89 (9.995)	10	8.49 (11.33)		4.8 %	-0.14 [-1.00, 0.71]
Liao 2011	10	0.25 (0.17)	10	0.03 (0.28)		4.3 %	0.91 [-0.02, 1.84]
Lo 2010	49	6.31 (11.76)	78	1.37 (12.1)		10.8 %	0.41 [0.05, 0.77]
Lum 2006	24	2.85 (1.21)	6	3.2 (1.4)		4.6 %	-0.27 [-1.17, 0.62]
Masiero 2007	17	32.6 (7.2)	18	25.5 (10.5)		6.4 %	0.77 [0.08, 1.46]
Masiero 2011	11	1.83 (1.4)	10	1 (0.7)		4.6 %	0.71 [-0.18, 1.60]
Rabadi 2008	10	25.49 (7.23)	20	28.29 (6.72)		5.6 %	-0.40 [-1.16, 0.37]
Wu 2012	14	3.26 (7.16)	28	-2.88 (9.56)		6.7 %	0.68 [0.02, 1.34]
Yoo 2013	11	0.4 (6.1)	11	0.1 (3.2)		5.0 %	0.06 [-0.78, 0.90]
Subtotal (95% CI)	**325**		**315**			**100.0 %**	**0.31 [0.07, 0.54]**

Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 27.25$, df = 15 (P = 0.03); $I^2 = 45\%$

Test for overall effect: Z = 2.59 (P = 0.0095)

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Analysis 2.2. Comparison 2 Sensitivity analysis: by trial methodology, Outcome 2 Arm function.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 2 Sensitivity analysis: by trial methodology

Outcome: 2 Arm function

Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
1 All studies with description of randomisation procedure							
Abdullah 2011	9	2.75 (1.8)	11	1 (1.69)		3.3 %	0.96 [0.02, 1.91]
Ang 2014	15	7.3 (3.5)	7	4.9 (4.1)		3.4 %	0.63 [-0.29, 1.55]
Brokaw 2014	7	1.8 (2)	5	1.2 (2)		2.3 %	0.28 [-0.88, 1.43]
Burgar 2011	36	10.6 (11.56)	18	14 (15.27)		6.8 %	-0.26 [-0.83, 0.31]
Conroy 2011	41	2.32 (3.42)	21	1.19 (3.4)		7.5 %	0.33 [-0.20, 0.86]
Hesse 2005	22	20.5 (19.85)	22	2.82 (4.98)		5.8 %	1.20 [0.55, 1.85]
Hesse 2014	25	11.1 (10.6)	25	14.6 (11.2)		7.0 %	-0.32 [-0.87, 0.24]
Hollenstein 2011	7	3.4 (3.9)	6	3.7 (4.1)		2.5 %	-0.07 [-1.16, 1.02]
Housman 2009	17	3.3 (2.4)	17	2.2 (2.6)		5.4 %	0.43 [-0.25, 1.11]
Hsieh 2011	12	4.17 (5.85)	6	2.83 (7.44)		3.0 %	0.20 [-0.78, 1.18]
Hsieh 2014	32	7.31 (5.53)	16	3.81 (5.02)		6.2 %	0.64 [0.03, 1.26]
Hwang 2012	9	3.5 (4.19)	6	1.3 (4.32)		2.7 %	0.49 [-0.56, 1.54]
Klamroth-Marganska 2014	39	3.25 (1.68)	38	2.47 (1.67)		8.9 %	0.46 [0.01, 0.91]
Kutner 2010	11	26.47 (17.54)	10	14.85 (19.86)		3.6 %	0.60 [-0.28, 1.48]
Liao 2011	10	6.3 (5.64)	10	1.3 (7.92)		3.5 %	0.70 [-0.21, 1.61]
Lo 2010	49	3.87 (7.35)	78	-0.03 (6.39)		10.9 %	0.57 [0.21, 0.94]
Masiero 2011	11	12.16 (8.3)	10	13.87 (10.2)		3.8 %	-0.18 [-1.04, 0.68]
Mayr 2008	4	3 (2.94)	4	1.25 (1.26)		1.5 %	0.67 [-0.79, 2.13]
Rabadi 2008	10	3.05 (8.12)	20	3.88 (6.94)		4.6 %	-0.11 [-0.87, 0.65]
Susanto 2015	9	5.11 (6.55)	10	5.7 (4.35)		3.5 %	-0.10 [-1.00, 0.80]
Timmermans 2014	11	1.6 (10.8)	11	3.5 (32.7)		3.9 %	-0.08 [-0.91, 0.76]
Subtotal (95% CI)	**386**		**351**			**100.0 %**	**0.33 [0.15, 0.52]**
Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 27.69$, df = 20 (P = 0.12); $I^2 = 28\%$							
Test for overall effect: Z = 3.49 (P = 0.00048)							
2 All studies with adequate concealed allocation							

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Favours control Favours treatment

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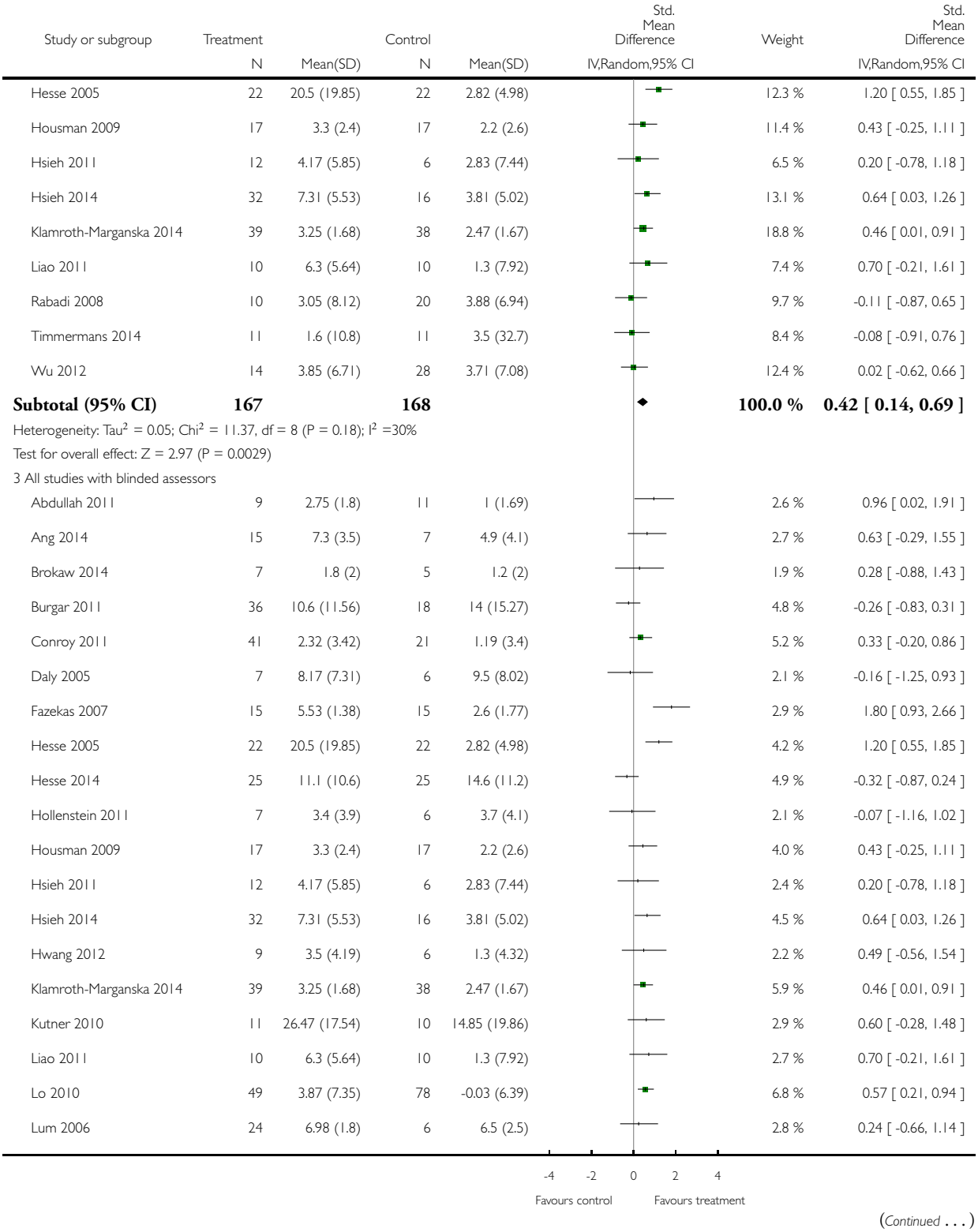

Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
Hesse 2005	22	20.5 (19.85)	22	2.82 (4.98)		12.3 %	1.20 [0.55, 1.85]
Housman 2009	17	3.3 (2.4)	17	2.2 (2.6)		11.4 %	0.43 [-0.25, 1.11]
Hsieh 2011	12	4.17 (5.85)	6	2.83 (7.44)		6.5 %	0.20 [-0.78, 1.18]
Hsieh 2014	32	7.31 (5.53)	16	3.81 (5.02)		13.1 %	0.64 [0.03, 1.26]
Klamroth-Marganska 2014	39	3.25 (1.68)	38	2.47 (1.67)		18.8 %	0.46 [0.01, 0.91]
Liao 2011	10	6.3 (5.64)	10	1.3 (7.92)		7.4 %	0.70 [-0.21, 1.61]
Rabadi 2008	10	3.05 (8.12)	20	3.88 (6.94)		9.7 %	-0.11 [-0.87, 0.65]
Timmermans 2014	11	1.6 (10.8)	11	3.5 (32.7)		8.4 %	-0.08 [-0.91, 0.76]
Wu 2012	14	3.85 (6.71)	28	3.71 (7.08)		12.4 %	0.02 [-0.62, 0.66]
Subtotal (95% CI)	**167**		**168**			**100.0 %**	**0.42 [0.14, 0.69]**
Heterogeneity: Tau^2 = 0.05; Chi^2 = 11.37, df = 8 (P = 0.18); I^2 =30%							
Test for overall effect: Z = 2.97 (P = 0.0029)							
3 All studies with blinded assessors							
Abdullah 2011	9	2.75 (1.8)	11	1 (1.69)		2.6 %	0.96 [0.02, 1.91]
Ang 2014	15	7.3 (3.5)	7	4.9 (4.1)		2.7 %	0.63 [-0.29, 1.55]
Brokaw 2014	7	1.8 (2)	5	1.2 (2)		1.9 %	0.28 [-0.88, 1.43]
Burgar 2011	36	10.6 (11.56)	18	14 (15.27)		4.8 %	-0.26 [-0.83, 0.31]
Conroy 2011	41	2.32 (3.42)	21	1.19 (3.4)		5.2 %	0.33 [-0.20, 0.86]
Daly 2005	7	8.17 (7.31)	6	9.5 (8.02)		2.1 %	-0.16 [-1.25, 0.93]
Fazekas 2007	15	5.53 (1.38)	15	2.6 (1.77)		2.9 %	1.80 [0.93, 2.66]
Hesse 2005	22	20.5 (19.85)	22	2.82 (4.98)		4.2 %	1.20 [0.55, 1.85]
Hesse 2014	25	11.1 (10.6)	25	14.6 (11.2)		4.9 %	-0.32 [-0.87, 0.24]
Hollenstein 2011	7	3.4 (3.9)	6	3.7 (4.1)		2.1 %	-0.07 [-1.16, 1.02]
Housman 2009	17	3.3 (2.4)	17	2.2 (2.6)		4.0 %	0.43 [-0.25, 1.11]
Hsieh 2011	12	4.17 (5.85)	6	2.83 (7.44)		2.4 %	0.20 [-0.78, 1.18]
Hsieh 2014	32	7.31 (5.53)	16	3.81 (5.02)		4.5 %	0.64 [0.03, 1.26]
Hwang 2012	9	3.5 (4.19)	6	1.3 (4.32)		2.2 %	0.49 [-0.56, 1.54]
Klamroth-Marganska 2014	39	3.25 (1.68)	38	2.47 (1.67)		5.9 %	0.46 [0.01, 0.91]
Kutner 2010	11	26.47 (17.54)	10	14.85 (19.86)		2.9 %	0.60 [-0.28, 1.48]
Liao 2011	10	6.3 (5.64)	10	1.3 (7.92)		2.7 %	0.70 [-0.21, 1.61]
Lo 2010	49	3.87 (7.35)	78	-0.03 (6.39)		6.8 %	0.57 [0.21, 0.94]
Lum 2006	24	6.98 (1.8)	6	6.5 (2.5)		2.8 %	0.24 [-0.66, 1.14]

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Study or subgroup	Treatment N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
Masiero 2007	17	15.8 (8.1)	18	10.3 (12.1)		4.0 %	0.52 [-0.16, 1.19]
Masiero 2011	11	12.16 (8.3)	10	13.87 (10.2)		3.0 %	-0.18 [-1.04, 0.68]
McCabe 2015	12	7.7 (3.84)	27	9.35 (4.87)		3.9 %	-0.35 [-1.04, 0.33]
Rabadi 2008	10	3.05 (8.12)	20	3.88 (6.94)		3.5 %	-0.11 [-0.87, 0.65]
Sale 2014	26	8.65 (7.52)	27	3.63 (10.7)		5.0 %	0.53 [-0.02, 1.08]
Susanto 2015	9	5.11 (6.55)	10	5.7 (4.35)		2.8 %	-0.10 [-1.00, 0.80]
Timmermans 2014	11	1.6 (10.8)	11	3.5 (32.7)		3.1 %	-0.08 [-0.91, 0.76]
Wu 2012	14	3.85 (6.71)	28	3.71 (7.08)		4.3 %	0.02 [-0.62, 0.66]
Yoo 2013	11	1.7 (9.94)	11	0.3 (3.93)		3.1 %	0.18 [-0.66, 1.02]
Subtotal (95% CI)	**508**		**485**			**100.0 %**	**0.33 [0.15, 0.51]**

Heterogeneity: $Tau^2 = 0.08$; $Chi^2 = 44.99$, df = 27 (P = 0.02); $I^2 = 40\%$

Test for overall effect: Z = 3.65 (P = 0.00026)

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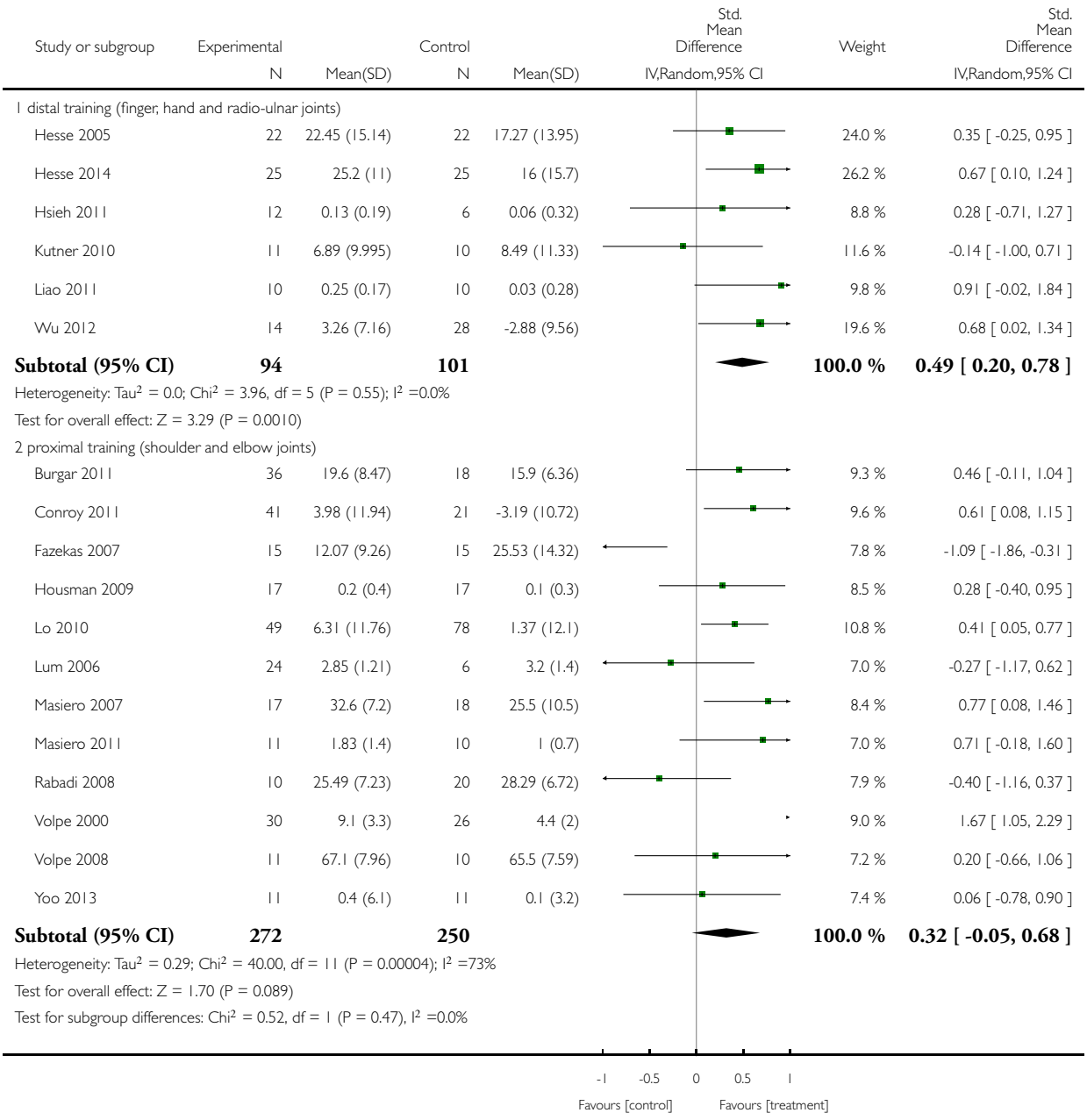
Analysis 3.1. Comparison 3 Subgroup analysis by treatment approach, Outcome 1 Activities of daily living at the end of intervention phase: subgroup analysis comparing different device groups.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 3 Subgroup analysis by treatment approach

