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Cochrane Database of Systematic Reviews 2007, Issue 2. Art. No.: CD004585.
DOI: [10.1002/14651858.CD004585.pub2](https://doi.org/10.1002/14651858.CD004585.pub2).

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[Intervention Review]

EMG biofeedback for the recovery of motor function after stroke

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Editorial group: Cochrane Stroke Group.

Publication status and date: Edited (no change to conclusions), published in Issue 1, 2010.

Citation: Woodford HJ, Price CIM. EMG biofeedback for the recovery of motor function after stroke. *Cochrane Database of Systematic Reviews* 2007, Issue 2. Art. No.: CD004585. DOI: [10.1002/14651858.CD004585.pub2](https://doi.org/10.1002/14651858.CD004585.pub2).

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ABSTRACT

Background

Electromyographic biofeedback (EMG-BFB) is a technique that is believed to have additional benefit when used with standard physiotherapy for the recovery of motor function in stroke patients. However, evidence from individual trials and previous systematic reviews has been inconclusive.

Objectives

To assess the effects of EMG-BFB for motor function recovery following stroke.

Search methods

We searched the Cochrane Stroke Group Trials Register (last searched 30 March 2006), the Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* Issue 4, 2005), MEDLINE (1966 to November 2005), EMBASE (1980 to November 2005), CINAHL (1983 to November 2005), PsycINFO (1974 to November 2005) and First Search (1966 to November 2005). We scanned reference lists for relevant articles and contacted equipment manufacturers and distributors.

Selection criteria

Randomised and quasi-randomised studies comparing EMG-BFB with control for motor function recovery in stroke patients.

Data collection and analysis

Two review authors independently assessed trial quality and extracted data. Where possible we contacted study authors for further information. Any reported adverse effects were noted.

Main results

Thirteen trials involving 269 people were included. All trials compared EMG-BFB plus standard physiotherapy to standard physiotherapy either alone or with sham EMG-BFB. Only one study used a motor strength assessment scale for evaluation of patients, which indicated benefit from EMG-BFB (WMD 1.09, 95% CI 0.48 to 1.70). EMG-BFB did not have a significant benefit in improving range of motion (ROM) through the ankle (SMD 0.05, 95% CI -0.36 to 0.46), knee or wrist joints. However, one trial suggested a benefit in ROM at the shoulder (SMD 0.88, 95% CI 0.07 to 1.70). Change in stride length or gait speed was not improved by EMG-BFB. Two studies used different assessment scores to quantify gait quality. One of these suggested a beneficial effect of EMG-BFB (SMD 0.90, 95% CI 0.01 to 1.78). Most of the studies examining functional outcomes used different assessment scales, which made meta-analysis impossible. Two studies that used the same scale did show a beneficial effect (SMD 0.69, 95% CI 0.15 to 1.23).

Authors' conclusions

Despite evidence from a small number of individual studies to suggest that EMG-BFB plus standard physiotherapy produces improvements in motor power, functional recovery and gait quality when compared to standard physiotherapy alone, combination of all the identified studies did not find a treatment benefit. Overall the results are limited because the trials were small, generally poorly designed and utilised varying outcome measures.

PLAIN LANGUAGE SUMMARY**EMG biofeedback for the recovery of motor function after stroke**

Electromyographic biofeedback (techniques using visual or sound signals to monitor muscle activity) has an uncertain impact on recovery after stroke. Electromyographic biofeedback (EMG-BFB) uses electrodes placed on a patient's muscles to generate a feedback signal (in vision or sound) in response to muscle activation. It is believed that this may allow patients to learn a more effective way of using their disabled limb. Amongst the 13 studies identified, there was a small amount of evidence to suggest that EMG-BFB had a beneficial effect when used with standard physiotherapy techniques. However EMG-BFB cannot currently be recommended as an effective routine treatment because other studies found no effect, and the positive trials were small.

BACKGROUND

Stroke is a major cause of disability. There are an estimated nine million stroke survivors worldwide per year and this figure is predicted to rise 30% between the years 1983 and 2023 (Wolfe 2000). Around one third of those alive at six months following a stroke are functionally dependent on others (Warlow 1998). To date, the major management of most strokes remains rehabilitation and secondary prevention. Any technique that could enable a more rapid or complete functional recovery would have major benefits both in terms of patients' well-being and health economics.

Biofeedback (BFB) has been used in rehabilitation for over 40 years (De Weerd 1985). The technique tries to transduce a physiological electrical response, which would normally be subliminal, into an auditory or visual stimulus to the patient. In terms of motor function recovery this is normally in the form of an electromyogram (EMG). This records a difference in potential along the length of a muscle using electrodes over the skin surface. After amplification, the signal is displayed in a simplified format to the patient, for example, by hearing a change in auditory tone or by seeing a response on an oscilloscope display (De Weerd 1986a).

The theory is that, following a stroke, the normal regulation of muscle tone is disrupted by neuronal damage, which leads to both inappropriate decreases and increases (spasticity) in muscular activity. It is proposed that the patient may have some unaffected pathways preserved but that these may not be initially obvious (Glanz 1997). By using electromyogram biofeedback (EMG-BFB) it may be possible for individuals to learn how to use these preserved pathways. They may then be able to control muscular activity in order to recover motor function following a stroke.

