Biofeedback improves activities of the lower limb after stroke: a systematic review

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Question: Is biofeedback during the practice of lower limb activities after stroke effective in improving performance of those activities, and are any benefits maintained after intervention ceases? **Design**: Systematic review with meta-analysis of randomised trials. **Participants**: People who have had a stroke. **Intervention**: Biofeedback during practice of sitting, standing up, standing, or walking. **Outcome measures**: Continuous measures of activity congruent with the activity trained. **Results**: 22 trials met the inclusion criteria and 19 contained data suitable for analysis. Effect sizes were calculated as standardised mean differences because different outcome measures were used. Since inclusion of all trials produced substantial statistical heterogeneity, only trials with a PEDro score > 4 (11 trials) were included in the final analysis (mean PEDro score 5.7). In the short-term, biofeedback improved lower limb activities compared with usual therapy/placebo (SMD = 0.49, 95% CI 0.22 to 0.75). Lower limb activities were still improved compared with usual therapy/placebo 1 to 5 months after the cessation of intervention (SMD = 0.41, 95% CI 0.06 to 0.75). **Conclusion**: Augmenting feedback through the use of biofeedback is superior to usual therapy/placebo at improving lower limb activities in people following stroke. Furthermore, these benefits are largely maintained in the longer term. Given that many biofeedback machines are relatively inexpensive, biofeedback could be utilised more widely in clinical practice. **[Stanton R, Ada L, Dean CM, Preston E (2011) Biofeedback improves activities of the lower limb after stroke: a systematic review. *Journal of Physiotherapy* 57: 145–155]**

Key words: Stroke, Physical therapy techniques, Exercise therapy, Rehabilitation, Review systematic, Meta-analysis, Randomized controlled trials

Introduction

Provision of specific feedback is important for effective skill learning (Thorndike 1927, Trowbridge and Cason 1932). Following stroke, patients usually need to re-learn to perform motor activities. Learning requires practice, and feedback is important for practice to be effective (Annett and Kay 1957, Wallace and Hagler 1979). Although feedback is a common part of stroke rehabilitation, the most effective method of implementation of feedback in this population remains unknown (van Vliet and Wulf 2006). During rehabilitation, patients will receive intrinsic biological feedback via sensory systems, and therapists traditionally provide extrinsic (ie, augmented) feedback within their role as 'coach'. This extrinsic feedback will either take the form of knowledge of results (ie, information about the accuracy of the activity) or knowledge of performance (ie, information about the way in which the activity was carried out). Biofeedback (ie, feedback about physiological processes) can be delivered using technology to provide information about performance. Biofeedback may have advantages over therapist feedback in that it delivers continuous, accurate information in order to enhance performance (Salmoni et al 1984). However, since biofeedback delivers feedback concurrently rather than terminally, any enhanced performance may not be retained and motor learning may not occur (van Vliet and Wulf 2006). The question therefore arises as to whether biofeedback is superior to usual therapist feedback or intrinsic patient feedback in enhancing motor learning.

Biofeedback can be delivered through various senses, such as visual, auditory, and tactile systems, and can provide information about the kinematics, kinetics, and/or electromyography (EMG) of activities. Previous reviews examining the effect of biofeedback have tended to focus on one aspect and have therefore often failed to produce clear findings due to insufficient data to perform a meta-analysis (Langhorne et al 2009). For example, one review that examined biofeedback during one activity (walking), separated the interventions into biofeedback providing kinematic, temporospatial, or kinetic information, and was unable to conduct a meta-analysis (Tate and Milner 2010). Other reviews that examined only one type of biofeedback have found that EMG feedback does not improve outcome either at the impairment or activity level (Woodford and Price 2009) or that ground reaction force feedback does not improve balance or mobility (Barclay-Goddard et al 2009, van Peppen et al 2006).

This systematic review examines the effect of biofeedback more broadly in enhancing the training of motor skills after stroke. Unlike previous reviews, it includes clinical trials where any form of biofeedback was provided during the practice of the whole activity (rather than practice of part of the activity) and where outcomes were measured during the same activity. The focus is on activities involving the lower limb such as sitting, standing up, standing and walking, since independence in these activities has a significant influence on quality of life and ability to participate in activities of daily living. Although there has been one previous review of biofeedback for lower limb activities (Glanz et al 1995), only outcomes at the impairment level were measured.

Biofeedback for stroke rehabilitation has been known about for decades (eg, since Basmajian et al 1975). However it

is not commonly used despite its relatively low cost. For biofeedback to be implemented widely into clinical practice, its effect as a form of augmented feedback to enhance motor skill learning needs to be determined. Therefore, the research questions for this systematic review were: In adults following stroke,

1. Is biofeedback during the practice of lower limb activities effective in improving those activities? and
2. Are any benefits maintained after intervention ceases?

In order to make recommendations based on the highest level of evidence, this review included only randomised or quasi-randomised trials with patients following stroke using biofeedback during whole task practice to improve activities of the lower limb.