Outcome: 1 Activities of daily living at the end of intervention phase: subgroup analysis comparing different device groups



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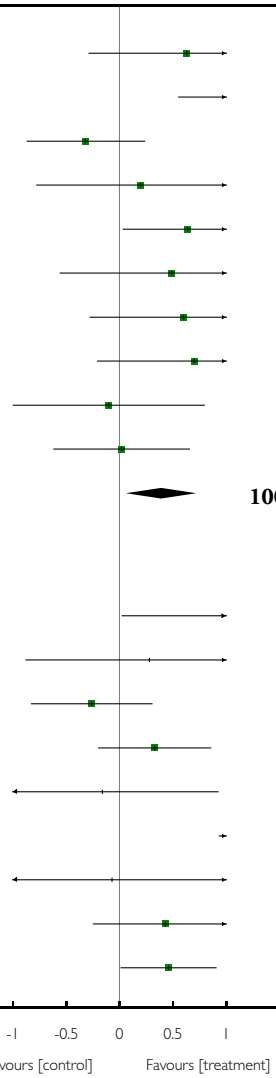
Analysis 3.2. Comparison 3 Subgroup analysis by treatment approach, Outcome 2 Arm function at the end of intervention phase: subgroup analysis comparing different device groups.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

Comparison: 3 Subgroup analysis by treatment approach

Outcome: 2 Arm function at the end of intervention phase: subgroup analysis comparing different device groups

Study or subgroup	Experimental N	Mean(SD)	Control N	Mean(SD)	Std. Mean Difference IV,Random,95% CI	Weight	Std. Mean Difference IV,Random,95% CI
1 distal training (finger, hand and radio-ulnar joints)							
Ang 2014	15	7.3 (3.5)	7	4.9 (4.1)		8.3 %	0.63 [-0.29, 1.55]
Hesse 2005	22	20.5 (19.85)	22	2.82 (4.98)		12.3 %	1.20 [0.55, 1.85]
Hesse 2014	25	11.1 (10.6)	25	14.6 (11.2)		14.0 %	-0.32 [-0.87, 0.24]
Hsieh 2011	12	4.17 (5.85)	6	2.83 (7.44)		7.6 %	0.20 [-0.78, 1.18]
Hsieh 2014	32	7.31 (5.53)	16	3.81 (5.02)		12.9 %	0.64 [0.03, 1.26]
Hwang 2012	9	3.5 (4.19)	6	1.3 (4.32)		6.9 %	0.49 [-0.56, 1.54]
Kutner 2010	11	26.47 (17.54)	10	14.85 (19.86)		8.8 %	0.60 [-0.28, 1.48]
Liao 2011	10	6.3 (5.64)	10	1.3 (7.92)		8.4 %	0.70 [-0.21, 1.61]
Susanto 2015	9	5.11 (6.55)	10	5.7 (4.35)		8.5 %	-0.10 [-1.00, 0.80]
Wu 2012	14	3.85 (6.71)	28	3.71 (7.08)		12.4 %	0.02 [-0.62, 0.66]
Subtotal (95% CI)	**159**		**140**			**100.0 %**	**0.39 [0.06, 0.72]**
Heterogeneity: $Tau^2 = 0.12$; $Chi^2 = 16.29$, df = 9 (P = 0.06); $I^2 = 45\%$							
Test for overall effect: Z = 2.32 (P = 0.020)							
2 proximal training (shoulder and elbow joints)							
Abdullah 2011	9	2.75 (1.8)	11	1 (1.69)		3.3 %	0.96 [0.02, 1.91]
Brokaw 2014	7	1.8 (2)	5	1.2 (2)		2.3 %	0.28 [-0.88, 1.43]
Burgar 2011	36	10.6 (11.56)	18	14 (15.27)		6.5 %	-0.26 [-0.83, 0.31]
Conroy 2011	41	2.32 (3.42)	21	1.19 (3.4)		7.0 %	0.33 [-0.20, 0.86]
Daly 2005	7	8.17 (7.31)	6	9.5 (8.02)		2.6 %	-0.16 [-1.25, 0.93]
Fazekas 2007	15	5.53 (1.38)	15	2.6 (1.77)		3.7 %	1.80 [0.93, 2.66]
Hollenstein 2011	7	3.4 (3.9)	6	3.7 (4.1)		2.6 %	-0.07 [-1.16, 1.02]
Housman 2009	17	3.3 (2.4)	17	2.2 (2.6)		5.2 %	0.43 [-0.25, 1.11]
Klamroth-Marganska 2014	39	3.25 (1.68)	38	2.47 (1.67)		8.2 %	0.46 [0.01, 0.91]



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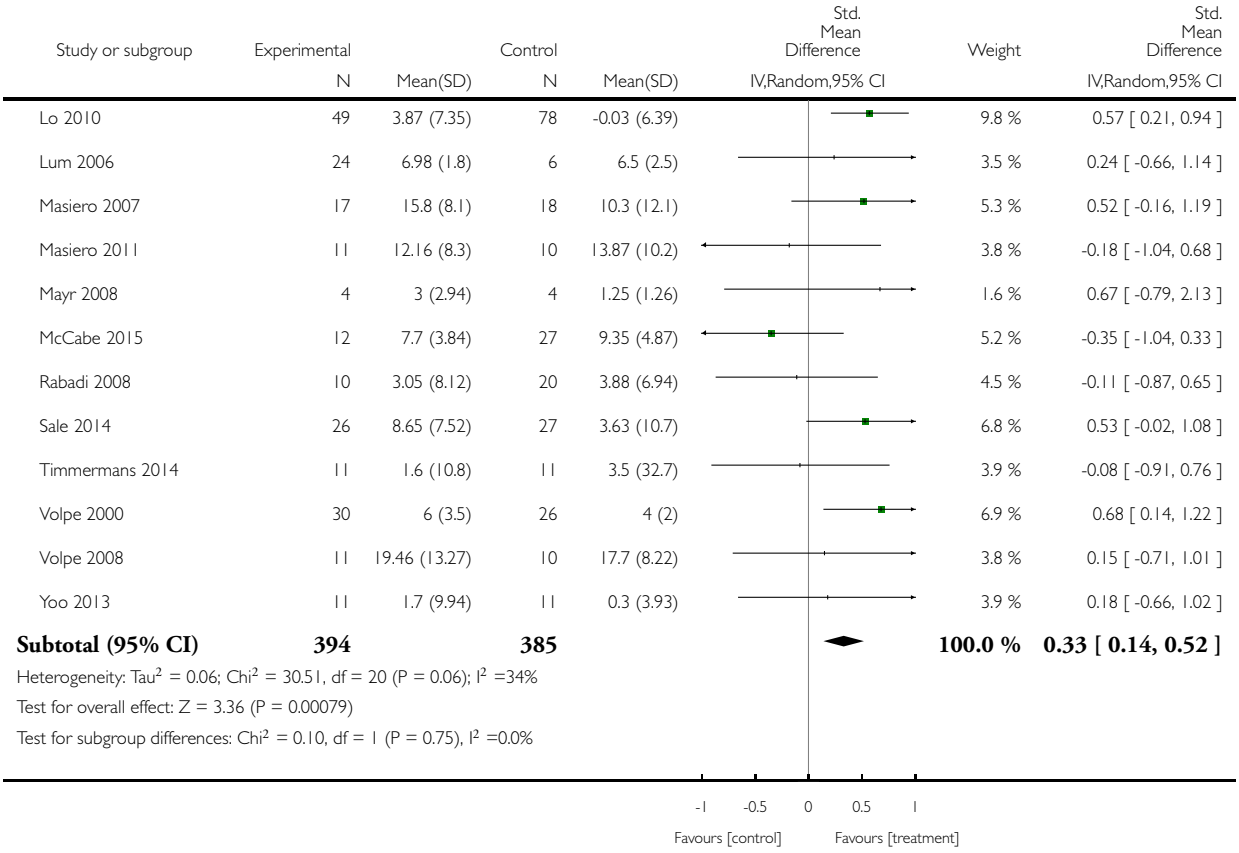

ADDITIONAL TABLES

Table 1. Participant characteristics in studies

Study ID	Age, mean (SD) EXP	Age, mean (SD) CON	Time post-stroke EXP	Time post-stroke CON	Gender EXP	Gender CON	Side-paresis EXP	Side-paresis CON	Stroke severity	Aetiology (ischaemic/haemorrhagic)
Abdullah 2011	76 (6) years	70 (16) years	4 (2) weeks	4 (2) weeks	3 F, 5 M	8 F, 3 M	3 L, 5 R	6 L, 4 R, 1 both	Stage 1-3 CMSA	Not stated
Amirabdollahian 2007	67 (7) years	68 (9) years	17 (12) months	31 (22) months	9 F, 7 M	5 F, 10 M	9 L, 7 R	7 L, 8 R	Not stated	Not stated