Despite its continuing use in rehabilitation, there remains doubt over the efficacy of this technique. EMG-BFB is referenced within the Royal College of Physicians' guidelines on stroke (RCPstroke 2004), concluding that there is currently no evidence of advantage over traditional therapy. A previous recommendation in favour of its use has been withdrawn. A number of review articles have not found clear evidence of benefit (De Weerd 1986b; Glanz 1995; Glanz 1997; Moreland 1998; Schleenbaker 1993).

OBJECTIVES

The specific objective of this review was to determine the efficacy of any form of EMG-BFB used after a stroke in order to aid motor function recovery.

METHODS

Criteria for considering studies for this review

Types of studies

We considered all randomised controlled trials (RCTs) and quasi-randomised controlled trials comparing EMG-BFB with no EMG-BFB or sham EMG-BFB. We contacted individual trialists, where necessary, in cases where treatment allocation was uncertain. We noted blinding of outcome assessment, but did not use this to exclude trials. We did not consider it essential that the control group received a sham treatment, but we noted any placebo.

Types of participants

We considered trials that included patients of any age or gender with a clinical diagnosis of stroke, with or without a computerised tomography (CT) scan. We did not use previous stroke as a basis for exclusion. We did not identify any otherwise suitable trials that included a mixed group of subjects with other causes for their neurological injury. No predetermined time limit was set for how soon after stroke the EMG-BFB technique was performed.

Types of interventions

We used the study authors' definitions of EMG-BFB. Techniques were expected to involve electrodes being placed on the skin surface above the muscle group being tested, with the electrical activity displayed to the patient in either a visual or auditory format. We recorded all variations in the muscle groups used, forms of biofeedback undertaken and duration of therapy to the recipient. We excluded studies which had EMG-BFB as only one part of a multiple intervention package (e.g. EMG-BFB plus electrical stimulation versus control) unless the results of the studies recorded the outcome data separately for the individual interventions.

Types of outcome measures

We extracted six types of outcome data from identified trials to allow an intention-to-treat analysis. The primary outcome measure was the change in muscle power relative to baseline in the intervention and control groups. The five secondary outcomes were:

- the change in range of motion through a specified joint (degrees) relative to baseline in intervention and control groups;
- improvement in gait, measured by changes in stride length (centimetres) or speed (seconds) and changes in needs for ambulation aids relative to baseline in intervention and control groups;
- the change in function ability relative to baseline in intervention and control groups;
- the change in electromyographic activity relative to the baseline recording;
- the proportion of subjects with muscle weakness due to stroke in treatment and control groups.

We did not include studies which only reported EMG activity as an outcome. EMG potentials alone have no direct functional significance, there is a wide variation in calibration, and as different authors average their values, the absolute readings are not directly comparable.

Search methods for identification of studies

See: 'Specialized register' section in [Cochrane Stroke Group](#)

We searched the Cochrane Stroke Group Trials Register, which was last searched by the Review Group Co-ordinator on 30 March 2006. In addition, we searched the Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* Issue 4, 2005), MEDLINE (January 1966 to November 2005), EMBASE (January 1980 to November 2005), First Search (January 1966 to November 2005), CINAHL (January 1983 to November 2005) and PsycINFO (January 1974 to November 2005) ([Appendix 1](#)).

In an attempt to identify further published, unpublished and ongoing trials, we scanned reference lists of relevant articles and contacted equipment manufacturers and distributors (Thought Technology Limited and Bio-Medical Instruments). Articles published in languages other than English were translated.

Data collection and analysis

Two independent review authors with a background in stroke rehabilitation medicine screened the titles and abstracts of articles identified by the electronic searches. They decided which trials met the inclusion criteria, and judged their methodological quality. Allocation concealment before randomisation was scored using The Cochrane Collaboration's grading system: A - adequate; B - unclear; C - inadequate; or D - not used. We used checklists to independently record details of the randomisation method, study population, EMG methods employed, length of follow up, and outcome measures. We carefully noted the proportions of participants that completed the intervention period, and reasons why they left the study prematurely. Analysis was by intention to treat. Extracted data were checked for agreement between review authors. We attempted to contact trialists to request missing data.

We calculated a weighted treatment effect for each of the outcome measures. Outcomes were combined using the weighted mean difference (WMD) for identical measures, and standardised mean difference (SMD) for different measures. Where there was obvious variation between the WMD or SMD of individual studies (P value < 0.1), a random-effects model was applied.

Motor function after stroke has been recorded by a variety of clinical rating scales such as the Medical Research Council scale. It has also been measured directly by force transduction devices. A number of functional assessment tools have been utilised, such as the upper extremity functional test (UEFT), the action research arm test (ARA), and the Nottingham 10 point activities of daily living (ADL) scale. It is not clear which method is best. Therefore, the results should be interpreted with some caution, and the reliability of such measures will be left to the judgement of readers of this review. We recorded length of follow up, and noted whether assessors were blinded to treatment allocation. We reported attrition rates if known.

We planned sensitivity analyses a priori for studies that had the following characteristics:

- true randomised versus quasi-randomised;
- blinded versus unblinded treatment;
- blinded versus unblinded outcome measurement;
- placebo (sham treatment) versus none;
- time after stroke before use of EMG biofeedback technique.