Method

Identification and selection of trials

Searches were conducted of MEDLINE (1950 to September 2010), CINAHL (1981 to September 2010), EMBASE (1980 to September 2010), PEDro (to September 2010), and the Cochrane Library (to September 2010) databases for relevant articles without language restrictions, using words related to *stroke* and *randomised*, *quasi-randomised* or *controlled trials* and words related to *biofeedback* (such as biofeedback, electromyography, joint position, and force) and *lower limb activities* (such as sitting, sit to stand, standing, and walking) (see Appendix 1 for full search strategy). Titles and abstracts (where available) were displayed and screened by one reviewer to identify relevant trials. Full paper copies of relevant trials were retrieved and their reference lists were screened. The methods of the retrieved papers were extracted and reviewed independently by two reviewers (RS and EP) using predetermined criteria (Box 1). Disagreement or ambiguities were resolved by consensus after discussion with a third reviewer (LA).

Box 1. Inclusion criteria

Design
- Randomised trial or quasi-randomised trial

Participants
- Adults
- Diagnosis of cerebrovascular stroke
- Any level of disability and any time after stroke

Intervention
- Experimental intervention includes biofeedback using any signal (EMG, force, position) via any sensory system (visual, auditory, tactile)
- Part of intervention must be biofeedback during practice of the whole activity
- Practice of whole activity must involve movement (such as reaching in sitting or weight shift in standing)

Outcome measures
- Measure/s of lower limb activity (sitting, standing up, standing or walking)
- Measure/s must be congruent with the activity trained
- Measure/s of activity must involve movement

Assessment of characteristics of trials

Quality: The quality of included trials was assessed by extracting PEDro scores from the Physiotherapy Evidence Database. Rating of trials on this database is carried out by two independent trained raters and disagreements are resolved by a third rater. Where a trial was not included on the database, it was assessed independently by two reviewers who had completed the PEDro Scale training tutorial on the Physiotherapy Evidence Database.

Participants: Trials involving adult participants of either gender, at any level of initial disability, at any time following stroke were included. Age, gender, and time since stroke were recorded to describe the trials.

Intervention: The experimental intervention could be of any type of biofeedback, ie, using any signal (position, force, EMG) via any sense (visual, auditory, tactile). At least some of the intervention had to involve practice of the whole activity and practice of the activity had to involve movement (such as reaching in sitting or weight shift in standing). The control intervention could be nothing, placebo, or usual therapy in any combination. Type of biofeedback, activity trained, and duration and frequency of the intervention were recorded to describe the trials.

Outcome measures: Measures of lower limb activity congruent with the activity in which biofeedback was applied were used in the analysis. Where multiple measures for one activity were reported, a measure was chosen that best reflected the aim of the biofeedback intervention (eg, step length). The measures used to record outcomes and timing of measurement were recorded to describe the trials.

Data analysis

Data were extracted from the included trials by one reviewer and cross-checked by a second reviewer. Information about the method (ie, design, participants, lower limb activity trained, intervention, measures) and data (ie, number of participants and mean (SD) of outcomes) were extracted. Authors were contacted where there was difficulty extracting and interpreting data from the paper.

Post-intervention scores were used to obtain the pooled estimate of the effect of intervention in the short term (after intervention) and in the longer term (some time after the cessation of intervention). Since different outcome measures were used, the effect size was reported as Cohen's standardised mean difference (95% CI). A fixed-effect model was used initially. In the case of significant statistical heterogeneity ($I^2 > 50\%$), a sensitivity analysis to confirm the source of the heterogeneity was carried out. The analyses were performed using the MIX[a] program (Bax et al 2006, Bax et al 2008). Possible sub-group analyses, such as by lower limb activity (eg, standing up compared with walking), by signal (eg, force compared with position), by sense (eg, auditory compared with visual feedback), were identified *a priori*.

Results

Flow of trials through the review

The electronic search strategy identified 1431 trials (excluding duplicates). After screening titles and abstracts, 46 potentially relevant full papers were retrieved. An

Table 2. PEDro scores* for included trials (n = 22).

Trial	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% dropouts	Intention-to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Aruin et al (2003)	Y	N	N	N	N	N	N	N	Y	Y	3
Bradley et al (1998)	Y	N	N	N	N	Y	Y	N	Y	N	4
Chen et al (2002)	Y	N	Y	N	N	N	N	N	Y	Y	4
Cheng et al (2001)	Y	N	Y	N	N	N	Y	N	Y	Y	5
Cheng et al (2004)	N	N	Y	N	N	N	Y	N	Y	Y	4
Colborne et al (1993)	Y	N	N	N	N	N	N	N	Y	Y	3
Cozean et al (1998)	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Engardt et al (1993; 1994a/b)	Y	N	Y	N	N	N	Y	N	Y	Y	5
Eser et al (2008)	Y	N	Y	N	N	Y	N	N	Y	Y	5
Geiger et al (2001)	Y	N	Y	N	N	N	Y	N	Y	Y	5
Gok et al (2008)	Y	Y	N	N	N	Y	Y	N	Y	Y	6
Grant et al (1997)	Y	N	Y	N	N	N	Y	N	Y	Y	5
Intiso et al (1994)	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Jonsdottir et al (2010)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Kerdoncuff et al (2004)	Y	N	N	N	N	N	N	N	Y	Y	3
Lin et al (1998)	Y	N	Y	N	N	N	N	N	Y	Y	4
Mandel et al (1990)	Y	N	N	N	N	Y	N	N	Y	N	3
Montoya et al (1994)	Y	N	Y	N	N	N	N	N	Y	Y	4
Morris et al (1992)	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Sackley & Lincoln (1997)	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Schauer & Mauritz (2003)	Y	N	Y	N	N	N	Y	N	N	Y	4
Walker et al (2000)	Y	N	Y	N	N	N	N	N	Y	Y	4