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Table 1. Participant characteristics in studies (*Continued*)

Ang 2014	52 (7) years	58 (19) years	350 (131) days	455 (110) days	4 F, 10 M	3 F, 4 M	Not stated	Not stated	Mean 27 points FMA upper extremity	11/10
Brokaw 2014	57 (12) years		3 (2) years		3 F, 9 M		7 L, 5 R		Mean 22 points FMA upper extremity	Not stated
Burgar 2011	60 (2) years*	68 (3) years*	17 (3) days*	11 (1) days*	Not stated	Not stated	18 L, 18 R	5 L, 13 R	Mean 27 points FIM upper limb	Not stated
Conroy 2011	59 (13) years	56 (6) years	4 (5) years	4 (6) years	23 F, 18 M	11 F, 10 M	Not stated	Not stated	Mean 72 points score on SIS, ADL	51/6
Daly 2005	Not stated	Not stated	> 12 months	> 12 months	0 F, 6 M	3 F, 3 M	Not stated	Not stated	Not stated	11/1
Fazekas 2007	57 years	56 years	23 months	10 months	8 F, 7 M	5 F, 10 M	7 L, 8 R	6 L, 9 R	Mean 30 points FIM self-care	Not stated: also included people after head trauma
Hesse 2005	65 (12) years	64 (12) years	5 (1) weeks	5 (1) weeks	12 F, 10 M	12 F, 10 M	14 L, 8 R	11 L, 11 R	Mean 42 of 100 Barthel points	40/4
Hesse 2014	71 (16) years	70 (17) years	5 (2) weeks	5 (1) weeks	12 F, 13 M	10 F, 15 M	14 L, 11 R	13 L, 12 R	Mean 27 of 100 Barthel points	41/9
Hollenstein 2011	71 (8) years	75 (11) years	33 (14) days	29 (10) days	4 F, 3 M	5 F, 1 M	4 L, 3 R	3 L, 3 R	Not stated	Not stated

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Table 1. Participant characteristics in studies (*Continued*)

Housman 2009	54 (12) years	56 (11) years	> 12 months	> 12 months	3 F, 11 M	7 F, 7 M	10 L, 4 R	10 L, 4 R	Not stated	17/9; 2 unknown
Hsieh 2011	54 (8) years	54 (8) years	17 (7) months	28 (20) months	2 F, 8 M	1 F, 5 M	6 L, 6 R	4 L, 2 R	Not stated	15/3
Hsieh 2014	53 (10) years	54 (10) years	22 (14) months	28 (19) months	10 F, 22 M	4 F, 12 M	19 L, 13 R	7 L, 9 R	Mean 34 points FMA upper extremity	27/21
Hwang 2012	50 (4) years	51 (3) years	7 (6) months	5 (6) months	4 F, 5 M	2 F, 4 M	Not stated		Mean 43 (16) SIS activities	Not stated
Kahn 2006	56 (12) years	56 (12) years	76 (46) months	103 (48) months	6 F, 4 M	2 F, 7 M	5 L, 5 R	6 L, 3 R	Not stated	Not stated
Klamroth-Marganska 2014	55 (13) years	58 (14) years	52 (44) months	40 (45) months	17 F, 21 M	10 F, 25 M	Not stated		Mean SIS total score 63 (11)	Not stated
Kutner 2010	62 (13) years	51 (11) years	270 (111) days	184 (127) days	5 F, 5 M	2 F, 5 M	Not stated	Not stated	SIS ADL mean 59 and 68 for EXP and CTL groups, respectively	12/5
Liao 2011	55 (11) years	54 (8) years	23 (13) months	22 (17) months	4 F, 6 M	3 F, 7 M	4 L, 6 R	3 L, 7 R	Mean 116 points FIM self-care	Not stated
Lo 2010	66 (11) years	64 (11) years	4 (4) months	5 (4) months	2 F, 47 M	3 F, 75 M	Not stated	Not stated	Mean 49 points score on SIS	108/19
Lum 2002	63 (4) years*	66 (2) years*	30 (6) months*	29 (6) months*	1 F, 12 M	6 F, 8 M	4 L, 9 R	4 L, 10 R	Mean 87 of 100	Not stated

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Table 1. Participant characteristics in studies (*Continued*)

									Barthel points	
Lum 2006#	67 years	60 years	11 weeks	11 weeks	8 F, 16 M	2 F, 4 M	11 L, 13 R	2 L, 4 R	Not stated	Not stated
Masiero 2007	63 (13) years	67 (12) years	Not stated	Not stated	7 F, 10 M	7 F, 11 M	4 L, 11 R	5 L, 10 R	Not stated	Not stated
Masiero 2011	72 (7) years	76 (5) years	10 (5) days	13 (5) days	2 F, 9 M	3 F, 7 M	9 L, 2 R	8 L, 2 R	Mean total FIM 30 points	18/3
Mayr 2008	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	4 L	4 L	Not stated	6/2
McCabe 2015	21-49 years: n = 2; 50-81 years: n = 10	21-49 years: n = 5; 50-81 years: n = 18	1-3 years: n = 9; ≥4 years: n = 3	1-3 years: n = 18; ≥4 years: n = 5	2 F, 10 M	10 F, 13 M	Not stated	Not stated	23 (6) FMA upper extremity points	Not stated
Rabadi 2008	80 (6) years	69 (11) years	10 (4) days	14 (13) days	5 F, 5 M	6 F, 14 M	Not stated	Not stated	Mean FIM score 39 (11)	3/0
Sale 2014	68 (14) years	68 (14) years	Not stated	Not stated	11 F, 15 M	11 F, 16 M	16 L, 10 R	13 L, 14 R	Mean CMSA 3 (1)	53/0
Susanto 2015	51 (9) years	55 (11) years	16 (6) months	16 (5) months	2 F, 7 M	3 F, 7 M	6 L, 3 R	6 L, 4 R	Mean FMA 33 (9)	8/11
Timmermans 2014	62 (7) years	57 (6) years	3 (3) years	4 (3) years	3 F, 8 M	3 F, 8 M	7 L, 4 R	8 L, 3 R	Mean FMA 52	Not stated
Volpe 2000	62 (2) years*	67 (2) years*	23 (1) days*	26 (1) days*	14 F, 16 M	12 F, 14 M	17 L, 13 R	14 L, 12 R	Not stated	49/7
Volpe 2008	62 (3) years*	60 (3) years*	35 (7) months*	40 (11) months*	3 F, 8 M	3 F, 7 M	5 L, 6 R	5 L, 5 R	Mean 17 points NIHSS	20/1
Wu 2012	56 (11) years	51 (6) years	18 (11) months	18 (10) months	6 F, 22 M	4 F, 22 M	16 L, 12 R	10 L, 4 R	Mean FMA 44 (10)	Not stated

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Table 1. Participant characteristics in studies (*Continued*)

									points	
Yoo 2013	51 (11) years	50 (9) years	46 (42) months	42 (33) months	4 F, 7 M	5 F, 6 M	6 L, 5 R	4 L, 7 R	Mean Barthel Index 76 (5)	15/7

*SE instead of SD
#EXP: all robot groups
ADL: activities of daily living
CMSA: Chedoke-McMaster Stroke Assessment
CON: control group
EXP: experimental group
F: female
FIM: Functional Independence Measure
FMA: Fugl-Meyer AssessmentL: left
M: male
NIHSS: National Institutes of Health Stroke ScaleR: right
SD: standard deviation
SE: standard error
SIS: Stroke Impact Scale

Table 2. Details of study interventions

Study ID	Duration of study	Frequency and intensity of treatment	Follow-up	Device used
Abdullah 2011	8 to 11 weeks	3 times a week (groups received the same time and frequency)	-	Adapted 5 DOF industrial robot
Amirabdollahian 2007	3 weeks	5 times a week (groups received the same time and frequency)	-	GENTLE/s
Ang 2014	6 weeks	3 times a week for 90 minutes (groups received the same time and frequency)	6 weeks and 18 weeks	Haptic Knob and Haptic Knob with Brain-Computer Interface
Brokaw 2014	3 months	12 hours within a month (groups received the same time and frequency)	-	ARMin III, HandSOME
Burgar 2011	3 weeks	1 experimental group and the control group had 15 x 1-hour therapy sessions over a 3-week period (1 robot group received 30 1-	6 months	MIME