RESULTS

Description of studies

The search strategy outlined above identified 23 RCTs utilising EMG-BFB in the rehabilitation of stroke patients. Ten of these were excluded from the analysis for a combination of the following reasons: insufficient raw data, despite attempts to contact the authors (Basmajian 1982; Ince 1987; Mandel 1990; Olney 1997; Prevo 1982; Shahani 1977; Taskiran 1993; Wolf 1994); the use of a cross-over design without the capacity to extract data after the first intervention period (Chen 1980); and inability to obtain the

original article (Ince 1991). Thirteen studies, involving 269 patients (mean number per study = 21, range 9 to 40), were included in the analysis (Armagan 2003; Basmajian 1987; Binder 1981; Bradley 1998; Burnside 1982; Cozean 1988; Crow 1989; Inglis 1984; Intiso 1994; Lee 1985; Mroczek 1978; Mulder 1986; Smith 1979).

From the studies that stated values, the mean age of subjects was 62 years (range 52 to 70), and the mean percentage of males was 62 (range 45% to 81%). It is worth noting that there was a very wide variation between studies for the time from the stroke to randomisation (mean time 255 days; range 35 to 1140 days). The duration of studies ranged from four to 16 weeks, with a six-week intervention period being most common. All participants had a residual weakness of either the upper or lower limb. Insufficient cognitive capacity to participate in the program, including receptive dysphasia, was a common reason for patient exclusion. There was a wide variation in the outcome measures used. None of the included studies used EMG potentials alone as an outcome assessment.

The studies had different time intervals between the intervention period and later outcome measures, so only the readings taken at the end of the intervention period were included.

Risk of bias in included studies

Details of the included studies are shown in the 'Characteristics of included studies' table. Reliable randomisation was described in only one study (Armagan 2003), which was by numbered envelopes. Four studies used quasi-randomised methods (Basmajian 1987; Burnside 1982; Crow 1989; Mroczek 1978). A sham form of EMG-BFB (the machine attached but either switched off or not visible to the patient) was used in two studies (Armagan 2003; Burnside 1982). In one study randomisation was not mentioned at all (Intiso 1994). Given the small number of suitable studies identified, this has still been included as the presentation of results suggests at least quasi-randomisation.

In all studies that specified within their methods, assessment was performed by an individual blinded to the patients' treatments. No adverse events relating to interventions were reported in any study. Two studies reported sub-optimal completion rates. In one, two patients in the control group died (Bradley 1998), in another two patients in the control group were withdrawn due to a further stroke and a fractured neck of femur (Intiso 1994). The data from these four patients were not included in the subsequent analyses.

Effects of interventions

Comparison 1.1: Change in motor strength

Although initially identified as the primary outcome prior to the search, only one study used a motor strength assessment (the Medical Research Council scale). Of course, this makes meta-analysis impossible. However, the result of this study was positive for a benefit of EMG-BFB (weighted mean difference (WMD) 1.09, 95% confidence interval (CI) 0.48 to 1.70).

Comparison 1.2: Change in range of motion

Eight trials used the range of motion (ROM) through a joint as an outcome measure: five at the ankle, and one each for the shoulder, wrist, and knee. A combination of results from studies assessing ankle ROM, including a total of 91 patients, did not demonstrate a significant effect of EMG-BFB (standardised mean difference (SMD) 0.05, 95% CI -0.36 to 0.46), nor did individual trial results for the

knee or wrist. However, the only trial assessing ROM at the shoulder did suggest a beneficial effect (SMD 0.88, 95% CI 0.07 to 1.70).

Comparison 1.3: Change in stride length

Two studies calculated the number of steps taken to walk a specified distance (6 or 10 metres). Two studies measured stride length before and after the intervention period. None of the results alone reached significance. The differing outcome measures made meta-analysis impossible.

Comparison 1.4: Change in gait speed

Three studies measured the time taken to walk a specified distance (6, 10 or 50 metres). A further study measured gait cycle time, and another measured walking velocity. The combined result of the three studies assessing time over a specified distance did not show a significant effect (SMD 0.13, 95% CI -0.55 to 0.80). None of the other studies demonstrate a significant benefit with EMG-BFB.

Comparison 1.5: Changes in functional ability

Six studies incorporated functional outcome measures into the patient assessments. Two of these studies used more than one functional measure. For the purposes of this review, only one measure was included from each study. Unfortunately only two of the studies used the same assessment scales as each other. A combination of the results for change in Brunnstrom Stages of Recovery scores did show a significant effect (SMD 0.69, 95% CI 0.15 to 1.23). Individual trial results did not demonstrate a significant effect.

Comparison 1.6: Change in gait quality score

Two studies used different assessment scores to quantify gait quality. One of these suggested a small positive effect of EMG-BFB compared to controls (SMD 0.90, 95% CI 0.01 to 1.78).

Sensitivity analyses were only possible for comparison of change in range of ankle motion between groups that had a sham intervention versus no placebo, and between those studies with a time interval of less than or more than six months after onset of stroke. There was only one study that used a sham intervention, and that showed no significant difference compared to no placebo. The comparison between groups less than or more than six months from stroke onset did not reveal any significant difference in outcomes.

DISCUSSION

Despite several decades of EMG-BFB use in stroke rehabilitation, a randomised trial recruiting over 40 patients has not been performed. The small sample sizes make it possible for a positive treatment effect to have been missed, even after combination of studies. Statistical combination of studies is also hampered by the different outcome measures used in each. Some studies could

not be included due to the inadequate publication of raw data in original articles, the inability to contact authors, and the loss of data (mainly due to the long time periods that have passed since the studies were done).