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Table 2. Details of study interventions (*Continued*)

		hour therapy sessions over a 3-week period)		
Conroy 2011	6 weeks	3 sessions per week for 1 hour (groups received the same time and frequency)	3 months	InMotion 2.0 Shoulder/Arm Robot
Daly 2005	12 weeks	5 hours a day, 5 days a week (groups received the same time and frequency)	3 months	InMotion
Fazekas 2007	5 weeks	Control group received 30-minute sessions on 20 consecutive workdays (Bobath, Kabat) Experimental group received same therapy as the control group, but also additional 30 minutes of robot therapy	-	REHAROB
Hesse 2005	6 weeks	30 minutes, 5 times a week (groups received the same time and frequency)	3 months	Bi-Manu-Track
Hesse 2014	4 weeks	30 minutes, 5 times a week (groups received the same time and frequency)	3 months	Bi-Manu-Track, Reha-Digit, Reha-Slide, Reha-Slide Duo
Hollenstein 2011	2 weeks	5 times a week for 30 minutes (groups received the same time and frequency)	-	Armeo
Housman 2009	8 to 9 weeks	3 times a week for 1 hour (groups received the same time and frequency)	6 months	T-WREX
Hsieh 2011	4 weeks	Higher-intensity robotic training group: 20 sessions for 90 to 105 minutes, 5 days per week Lower-intensity robotic training group: same amount, but had only half of the repetitions by the device as in first group Conventional treatment	-	Bi-Manu-Track

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Table 2. Details of study interventions (*Continued*)

		group: same amount as in the other groups (groups received the same time and frequency)		
Hsieh 2014	4 weeks	Participants in each group received 20 training sessions of 90 to 105 minutes/day, 5 days/week for 4 weeks. In addition to the intervention provided in the clinics, all participants were encouraged to use their affected upper limb during activities in their daily life situations (e.g. at home) RT + CIT group (received 2 weeks robot-assisted arm therapy (Bi-Manu-Track 40 to 55 minutes plus 15 to 20 minutes conventional therapy without robot), afterwards 2 weeks constraint-induced therapy 90 to 105 minutes therapy a day and 6 hours constraint daily) RT group (received robot-assisted arm therapy (Bi-Manu-Track) as above) CT group (received a therapist- mediated intervention using conventional occupational therapy techniques, including neurodevelopmental techniques, functional task practice, fine-motor training, arm exercises or gross-motor training, and muscle strengthening)	-	Bi-Manu-Track
Hwang 2012	4 weeks	4 weeks (20 sessions) of active robot-assisted intervention versus 2 weeks (10 sessions) of early passive therapy followed by	4 weeks	Amadeo

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Table 2. Details of study interventions (*Continued*)

		2 weeks (10 sessions) of active robot-assisted intervention (groups received the same time and frequency)		
Kahn 2006	8 weeks	24 sessions for 45 minutes (groups received the same time and frequency)	-	ARM Guide
Klamroth-Marganska 2014	8 weeks	Robotic training or conventional therapy 3 times a week for at least 45 minutes (groups received the same time and frequency)	26 weeks	ARMin
Kutner 2010	3 weeks	1) 60 hours of repetitive-task training over the course of 3 weeks 2) 30 hours of repetitive-task training plus 30 hours of robotic-assisted training with the Hand Mentor device over the course of 3 weeks (groups received the same time and frequency)	2 months	Hand Mentor
Liao 2011	4 weeks	5 days a week for 90 to 105 minutes per session (groups received the same time and frequency)	-	Bi-Manu-Track
Lo 2010	12 weeks	Group A: a maximum of 36 sessions over a period of 12 weeks Group B: same time and frequency Group C: usual care at different time and frequency	3, 6, 9 months	MIT-Manus
Lum 2002	8 weeks	Control group received 55 minutes of physiotherapy for the arm and 5 minutes of robot training at each of the 24 sessions Experimental group received robot therapy for the same time and frequency	8 months	MIME

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Table 2. Details of study interventions (*Continued*)

Lum 2006	4 weeks	All groups received 15 1-hour treatment sessions (all groups had same time and frequency)	6 months	MIME
Masiero 2007	5 weeks	Experimental group received additional robotic training twice a day, 5 days a week Control group received similar exposure to the robot but with the unimpaired arm (both groups had same time and frequency)	3 and 8 months	NeReBot
Masiero 2011	5 weeks	Experimental group received robotic training twice a day for 20 minutes, and 40 minutes conventional training, 5 days a week Control group received conventional functional rehabilitation for 80 minutes a day (groups received the same time and frequency)	3 months	NeReBot
Mayr 2008	6 weeks	5 times per week (both groups received the same time and frequency)	-	ARMOR
McCabe 2015	5 weeks	5 hours per day for 12 weeks (all groups received the same time and frequency)	-	InMotion2 Shoulder/Elbow Robot
Rabadi 2008	Not stated	Standard occupational and physical therapy for 3 hours per day + 12 additional sessions of 40 minutes of either occupational therapy, arm ergometry, or robotic-assisted training for 5 days per week	-	MIT-Manus

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Table 2. Details of study interventions (*Continued*)

Sale 2014	6 weeks	30 sessions of robot-assisted therapy (5 days a week for 6 weeks) versus 30 sessions (5 days a week for 6 weeks) of conventional rehabilitative treatment Experimental and control therapies were applied in addition to usual rehabilitation (groups received the same time and frequency)	-	MIT-Manus/InMotion2
Susanto 2015	5 weeks	Hand exoskeleton robot-assisted training for 20 1-hour sessions versus control group (non-assisted group) for 20 1-hour sessions (groups received the same time and frequency)	6 months	Self designed hand exoskeleton robot
Timmermans 2014	8 weeks	Robotic-assisted training with the end-effector robot HapticMaster versus arm-hand training program during 8 weeks, 4 times/week, twice a day for 30 minutes (groups received the same time and frequency)	6 month	HapticMaster
Volpe 2000	5 weeks	1 hour per day, 5 days a week (for at least 25 sessions) (both groups received the same time and frequency)	-	MIT-Manus
Volpe 2008	6 weeks	1 hour per session, 3 times a week (both groups received the same time and frequency)	3 months	InMotion2
Wu 2012	4 weeks	Therapist-mediated bilateral arm training (TBAT group) versus robot-assisted (Bi-Manu-Track) arm trainer (RBAT group)	-	Bi-Manu-Track

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Table 2. Details of study interventions (*Continued*)

		versus conventional therapy (involved weight bearing, stretching, strengthening of the paretic arms, co-ordination, unilateral and bilateral fine-motor tasks, balance, and compensatory practice on functional tasks; CT group). Each group received treatment for 90 to 105 minutes per session, 5 sessions on weekdays, for 4 weeks (groups received the same time and frequency)		
Yoo 2013	6 weeks	3-dimensional robot-assisted therapy (RAT) and conventional rehabilitation therapy (CRT) for a total of 90 minutes (RAT: 30 minutes, CRT: 60 minutes) a day with 10 minutes rest halfway through the session, received training 3 days a week for 6 weeks. The control group received only CRT for 60 minutes a day on the same days as the first group	-	ReoGo

DOF: Degrees of Freedom
MIME: mirror image motion enabler

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APPENDICES

Appendix 1. CENTRAL search strategy

Cochrane Central Register of Controlled Trials (CENTRAL) The Cochrane Library
#1 [mh ^"cerebrovascular disorders"] or [mh "basal ganglia cerebrovascular disease"] or [mh "brain ischemia"] or [mh "carotid artery diseases"] or [mh "cerebral small vessel diseases"] or [mh "intracranial arterial diseases"] or [mh "intracranial embolism and thrombosis"] or [mh "intracranial hemorrhages"] or [mh ^stroke] or [mh "brain infarction"] or [mh ^"stroke, lacunar"] or [mh ^"vasospasm, intracranial"] or [mh ^"vertebral artery dissection"] or [mh ^"brain injuries"] or [mh ^"brain injury, chronic"]
#2 (stroke* or poststroke or apoplex* or cerebral next vasc* or brain next vasc* or cerebrovasc* or cva* or SAH):ti,ab
#3 ((brain or cerebr* or cerebell* or vertebrobasil* or hemispher* or intracran* or intracerebral or infratentorial or supratentorial or "middle cerebral artery" or MCA* or "anterior circulation" or "posterior circulation" or "basilar artery" or "vertebral artery" or "space-occupying") near/5 (isch*emi* or infarct* or thrombo* or emboli* or occlus* or hypoxi*)):ti,ab
#4 ((brain* or cerebr* or cerebell* or intracerebral or intracran* or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal next gangli* or putaminal or putamen or "posterior fossa" or hemispher* or subarachnoid) near/5 (hemorrhag* or haemorrhage* or hematoma* or haematoma* or bleed*)):ti,ab
#5 [mh ^hemiplegia] or [mh paresis]
#6 (hemipleg* or hemipar* or paresis or paretic or brain next injur*):ti,ab
#7 #1 or #2 or #3 or #4 or #5 or #6
#8 [mh "upper extremity"]
#9 (upper next limb* or upper next extremit* or arm or arms or shoulder or shoulders or hand or hands or axilla* or elbow* or forearm* or finger* or wrist*):ti,ab
#10 #8 or #9
#11 [mh robotics] or [mh automation] or [mh "orthotic devices"]
#12 [mh "equipment and supplies"] or [mh "self-help devices"]
#13 [mh "physical therapy modalities"] or [mh "occupational therapy"]
#14 [mh "therapy, computer-assisted"] or [mh "man-machine systems"]
#15 [mh "exercise movement techniques"] or [mh exercise] or [mh "exercise therapy"] or [mh "muscle stretching techniques"] or [mh "motion therapy, continuous passive"]
#16 (robot* or orthos* or orthotic or automat* or computer next aided or computer next assisted or device*):ti,ab
#17 (electromechanical or "electro-mechanical" or mechanical or mechanised or mechanized or driven):ti,ab
#18 ((continuous passive or cpm) near/3 therap*):ti,ab
#19 (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin):ti,ab
#20 (assist* near/5 (train* or aid* or rehabilitat* or re-educat*)):ti,ab
#21 #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20
#22 #7 and #10 and #21
Number of hits: n=930

Appendix 2. MEDLINE (Ovid) search strategy

Medline (Ovid) Revised March 2015
1. cerebrovascular disorders/ or exp basal ganglia cerebrovascular disease/ or exp brain ischemia/ or exp carotid artery diseases/ or exp cerebral small vessel diseases/ or exp intracranial arterial diseases/ or exp "intracranial embolism and thrombosis"/ or exp intracranial hemorrhages/ or stroke/ or exp brain infarction/ or stroke, lacunar/ or vasospasm, intracranial/ or vertebral artery dissection/ or brain injuries/ or brain injury, chronic/
2. (stroke$ or poststroke or apoplex$ or cerebral vasc$ or brain vasc$ or cerebrovasc$ or cva$ or SAH).tw.
3. ((brain or cerebr$ or cerebell$ or vertebrobasil$ or hemispher$ or intracran$ or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA$ or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying) adj5 (isch?emi$ or infarct$ or thrombo$ or emboli$ or occlus$ or hypoxi$)).tw.
4. ((brain$ or cerebr$ or cerebell$ or intracerebral or intracran$ or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli$ or putaminal or putamen or posterior fossa or hemispher$ or subarachnoid) adj5 (h?emorrhag$ or h?ematoma$ or bleed$)).tw.

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5. hemiplegia/ or exp paresis/
6. (hemipleg$ or hemipar$ or paresis or paretic or brain injur$).tw.
7. or/1-6
8. exp upper extremity/
9. (upper limb$ or upper extremit$ or arm or arms or shoulder or shoulders or hand or hands or axilla$ or elbow$ or forearm$ or finger$ or wrist$).tw.
10. 8 or 9
11. robotics/ or automation/ or orthotic devices/
12. "equipment and supplies"/ or self-help devices/
13. physical therapy modalities/ or occupational therapy/
14. therapy, computer-assisted/ or man-machine systems/
15. exercise movement techniques/ or exercise/ or exercise therapy/ or muscle stretching techniques/ or motion therapy, continuous passive/
16. (robot$ or orthos$ or orthotic or automat$ or computer aided or computer assisted or device$).tw.
17. (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven).tw.
18. ((continuous passive or cpm) adj3 therap$).tw.
19. (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin).tw.
20. (assist$ adj5 (train$ or aid$ or rehabilitat$ or re-educat$)).tw.
21. or/11-20
22. Randomized Controlled Trials as Topic/
23. random allocation/
24. Controlled Clinical Trials as Topic/
25. control groups/
26. clinical trials as topic/ or clinical trials, phase i as topic/ or clinical trials, phase ii as topic/ or clinical trials, phase iii as topic/ or clinical trials, phase iv as topic/
27. double-blind method/
28. single-blind method/
29. Placebos/
30. placebo effect/
31. cross-over studies/
32. randomized controlled trial.pt.
33. controlled clinical trial.pt.
34. (clinical trial or clinical trial phase i or clinical trial phase ii or clinical trial phase iii or clinical trial phase iv).pt.
35. (random$ or RCT or RCTs).tw.
36. (controlled adj5 (trial$ or stud$)).tw.
37. (clinical$ adj5 trial$).tw.
38. ((control or treatment or experiment$ or intervention) adj5 (group$ or subject$ or patient$)).tw.
39. (quasi-random$ or quasi random$ or pseudo-random$ or pseudo random$).tw.
40. ((control or experiment$ or conservative) adj5 (treatment or therapy or procedure or manage$)).tw.
41. ((singl$ or doubl$ or tripl$ or trebl$) adj5 (blind$ or mask$)).tw.
42. (cross-over or cross over or crossover).tw.
43. (placebo$ or sham).tw.
44. trial.ti.
45. (assign$ or allocat$).tw.
46. controls.tw.
47. or/22-46
48. 7 and 10 and 21 and 47
49. exp animals/ not humans.sh.
50. 48 not 49
Number of hits: n=552

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Appendix 3. EMBASE (Ovid) search strategy

EMBASE (Ovid) Revised March 2015

1. cerebrovascular disease/ or exp basal ganglion hemorrhage/ or exp brain hematoma/ or exp brain hemorrhage/ or exp brain infarction/ or exp brain ischemia/ or exp carotid artery disease/ or cerebral artery disease/ or exp cerebrovascular accident/ or exp intracranial aneurysm/ or exp occlusive cerebrovascular disease/ or stroke unit/ or stroke patient/ or brain injury/ or acquired brain injury/
2. (stroke$ or poststroke or apoplex$ or cerebral vasc$ or brain vasc$ or cerebrovasc$ or cva$ or SAH).tw.
3. ((brain or cerebr$ or cerebell$ or vertebrobasil$ or hemispher$ or intracran$ or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA$ or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying) adj5 (isch?emi$ or infarct$ or thrombo$ or emboli$ or occlus$ or hypoxi$)).tw.
4. ((brain$ or cerebr$ or cerebell$ or intracerebral or intracran$ or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli$ or putaminal or putamen or posterior fossa or hemispher$ or subarachnoid) adj5 (h?emorrhag$ or h?ematoma$ or bleed$)).tw.
5. hemiparesis/ or hemiplegia/ or paresis/
6. (hemipleg$ or hemipar$ or paresis or paretic or brain injur$).tw.
7. 1 or 2 or 3 or 4 or 5 or 6
8. exp arm/ or arm weakness/ or arm exercise/ or arm movement/
9. (upper limb$ or upper extremit$ or arm or arms or shoulder or shoulders or hand or hands or axilla$ or elbow$ or forearm$ or finger$ or wrist$).tw.
10. 8 or 9
11. robotics/ or automation/ or orthotics/
12. man machine interaction/ or biomedical engineering/ or device/ or machine/ or assistive technology/ or assistive technology device/ or computer assisted therapy/
13. passive movement/ or movement therapy/ or kinesiotherapy/ or exp exercise/ or muscle stretching/ or muscle training/
14. (robot$ or orthos$ or orthotic or automat$ or computer aided or computer assisted or computeri?ed or device$).tw.
15. (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven).tw.
16. ((continuous passive or cpm) adj3 therap$).tw.
17. (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin).tw.
18. (assist$ adj5 (train$ or aid$ or rehabilitat$ or re-educat$)).tw.
19. or/11-18
20. Randomized Controlled Trial/ or "randomized controlled trial (topic)"/
21. Randomization/
22. Controlled clinical trial/ or "controlled clinical trial (topic)"/
23. control group/ or controlled study/
24. clinical trial/ or "clinical trial (topic)"/ or phase 1 clinical trial/ or phase 2 clinical trial/ or phase 3 clinical trial/ or phase 4 clinical trial/
25. Crossover Procedure/
26. Double Blind Procedure/
27. Single Blind Procedure/ or triple blind procedure/
28. placebo/ or placebo effect/
29. (random$ or RCT or RCTs).tw.
30. (controlled adj5 (trial$ or stud$)).tw.
31. (clinical$ adj5 trial$).tw.
32. ((control or treatment or experiment$ or intervention) adj5 (group$ or subject$ or patient$)).tw.
33. (quasi-random$ or quasi random$ or pseudo-random$ or pseudo random$).tw.
34. ((control or experiment$ or conservative) adj5 (treatment or therapy or procedure or manage$)).tw.
35. ((singl$ or doubl$ or tripl$ or trebl$) adj5 (blind$ or mask$)).tw.
36. (cross-over or cross over or crossover).tw.
37. (placebo$ or sham).tw.
38. trial.ti.
39. (assign$ or allocat$).tw.
40. controls.tw.