Overall, the data available do not demonstrate an effect of EMG-BFB in the restoration of ROM through a specified joint, functional ability scales, or in improvements in stride length or gait speed following a disabling stroke. However, there is some evidence from individual trials of improvements in gait quality assessments, ROM at the shoulder and restoration of motor power. In addition, when combined, two trials suggested a benefit in a functional recovery score. It would seem reasonable to expect that improvements in motor power would lead to an increase in ROM at a joint, and that improved gait quality should result in improved gait speed and stride length. The discrepancy between the findings is physiologically inconsistent.

The reasons for study outcome variance may be related to the small numbers of participants and short time periods used in the studies. Also, the trials vary in the time from stroke to randomisation. However, the trials showing benefit in motor power and gait quality scores had the longest mean time interval from stroke ([Burnside 1982](#); [Smith 1979](#)), yet the trials demonstrating benefit in functional assessment scales included those with the shortest time interval ([Bradley 1998](#); [Crow 1989](#)). This analysis is not able to assess whether the observed benefits are maintained or tend to reduce over time.

AUTHORS' CONCLUSIONS

Implications for practice

When all the available data are combined, EMG-BFB does not appear to have any positive benefit for recovery after stroke. It cannot be recommended as a routine treatment. A small amount of evidence from individual studies suggests that using EMG-BFB in combination with standard physiotherapy regimes may result in improvements in motor power, ROM at the shoulder, functional recovery and gait quality beyond those of standard physiotherapy alone. As there were no reported adverse effects, it would seem reasonable for EMG-BFB to be considered as a cautious treatment approach for individual patients whose circumstances match the inclusion criteria of the studies included in this review.

Implications for research

There is need for a randomised clinical trial with adequate power, using standardised assessment scales and robust adverse event reporting, to assess the effectiveness of EMG-BFB.

ACKNOWLEDGEMENTS

None

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CHARACTERISTICS OF STUDIES
Characteristics of included studies [ordered by study ID]

Armagan 2003

Methods	RCT of 4-week duration Randomisation by numbered envelopes Assessments by a blinded evaluator
Participants	27 participants (14 intervention, 13 control) Mean age 57 years (range 39 to 77 years) Mean time from stroke of 4.6 months (range 3 to 6 months) 59% male Exclusions included significant cognitive impairment or limb spasticity, and previous physiotherapy or EMG feedback therapy
Interventions	Exercise program plus EMG-BFB or exercise plus placebo EMG-BFB 20-minute sessions 5 times a week for 4 weeks
Outcomes	Brunstrom's Stages of Hand Recovery, a scale for judging drinking from a glass, active range of motion at wrist and EMG surface potentials
Notes	

EMG biofeedback for the recovery of motor function after stroke (Review)

Armagan 2003 (Continued)

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Low risk	A - Adequate

Basmajian 1987

Methods	RCT of 5-week duration plus 9 month follow up Randomisation method 'balanced' after every 4 patients and across strata Assessments by a blinded evaluator	
Participants	29 participants (13 intervention, 16 control) Mean age 62 years Mean time from stroke 16 weeks 66% male	
Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB 45-minute sessions 3 times a week for 5 weeks	
Outcomes	Upper Extremity Function Test Finger Oscillation Test	
Notes		

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	High risk	C - Inadequate

Binder 1981

Methods	RCT of 4-week duration Randomisation method that maintained equivalent numbers between groups Assessments performed by a blinded evaluator	
Participants	10 participants (5 in each group) Mean age unknown, at least 16 months from stroke event % male unknown Patients with residual lower limb weakness but able to walk short distances	
Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB 30 to 40-minute treatment sessions 3 times a week for 4 weeks	
Outcomes	Active range of ankle movement Time to walk 50 metres on both smooth and carpeted surfaces	
Notes		

Risk of bias

Bias	Authors' judgement	Support for judgement
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EMG biofeedback for the recovery of motor function after stroke (Review)

Binder 1981 (Continued)

Allocation concealment?	High risk	C - Inadequate
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Bradley 1998

Methods	RCT of 6-week duration plus further 12 week follow up Randomisation method not stated
Participants	Data available for a total of 21 participants (12 intervention, 9 control) Mean age 70 years Mean time from stroke 36 days
Interventions	Physiotherapy plus EMG-BFB vs physiotherapy alone
Outcomes	Time taken and number of steps to do a 10 metre walk (but only 14 subjects able to perform) Rivermead mobility index Range of movement at ankle Nottingham extended ADL index
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Burnside 1982

Methods	RCT of 6-week duration with 12-week follow up Groups matched on age, duration and initial strength Assessments by a blinded evaluator
Participants	22 participants (11 in each group) Mean age 70 years Mean time from stroke of 4.8 years 46% male Patients at least 3 months from a stroke event and with residual lower limb weakness but able to walk short distances
Interventions	Exercise program plus EMG-BFB or exercise plus placebo EMG-BFB 15-minute sessions twice a week for 6 weeks
Outcomes	Muscle strength of tibialis anterior (MRC scale 0 to 5) Active range of movement at ankle Basmajian's rating scale for gait
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	High risk	C - Inadequate

EMG biofeedback for the recovery of motor function after stroke (Review)