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41. or/20-40
42. 7 and 10 and 19 and 41
43. (exp animals/ or exp invertebrate/ or animal experiment/ or animal model/ or animal tissue/ or animal cell/ or nonhuman/) not (human/ or normal human/ or human cell/)
44. 42 not 43
Number of hits: n=1265

Appendix 4. CINAHL (Ebsco) search strategy

CINAHL (Ebsco) Revised March 2015
S1 .(MH "Cerebrovascular Disorders") OR (MH "Basal Ganglia Cerebrovascular Disease+") OR (MH "Carotid Artery Diseases+") OR (MH "Cerebral Ischemia+") OR (MH "Cerebral Vasospasm") OR (MH "Intracranial Arterial Diseases+") OR (MH "Intracranial Embolism and Thrombosis") OR (MH "Intracranial Hemorrhage+") OR (MH "Stroke") OR (MH "Vertebral Artery Dissections") OR .(MH "Brain Injuries")
S2 .(MH "Stroke Patients") OR (MH "Stroke Units")
S3 .TI (stroke* or poststroke or apoplex* or cerebral vasc* or brain vasc* or cerebrovasc* or cva* or SAH) or AB (stroke* or poststroke or apoplex* or cerebral vasc* or brain vasc* or cerebrovasc* or cva* or SAH)
S4 .TI (brain or cerebr* or cerebell* or vertebrobasil* or hemispher* or intracran* or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA* or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying) or AB (brain or cerebr* or cerebell* or vertebrobasil* or hemispher* or intracran* or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA* or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying)
S5 .TI (ischemi* or ischaemi* or infarct* or thrombo* or emboli* or occlus* or hypoxi*) or AB (ischemi* or ischaemi* or infarct* or thrombo* or emboli* or occlus* or hypox*)
S6 .S4 and S5
S7 .TI (brain* or cerebr* or cerebell* or intracerebral or intracran* or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli* or putaminal or putamen or posterior fossa or hemispher* or subarachnoid) or AB (brain* or cerebr* or cerebell* or intracerebral or intracran* or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli* or putaminal or putamen or posterior fossa or hemispher* or subarachnoid)
S8 .TI (haemorrhage* or hemorrhage* or haematoma* or hematoma* or bleed*) or AB (haemorrhage* or hemorrhage* or haematoma* or hematoma* or bleed*)
S9 .S7 and S8
S10 ..(MH "Hemiplegia")
S11 .TI (hemipleg* or hemipar* or paresis or paretic or brain injur*) or AB (hemipleg* or hemipar* or paresis or paretic or brain injur*)
S12 .S1 OR S2 OR S3 OR S6 OR S9 OR S10 OR S11
S13 .(MH "Upper Extremity+")
S14 .TI (upper limb* or upper extremit* or arm or arms or shoulder or shoulders or hand or hands or axilla* or elbow* or forearm* or finger* or wrist*) or AB (upper limb* or upper extremit* or arm or arms or shoulder or shoulders or hand or hands or axilla* or elbow* or forearm* or finger* or wrist*)
S15 .S13 or S14
S16 ..(MH "Therapeutic Exercise") OR (MH "Motion Therapy, Continuous Passive") OR (MH "Muscle Strengthening+") OR (MH "Neuromuscular Facilitation") OR (MH "Upper Extremity Exercises+")
S17 .(MH "Exercise+")
S18 .(MH "Movement+")
S19 .(MH "Assistive Technology") OR (MH "Automation") OR (MH "Robotics")
S20 .(MH "Orthoses") OR (MH "Orthoses Design")
S21 .(MH "Biomedical Engineering") OR (MH "Assistive Technology Services")
S22 .(MH "Assistive Technology Devices") OR (MH "Equipment and Supplies")
S23 .(MH "Therapy, Computer Assisted
S24 .(MH "Biomechanics")
S25 .TI (robot* or orthos* or orthotic or automat* or computer aided or computer assisted or device*) OR AB (robot* or orthos* or orthotic or automat* or computer aided or computer assisted or device*)

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S26 .TI (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven) OR AB (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven)
S27 .TI (continuous passive or cpm) OR AB (continuous passive or cpm)
S28 .TI therap* OR AB therap*
S29 .S27 and S28
S30 .TI (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin) OR AB (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin)
S31 .TI assist* OR AB assist*
S32 .TI (train* or aid* or rehabilitat* or re-educat*) OR AB (train* or aid* or rehabilitat* or re-educat*)
S33 .S31 AND S32
S34 .S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S29 OR S30 OR S33
S35 .(MH "Randomized Controlled Trials") or (MH "Random Assignment") or (MH "Random Sample+")
S36 .(MH "Clinical Trials") or (MH "Intervention Trials") or (MH "Therapeutic Trials")
S37 .(MH "Double-Blind Studies") or (MH "Single-Blind Studies") or (MH "Triple-Blind Studies")
S38 .(MH "Control (Research)") or (MH "Control Group") or (MH "Placebos") or (MH "Placebo Effect")
S39 .(MH "Crossover Design") OR (MH "Quasi-Experimental Studies")
S40 .PT (clinical trial or randomized controlled trial)
S41 .TI (random* or RCT or RCTs) or AB (random* or RCT or RCTs)
S42 .TI (controlled N5 (trial* or stud*)) or AB (controlled N5 (trial* or stud*))
S43 .TI (clinical* N5 trial*) or AB (clinical* N5 trial*)
S44 .TI ((control or treatment or experiment* or intervention) N5 (group* or subject* or patient*)) or AB ((control or treatment or experiment* or intervention) N5 (group* or subject* or patient*))
S45 .TI ((control or experiment* or conservative) N5 (treatment or therapy or procedure or manage*)) or AB ((control or experiment* or conservative) N5 (treatment or therapy or procedure or manage*))
S46 .TI ((singl* or doubl* or tripl* or trebl*) N5 (blind* or mask*)) or AB ((singl* or doubl* or tripl* or trebl*) N5 (blind* or mask*))
S47 .TI (cross-over or cross over or crossover) or AB (cross-over or cross over or crossover)
S48 .TI (placebo* or sham) or AB (placebo* or sham)
S49 .TI trial
S50 .TI (assign* or allocat*) or AB (assign* or allocat*)
S51 .TI controls or AB controls
S52 .TI (quasi-random* or quasi random* or pseudo-random* or pseudo random*) or AB (quasi-random* or quasi random* or pseudo-random* or pseudo random*)
S53 .S35 OR S36 OR S37 OR S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44 OR S45 OR S46 OR S47 OR S48 OR S49 OR S50 OR S51 OR S52
S54 .S12 AND S15 AND S34 AND S53
Number of hits: n=298

Appendix 5. AMED (Ovid) search strategy

1. cerebrovascular disorders/ or cerebral hemorrhage/ or cerebral infarction/ or cerebral ischemia/ or cerebrovascular accident/ or stroke/ or brain injuries/
2. (stroke$ or poststroke or apoplex$ or cerebral vasc$ or brain vasc$ or cerebrovasc$ or cva$ or SAH).tw.
3. ((brain or cerebr$ or cerebell$ or vertebrobasil$ or hemispher$ or intracran$ or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA$ or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying) adj5 (isch?emi$ or infarct$ or thrombo$ or emboli$ or occlus$ or hypoxi$)).tw.
4. ((brain$ or cerebr$ or cerebell$ or intracerebral or intracran$ or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli$ or putaminal or putamen or posterior fossa or hemispher$ or subarachnoid) adj5 (h?emorrhag$ or h?ematoma$ or bleed$)).tw.
5. hemiplegia/
6. (hemipleg$ or hemipar$ or paresis or paretic or brain injur$).tw.
7. or/1-6

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8. exp arm/
9. (upper limb$ or upper extremit$ or arm or arms or shoulder or shoulders or hand or hands or axilla$ or elbow$ or forearm$ or finger$ or wrist$).tw.
10. 8 or 9
11. robotics/ or orthotic devices/ or biomechanics/ or equipment design/ or equipment/ or biomechanics equipment/ or therapy computer assisted/
12. exercise/ or exercise movement techniques/ or exercise therapy/ or exp movement/ or continuous passive motion/
13. engineering/ or technology/ or technology medical/
14. (robot$ or orthos$ or orthotic or automat$ or computer aided or computer assisted or device$).tw.
15. (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven).tw.
16. ((continuous passive or cpm) adj3 therap$).tw.
17. (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin).tw.
18. (assist$ adj5 (train$ or aid$ or rehabilitat$ or re-educat$)).tw.
19. or/11-18
20. clinical trials/ or randomized controlled trials/ or random allocation/
21. research design/ or comparative study/
22. double blind method/ or single blind method/
23. placebos/
24. (random$ or RCT or RCTs).tw.
25. (controlled adj5 (trial$ or stud$)).tw.
26. (clinical$ adj5 trial$).tw.
27. ((control or treatment or experiment$ or intervention) adj5 (group$ or subject$ or patient$)).tw.
28. (quasi-random$ or quasi random$ or pseudo-random$ or pseudo random$).tw.
29. ((control or experiment$ or conservative) adj5 (treatment or therapy or procedure or manage$)).tw.
30. ((singl$ or doubl$ or tripl$ or trebl$) adj5 (blind$ or mask$)).tw.
31. (cross-over or cross over or crossover).tw.
32. (placebo$ or sham).tw.
33. trial.ti.
34. (assign$ or allocat$).tw.
35. controls.tw.
36. or/20-35
37. 7 and 10 and 19 and 36
Number of hits: n=117