Cozean 1988

Methods	RCT of 6-week duration Randomisation method not stated Assessments by a blinded evaluator 1 drop out from each group Comparison also made to functional electrical stimulation (data not included in this review)
Participants	16 participants (8 in each group) Mean age 57 years Mean time from stroke not stated 63 % male Sufficient cognitive capacity to participate and able to mobilise with the assistance of one therapist
Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB 30-minute sessions 3 times a week for 6 weeks
Outcomes	Stride length Gait cycle time Angles of knee and ankle during walking
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Crow 1989

Methods	RCT of 6-week duration plus 12-week follow up Randomisation by a method to balance stratified groups 3 patients died during the trial, their allocation groups are not stated
Participants	40 participants (20 in each group) Mean age 68 years Between 2 and 8 weeks poststroke 63% male Residual arm weakness but at least some movement, reasonable cognitive ability
Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB
Outcomes	Brunnstrom-Fugl Meyer test Action Research Arm test
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	High risk	C - Inadequate

Inglis 1984

Methods	Cross-over design; data extracted for first intervention period only Randomisation method not stated
Participants	30 participants (15 in each group) Mean age 61 years Mean time of 19 months post-stroke 66% male
Interventions	20 sessions of EMG-BFB plus physiotherapy or physiotherapy alone
Outcomes	Brunnstrom Stages of recovery (raw data not available for active range of motion at the shoulder or Oxford Scale muscle strength scores)
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Intiso 1994

Methods	Unclear if the study was truly randomised; randomisation of the patients is not mentioned in the published article and so caution should be used when interpreting this study 2-month duration
Participants	16 participants (8 in each group) but 2 from the control group did not complete the rehabilitation program Mean age 57 years Mean time from stroke 9.8 months
Interventions	EMG plus physical therapy vs physical therapy alone
Outcomes	Barthel, Canadian, Adams, Basmajian and Ashworth scales used Stride length and gait speed
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Lee 1985

Methods	RCT of 16-week duration Randomisation method unknown
Participants	26 participants (13 in each group) Mean age 52 years

Lee 1985 (Continued)

Mean time from stroke 5.1 months
81% male

Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB
Outcomes	Active range of motion at wrist and ankle EMG potentials
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Mroczek 1978

Methods	RCT of 4-week duration Cross-over design; data extracted for first intervention period only Randomisation method not stated 2 patients with a left-sided hemiplegia were specifically allocated one to each group
Participants	9 participants (5 intervention, 4 control) Age range 50 to 75 years Between 1 and 10 years post-stroke
Interventions	EMG plus physical therapy vs physical therapy alone
Outcomes	Active range of motion at wrist EMG potentials
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
Allocation concealment?	High risk	C - Inadequate

Mulder 1986

Methods	RCT of 5-week duration Randomisation method not stated Assessments by a blinded evaluator
Participants	12 participants (6 in each group) Age range 34 to 68 years 67% male Patients at least 6 months from a stroke event with residual lower limb weakness but able to walk short distances, adequate mental function
Interventions	Physiotherapy alone vs physiotherapy plus EMG-BFB

EMG biofeedback for the recovery of motor function after stroke (Review)

Mulder 1986 (Continued)

40-minute sessions 3 times a week for 5 weeks

Outcomes	Active range of movement at ankle joint (but raw data not provided for this outcome measure) EMG potentials Analysis of gait	
Notes		
<i>Risk of bias</i>		
Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

Smith 1979

Methods	RCT of 6-week duration Randomisation method not stated Assessments by a blinded evaluator	
Participants	11 participants (6 intervention, 5 control) Mean age 52 years Mean time from stroke 18 months (1 with subarachnoid haemorrhage) 46% male Patients at least 6 months from a stroke event with residual lower limb weakness but able to walk short distances, adequate mental function	
Interventions	Exercise program plus EMG-BFB or exercise alone 1-hour sessions twice a week for 6 weeks	
Outcomes	Grading score of gait from video analysis Patient questionnaires on perceived sensory and motor function of affected limb	
Notes		
Risk of bias		
Bias	Authors' judgement	Support for judgement
Allocation concealment?	Unclear risk	B - Unclear

ADL: activities of daily living

EMG: electromyograph

EMG-BFB: electromyographic biofeedback

RCT: randomised controlled trial

vs: versus

Characteristics of excluded studies [ordered by study ID]

Study	Reason for exclusion
Basmajian 1982	Insufficient data published in the study to perform analyses Unable to contact the authors for further data

Study	Reason for exclusion
Chen 1980	Insufficient data to extract results from the first stage of the trial (cross-over design)
Ince 1987	Only ever published as an abstract Unable to contact the authors for further data
Ince 1991	Unable to obtain copies of articles from the journal 'Medical Psychotherapy' from any library in the UK
Mandel 1990	Insufficient data published to perform analyses Unable to obtain further information from authors
Olney 1997	Only ever published as an abstract Insufficient data available and unclear if EMG-BFB was used in isolation
Prevo 1982	Insufficient data published to allow analysis Unable to contact the authors for further information
Shahani 1977	Only published as an abstract Unable to contact the authors for further data
Taskiran 1993	Difficulties with translation from Turkish Unclear what outcome measures were used
Wolf 1994	Insufficient data published to perform analyses Unable to contact authors for further information

EMG-BFB: electromyographic biofeedback

DATA AND ANALYSES

Comparison 1. Electromyographic biofeedback plus physical therapy versus physical therapy alone