Appendix 6. SPORTDiscus (Ebsco) search strategy

SportDISCUS (Ebsco) Revised march 2015
S1 .DE "CEREBROVASCULAR disease" OR DE "BRAIN -- Hemorrhage" OR DE "CEREBRAL embolism & thrombosis" OR DE "STROKE" OR DE "BRAIN -- Wounds & injuries" OR DE "BRAIN damage"
S2 .DE "CEREBROVASCULAR disease -- Patients"
S3 .TI (stroke* or poststroke or apoplex* or cerebral vasc* or brain vasc* or cerebrovasc* or cva* or SAH) or AB (stroke* or poststroke or apoplex* or cerebral vasc* or brain vasc* or cerebrovasc* or cva* or SAH)
S4 .TI (brain or cerebr* or cerebell* or vertebrobasil* or hemispher* or intracran* or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA* or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying) or AB (brain or cerebr* or cerebell* or vertebrobasil* or hemispher* or intracran* or intracerebral or infratentorial or supratentorial or middle cerebral artery or MCA* or anterior circulation or posterior circulation or basilar artery or vertebral artery or space-occupying)
S5 .TI (ischemi* or ischaemi* or infarct* or thrombo* or emboli* or occlus* or hypoxi*) or AB (ischemi* or ischaemi* or infarct* or thrombo* or emboli* or occlus* or hypox*)
S6 .S4 AND S5
S7 .TI (brain* or cerebr* or cerebell* or intracerebral or intracran* or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli* or putaminal or putamen or posterior fossa or hemispher* or subarachnoid) or AB (

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brain* or cerebr* or cerebell* or intracerebral or intracran* or parenchymal or intraparenchymal or intraventricular or infratentorial or supratentorial or basal gangli* or putaminal or putamen or posterior fossa or hemispher* or subarachnoid)
S8 .TI (haemorrhage* or hemorrhage* or haematoma* or hematoma* or bleed*) or AB (haemorrhage* or hemorrhage* or haematoma* or hematoma* or bleed*)
S9 .S7 AND S8
S10 .DE "HEMIPLEGIA" OR DE "HEMIPLEGICS"
S11 .TI (hemipleg* or hemipar* or paresis or paretic or brain injur*) or AB (hemipleg* or hemipar* or paresis or paretic or brain injur*)
S12 .S1 OR S2 OR S3 OR S6 OR S9 OR S10 OR S11
S13 .DE "ARM" OR DE "BICEPS brachii" OR DE "ELBOW" OR DE "FOREARM" OR DE "HAND" OR DE "HUMERUS" OR DE "TRICEPS" OR DE "WRIST" OR DE "ARM exercises" OR DE "HAND exercises" OR DE "SHOULDER exercises"
S14 .TI (upper limb* or upper extremit* or arm or arms or shoulder or shoulders or hand or hands or axilla* or elbow* or forearm* or finger* or wrist*) or AB (upper limb* or upper extremit* or arm or arms or shoulder or shoulders or hand or hands or axilla* or elbow* or forearm* or finger* or wrist*)
S15 .S13 OR S14
S16 .DE "EXERCISE" OR DE "EXERCISE therapy" OR DE "STRENGTH training" OR DE "MOVEMENT therapy" OR DE "SELF-help devices for people with disabilities" OR DE "ROBOTICS in sports"
S17 .DE "ORTHOPEDIC apparatus" OR DE "EQUIPMENT & supplies" OR DE "ORTHOPEDIC braces" OR DE "ORTHOPEDIC slings"
S18 .DE "BIOMEDICAL engineering"
S19 .DE "ELECTRONIC games" OR DE "COMPUTER games" OR DE "INTERNET games" OR DE "VIDEO games"
S20 .DE "BIOMECHANICS"
S21 .TI (robot* or orthos* or orthotic or automat* or computer aided or computer assisted or device*) OR AB (robot* or orthos* or orthotic or automat* or computer aided or computer assisted or device*)
S22 .TI (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven) OR AB (electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven)
S23 .TI (continuous passive or cpm) OR AB (continuous passive or cpm)
S24 .TI therap* OR AB therap*
S25 .S23 AND S24
S26 .TI (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin) OR AB (MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin)
S27 .TI assist* OR AB assist*
S28 .TI (train* or aid* or rehabilitat* or re-educat*) OR AB (train* or aid* or rehabilitat* or re-educat*)
S29 .S27 AND S28
S30 .S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S25 OR S26 OR S29
S31 .S12 AND S15 AND S30
Number of hits: n=773

Appendix 7. Compendex and Inspec (Engineering Village) search strategy

Compendex and Inspec (Engineering Village)
((((robot* or orthos* or orthotic or automat* or computer aided or computer assisted or device* or electromechanical or electro-mechanical or mechanical or mechanised or mechanized or driven or MIT-Manus or ARM guide or Bi-Manu-Track or ARMtrainer or MIME or Mirror-Image Motion Enabler or InMOTION or REHAROB or NeReBot or "GENTLE/S" or ARMin) WN KY) AND ((stroke or cerebrovascular or poststroke or post-stroke or hemipleg*) WN TI)) AND ((upper limb* or upper extremit* or arm* or shoulder* or hand* or axilla* or elbow* or forearm* or finger* or wrist*) WN KY))
Number of hits Compendex: n=718
Number of hits Inspec: n=655

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WHAT'S NEW

Last assessed as up-to-date: 1 June 2015.

Date	Event	Description
2 June 2015	New citation required and conclusions have changed	The conclusions of the review have changed. The previous version concluded that people who receive electromechanical and robot-assisted arm training after stroke were more likely to improve their activities of daily living, paretic arm function may improve, but arm strength did not improve This updated version concluded that people who receive electromechanical and robot-assisted arm training after stroke are more likely to improve their activities of daily living, arm function, and arm muscle strength
2 June 2015	New search has been performed	We have updated the searches to March 2015, and revised the text as appropriate. We have included 34 trials with 1160 participants in this update compared with 19 trials with 666 participants in the 2011 version of this review

HISTORY

Protocol first published: Issue 1, 2008

Review first published: Issue 4, 2008

Date	Event	Description
27 October 2011	New citation required and conclusions have changed	The conclusions of the review have changed. The previous version of this review concluded that people who receive electromechanical and robot-assisted arm training after stroke are not more likely to improve their generic activities of daily living, but arm function and muscle strength of the paretic arm may improve. This updated version of the review concluded that people who receive electromechanical and robot-assisted arm training after stroke are more likely to improve their activities of daily living, and paretic arm function may improve, but not arm strength
9 August 2011	New search has been performed	We have updated the searches to July and August 2011, and revised the text as appropriate. We have included 19 trials with 666 participants in this update compared with 11 trials with 328 participants in the 2008 version of this review

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(*Continued*)

31 March 2008	Amended	Converted to new review format.

CONTRIBUTIONS OF AUTHORS

Jan Mehrholz contributed to the conception and design of the protocol and approved the final manuscript. He searched electronic databases and conference proceedings, screened titles and abstracts of publications identified by the search, selected and assessed trials, extracted trial and outcome data, guided the analysis and interpretation of the data, and contributed to and approved the final manuscript of the review.

Marcus Pohl extracted trial and outcome data, contributed to the conception and design of the review, and drafted the protocol. Together with Jan Mehrholz, he contacted trialists about unpublished data and also entered the data, carried out statistical analysis, helped with the interpretation of the data, drafted the review, and approved the final manuscript of the review.

Thomas Platz contributed to the interpretation of the data and approved the final manuscript of the review.

Joachim Kugler assessed and extracted trial and outcome data, assessed the methodological quality of selected trials, contributed to the interpretation of the data, and contributed to and approved the final manuscript of the review.

Bernhard Elsner searched electronic databases and conference proceedings, screened titles and abstracts of publications identified by the search, selected and assessed trials, extracted trial data, guided the analysis and the interpretation of the data, and contributed to and approved the final manuscript of the review.

DECLARATIONS OF INTEREST

Jan Mehrholz: was a co-author of one included trial (Hesse 2005). He did not participant in the quality assessment or data extraction of this study.

Marcus Pohl: was a co-author of one included trial (Hesse 2005). He did not participant in the quality assessment or data extraction of this study.

Thomas Platz: none known.

Joachim Kugler: none known.

Bernhard Elsner: none known.

SOURCES OF SUPPORT

Internal sources

- Wissenschaftliches Institut, Klinik Bavaria Kreischa, Germany.
- Department of Public Health, TU Dresden, Germany.
- SRH Fachhochschule für Gesundheit Gera gGmbH, Germany.

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External sources

- No sources of support supplied

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

In our protocol we stated that we would use the PEDro scale to assess the methodological quality of the included trials. However, in Chapter 8 of the latest edition of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011), it is suggested that scales that yield a summary score should be avoided. We therefore have not used the PEDro scale to assess the methodological quality of the included trials, but used the Cochrane 'Risk of bias' tool instead.

In our protocol we planned to quantify heterogeneity with the I^2 statistic and to use a cutoff of I^2 = 50% for all comparisons. Additonally, we planned to calculate the overall effects using a random-effects model instead of a fixed-effect model when we found substantial heterogeneity. However, in this update we calculated the overall effects using a random-effects model regardless of the level of heterogeneity.

INDEX TERMS

Medical Subject Headings (MeSH)

*Activities of Daily Living; *Artificial Limbs; *Recovery of Function; *Robotics; *Stroke Rehabilitation; *Upper Extremity; Exercise Therapy [*instrumentation; methods]; Muscle Strength [physiology]; Randomized Controlled Trials as Topic; Stroke [physiopathology]

MeSH check words

Adult; Aged; Aged, 80 and over; Humans; Middle Aged; Young Adult

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