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Change in motor strength (MRC scale)	1	22	Mean Difference (IV, Fixed, 95% CI)	1.09 [0.48, 1.70]
2 Change in range of motion	6		Std. Mean Difference (IV, Fixed, 95% CI)	Subtotals only
2.1 Ankle joint	5	91	Std. Mean Difference (IV, Fixed, 95% CI)	0.05 [-0.36, 0.46]
2.2 Shoulder joint	1	26	Std. Mean Difference (IV, Fixed, 95% CI)	0.88 [0.07, 1.70]
2.3 Knee joint	1	16	Std. Mean Difference (IV, Fixed, 95% CI)	-0.67 [-1.68, 0.35]
2.4 Wrist joint	1	9	Std. Mean Difference (IV, Fixed, 95% CI)	0.96 [-0.48, 2.40]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3 Change in stride length	4		Mean Difference (IV, Fixed, 95% CI)	Subtotals only
3.1 Change in number of steps taken to walk 6 metres or 10 metres	2	26	Mean Difference (IV, Fixed, 95% CI)	-0.51 [-3.27, 2.25]
3.2 Stride length at end of intervention (metres)	2	32	Mean Difference (IV, Fixed, 95% CI)	0.05 [-0.08, 0.19]
4 Change in gait speed	5		Std. Mean Difference (IV, Fixed, 95% CI)	Subtotals only
4.1 Change in time taken to walk a specified distance	3	36	Std. Mean Difference (IV, Fixed, 95% CI)	0.13 [-0.55, 0.80]
4.2 Gait cycle time at end of intervention	1	16	Std. Mean Difference (IV, Fixed, 95% CI)	-0.81 [-1.84, 0.23]
4.3 Walking velocity (m/s) at end of intervention	1	16	Std. Mean Difference (IV, Fixed, 95% CI)	0.0 [-0.98, 0.98]
5 Changes in functional ability	6		Std. Mean Difference (IV, Fixed, 95% CI)	Subtotals only
5.1 Change in Brunnstrom Stages of Recovery score	2	57	Std. Mean Difference (IV, Fixed, 95% CI)	0.69 [0.15, 1.23]
5.2 Change in Brunnstrom-Fugl Meyer test score	1	40	Std. Mean Difference (IV, Fixed, 95% CI)	0.44 [-0.19, 1.07]
5.3 Upper Extremity Function test score at end of intervention	1	29	Std. Mean Difference (IV, Fixed, 95% CI)	-0.17 [-0.90, 0.56]
5.4 Barthel index score at end of intervention	1	16	Std. Mean Difference (IV, Fixed, 95% CI)	-0.21 [-1.20, 0.77]
5.5 Change in Rivermead Mobility Index score	1	21	Std. Mean Difference (IV, Fixed, 95% CI)	-0.36 [-1.24, 0.51]
6 Change in gait quality score	2		Std. Mean Difference (IV, Fixed, 95% CI)	Subtotals only
7 Sham EMG-BFB versus no placebo: range of motion at ankle joint	4	75	Mean Difference (IV, Fixed, 95% CI)	0.35 [-3.27, 3.96]
7.1 Sham therapy	1	22	Mean Difference (IV, Fixed, 95% CI)	1.72 [-7.08, 10.52]
7.2 No placebo	3	53	Mean Difference (IV, Fixed, 95% CI)	0.07 [-3.89, 4.03]
8 Time from stroke and change in range of movement at ankle	4	75	Mean Difference (IV, Fixed, 95% CI)	0.35 [-3.27, 3.96]
8.1 Less than 6 months	2	43	Mean Difference (IV, Fixed, 95% CI)	1.96 [-3.48, 7.40]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
8.2 More than 6 months	2	32	Mean Difference (IV, Fixed, 95% CI)	-0.92 [-5.75, 3.90]

Analysis 1.1. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 1 Change in motor strength (MRC scale).

Analysis 1.2. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 2 Change in range of motion.

Study or subgroup	Treatment		Control		Std. Mean Difference			Weight	Std. Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI				
					-4-2024				
					Favours controlFavours treatment				

Analysis 1.3. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 3 Change in stride length.

Study or subgroup	Treatment		Control		Mean Difference Fixed, 95% CI	Weight	Mean Difference Fixed, 95% CI
	N	Mean(SD)	N	Mean(SD)			
1.3.1 Change in number of steps taken to walk 6 metres or 10 metres							
Bradley 1998	9	-7.4 (7.8)	5	-8 (6.5)		13.02%	0.56[-7.09,8.21]
Mulder 1986	6	-0.5 (2)	6	0.2 (3.1)		86.98%	-0.67[-3.63,2.29]
Subtotal ***	15		11			100%	-0.51[-3.27,2.25]
Heterogeneity: Tau ² =0; Chi ² =0.09, df=1(P=0.77); I ² =0%							
Test for overall effect: Z=0.36(P=0.72)							
1.3.2 Stride length at end of intervention (metres)							
Cozean 1988	8	0.6 (0.2)	8	0.5 (0.2)		58.61%	0.07[-0.11,0.25]
Intiso 1994	8	0.5 (0.2)	8	0.5 (0.2)		41.39%	0.03[-0.18,0.24]
Subtotal ***	16		16			100%	0.05[-0.08,0.19]
Heterogeneity: Tau ² =0; Chi ² =0.08, df=1(P=0.78); I ² =0%							
Test for overall effect: Z=0.77(P=0.44)							
Test for subgroup differences: Chi ² =0.16, df=1 (P=0.69), I ² =0%							
					-10 -5 0 5 10		
					Favours treatment Favours control		

Analysis 1.4. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 4 Change in gait speed.

Study or subgroup	Treatment		Control		Std. Mean Difference Fixed, 95% CI	Weight	Std. Mean Difference Fixed, 95% CI
	N	Mean(SD)	N	Mean(SD)			
1.4.1 Change in time taken to walk a specified distance							
Binder 1981	5	18.8 (49.6)	5	-10.9 (17.7)		26.77%	0.72[-0.58,2.02]
Bradley 1998	9	-24.4 (22.1)	5	-18.6 (19.5)		37.71%	-0.26[-1.36,0.84]
Mulder 1986	6	-2.2 (5.1)	6	-3.1 (13.3)		35.52%	0.09[-1.05,1.22]
Subtotal ***	20		16			100%	0.13[-0.55,0.8]
Heterogeneity: Tau ² =0; Chi ² =1.27, df=2(P=0.53); I ² =0%							
Test for overall effect: Z=0.37(P=0.71)							
1.4.2 Gait cycle time at end of intervention							
Cozean 1988	8	2.3 (0.8)	8	3.1 (1)		100%	-0.81[-1.84,0.23]
Subtotal ***	8		8			100%	-0.81[-1.84,0.23]
Heterogeneity: Not applicable							
Test for overall effect: Z=1.53(P=0.13)							
1.4.3 Walking velocity (m/s) at end of intervention							
Intiso 1994	8	0.2 (0.1)	8	0.2 (0.1)		100%	0[-0.98,0.98]
Subtotal ***	8		8			100%	0[-0.98,0.98]
Heterogeneity: Not applicable							
					-4 -2 0 2 4		
					Favours treatment Favours control		

Study or subgroup	Treatment		Control		Std. Mean Difference Fixed, 95% CI	Weight	Std. Mean Difference Fixed, 95% CI
	N	Mean(SD)	N	Mean(SD)			
Test for overall effect: Not applicable							
Test for subgroup differences: Chi²=2.27, df=1 (P=0.32), I²=11.86%							
					-4-2024	Favours treatment Favours control	

Analysis 1.5. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 5 Changes in functional ability.

Study or subgroup	Treatment		Control		Std. Mean Difference Fixed, 95% CI	Weight	Std. Mean Difference Fixed, 95% CI
	N	Mean(SD)	N	Mean(SD)			
1.5.1 Change in Brunnstrom Stages of Recovery score							
Armagan 2003	14	0.9 (0.4)	13	0.5 (0.5)		47.25%	0.7[-0.08,1.48]
Inglis 1984	15	0.5 (0.5)	15	0.2 (0.4)		52.75%	0.69[-0.05,1.43]
Subtotal ***	29		28			100%	0.69[0.15,1.23]
Heterogeneity: Tau ² =0; Chi ² =0, df=1(P=0.98); I ² =0%							
Test for overall effect: Z=2.52(P=0.01)							
1.5.2 Change in Brunnstrom-Fugl Meyer test score							
Crow 1989	20	12.1 (12.5)	20	6.9 (10.7)		100%	0.44[-0.19,1.07]
Subtotal ***	20		20			100%	0.44[-0.19,1.07]
Heterogeneity: Not applicable							
Test for overall effect: Z=1.37(P=0.17)							
1.5.3 Upper Extremity Function test score at end of intervention							
Basmajian 1987	13	47 (27)	16	52.4 (32.9)		100%	-0.17[-0.9,0.56]
Subtotal ***	13		16			100%	-0.17[-0.9,0.56]
Heterogeneity: Tau ² =0; Chi ² =0, df=0(P<0.0001); I ² =100%							
Test for overall effect: Z=0.46(P=0.65)							
1.5.4 Barthel index score at end of intervention							
Intiso 1994	8	78.7 (18.2)	8	82.5 (15.4)		100%	-0.21[-1.2,0.77]
Subtotal ***	8		8			100%	-0.21[-1.2,0.77]
Heterogeneity: Not applicable							
Test for overall effect: Z=0.42(P=0.67)							
1.5.5 Change in Rivermead Mobility Index score							
Bradley 1998	12	2.6 (3.4)	9	3.8 (2.9)		100%	-0.36[-1.24,0.51]
Subtotal ***	12		9			100%	-0.36[-1.24,0.51]
Heterogeneity: Not applicable							
Test for overall effect: Z=0.82(P=0.41)							
Test for subgroup differences: Chi ² =6.96, df=1 (P=0.14), I ² =42.56%							
					-4 -2 0 2 4	Favours control Favours treatment	

Analysis 1.6. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 6 Change in gait quality score.

Study or subgroup	Treatment		Control		Std. Mean Difference Fixed, 95% CI	Weight	Std. Mean Difference Fixed, 95% CI
	N	Mean(SD)	N	Mean(SD)			
Burnside 1982	11	0.7 (0.7)	11	0.1 (0.7)		0%	0.9[0.01,1.78]
Smith 1979	6	8.4 (5.8)	5	5.7 (4.8)		0%	0.47[-0.74,1.68]

Analysis 1.7. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 7 Sham EMG-BFB versus no placebo: range of motion at ankle joint.

Study or subgroup	Treatment		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI		
1.7.1 Sham therapy							
Burnside 1982	11	6.9 (12.3)	11	5.2 (8.4)		16.84%	1.72[-7.08,10.52]
Subtotal ***	11		11			16.84%	1.72[-7.08,10.52]
Heterogeneity: Not applicable							
Test for overall effect: Z=0.38(P=0.7)							
1.7.2 No placebo							
Binder 1981	5	15.4 (6.6)	5	17.4 (0.3)		39.15%	-2.06[-7.83,3.71]
Lee 1985	13	12.3 (9.5)	13	11.9 (17.8)		10.81%	0.39[-10.6,11.38]
Bradley 1998	10	14.9 (8.5)	7	12.4 (4.6)		33.2%	2.47[-3.8,8.74]
Subtotal ***	28		25			83.16%	0.07[-3.89,4.03]
Heterogeneity: Tau ² =0; Chi ² =1.09, df=2(P=0.58); I ² =0%							
Test for overall effect: Z=0.03(P=0.97)							
Total ***	39		36			100%	0.35[-3.27,3.96]
Heterogeneity: Tau ² =0; Chi ² =1.2, df=3(P=0.75); I ² =0%							
Test for overall effect: Z=0.19(P=0.85)							
Test for subgroup differences: Chi ² =0.11, df=1 (P=0.74), I ² =0%

Analysis 1.8. Comparison 1 Electromyographic biofeedback plus physical therapy versus physical therapy alone, Outcome 8 Time from stroke and change in range of movement at ankle.

Study or subgroup	Treatment		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI		Fixed, 95% CI
1.8.1 Less than 6 months							
Lee 1985	13	12.3 (9.5)	13	11.9 (17.8)		10.81%	0.39[-10.6,11.38]
Bradley 1998	10	14.9 (8.5)	7	12.4 (4.6)		33.2%	2.47[-3.8,8.74]
Subtotal ***	23		20			44.01%	1.96[-3.48,7.4]
Heterogeneity: Tau ² =0; Chi ² =0.1, df=1(P=0.75); I ² =0%							
Test for overall effect: Z=0.71(P=0.48)							
1.8.2 More than 6 months							
Binder 1981	5	15.4 (6.6)	5	17.4 (0.3)		39.15%	-2.06[-7.83,3.71]
Burnside 1982	11	6.9 (12.3)	11	5.2 (8.4)		16.84%	1.72[-7.08,10.52]

APPENDICES

Appendix 1. MEDLINE search strategy

The following strategy was used for MEDLINE and modified for the other databases.

MEDLINE (Ovid)

1. electromyography/
2. "biofeedback (psychology)"/ or feedback/ or feedback, psychological/
3. (electromyograph\$ or electromyogram\$ or EMG\$).tw.
4. (biofeedback or feedback).tw.
5. 1 or 2 or 3 or 4
6. cerebrovascular disorders/ or exp basal ganglia cerebrovascular disease/ or exp brain ischemia/ or exp carotid artery diseases/ or exp cerebrovascular accident/ or exp hypoxia-ischemia, brain/ or exp intracranial artery diseases/ or exp "intracranial embolism and thrombosis"/ or exp intracranial hemorrhages/
7. (stroke or poststroke or cerebrovasc\$ or cerebral vasc\$ or cva\$).tw.
8. ((cerebral or cerebellar or brain\$ or vertebrobasilar) adj5 (infarct\$ or isch?emi\$ or thrombo\$ or emboli\$ or apoplexy)).tw.
9. ((cerebral or brain\$ or subarachnoid) adj5 (haemorrhage or hemorrhage or haematoma or hematoma or bleed\$)).tw.
10. hemiplegia/ or (hemipleg\$ or hemipar\$).tw.
11. 6 or 7 or 8 or 9 or 10
12. 5 and 11
13. limit 12 to human
14. cerebrovascular disorders/rh or exp basal ganglia cerebrovascular disease/rh or exp brain ischemia/rh or exp carotid artery diseases/rh or exp cerebrovascular accident/rh or exp hypoxia-ischemia, brain/rh or exp intracranial arterial diseases/rh or exp "intracranial embolism and thrombosis"/rh or exp intracranial hemorrhages/rh
15. hemiplegia/ or paresis/rh
16. 14 or 15
17. 5 and 16
18. exp rehabilitation/
19. motor activity/ or movement/ or range of motion, articular/
20. recovery of function/ or disability evaluation/ or muscle weakness/
21. gait/ or locomotion/ or walking/
22. (recovery or motor function or gait or ambulation or muscle weakness or muscle power or movement or mobility).tw.
23. 18 or 19 or 20 or 21 or 22
24. 13 and 23
25. 17 or 24

WHAT'S NEW

Date	Event	Description
19 August 2008	Amended	Converted to new review format.

CONTRIBUTIONS OF AUTHORS

Initial literature search and wording of the background by Henry Woodford. Guidance and feedback comments provided by Christopher Price. Study articles reviewed by both authors.

DECLARATIONS OF INTEREST

None known

INDEX TERMS

Medical Subject Headings (MeSH)

*Recovery of Function; *Stroke Rehabilitation; Biofeedback, Psychology [*methods]; Electromyography [*methods]; Motor Skills; Randomized Controlled Trials as Topic; Stroke [physiopathology]

MeSH check words

Humans