*PEDro scores from website www.pedro.org.au

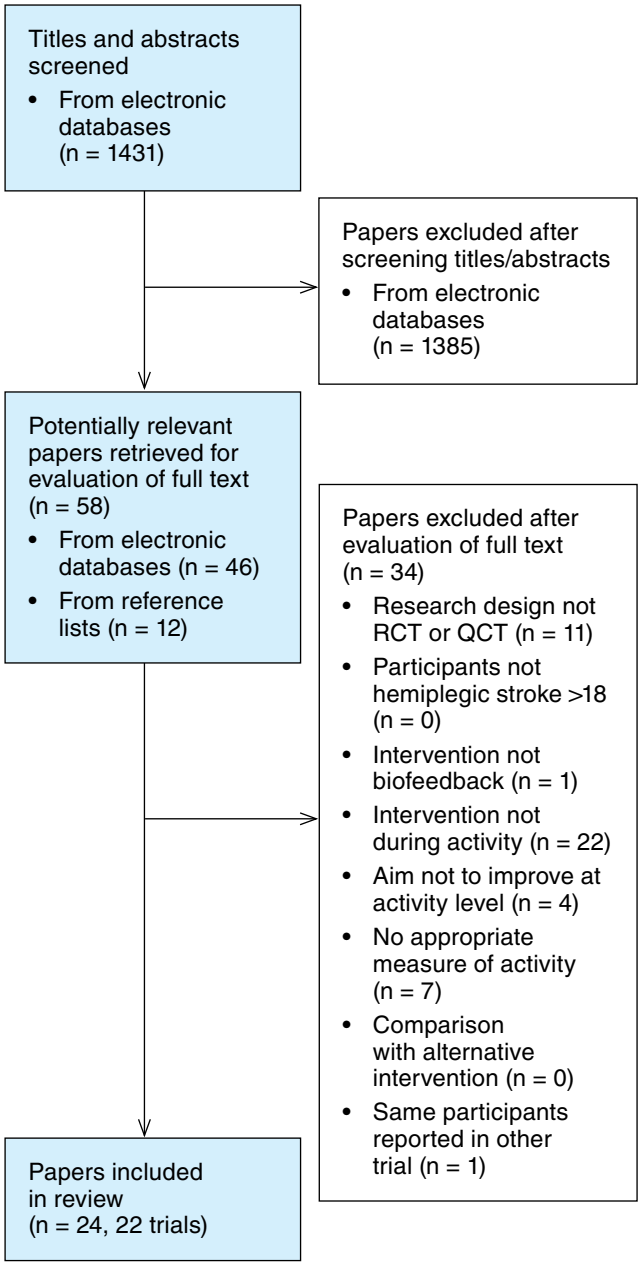

Figure 1. Identification and selection of studies. Papers may have been excluded for failing to meet more than one inclusion criterion.

additional 12 potentially relevant trials were obtained following hand screening the reference lists of included trials and previous systematic reviews (1531 references screened). After being assessed against the inclusion criteria, 24 papers reporting 22 randomised trials were included in this review (Figure 1). Table 1 on the eAddenda provides a summary of the excluded papers.

Characteristics of included trials

The 22 trials involved 591 participants and investigated biofeedback as an intervention to improve activities of the lower limb following stroke. Activities trained included standing up (2 trials), standing (9 trials), and walking (11 trials). The quality of included trials is presented in Table 2 and a summary of the trials is presented in Table 3. Additional information was obtained from the authors for two trials (Jonsdottir et al 2010, Intiso et al 1994).

Quality: The median PEDro score of the included trials was 4.5, with a mean of 4.7 and a range of 3 to 7. Concealed allocation of randomisation occurred in 9% of trials, assessor blinding in 41%, intention-to-treat analysis in 9%, and less than 15% loss to follow-up in 59%. No trials blinded participants or therapists.

Participants: Across the trials, the mean age ranged from 55 to 71 years, and 59% of participants were male. The mean time after stroke ranged from less than 1 month to 4 years, with 71% of the trials carried out within 6 months after stroke.

Intervention: Experimental interventions included biofeedback of ground reaction force from a force platform via visual and/or auditory feedback (13 trials); muscle activity from EMG via visual and/or auditory feedback (5 trials); joint position from an electrogoniometer via visual and auditory feedback (3 trials); and limb position via auditory feedback (1 trial). Visual feedback was used in 10 trials; auditory in 6 trials; and a combination of both in 6 trials. The duration of intervention was from 2 to 8 weeks, with a frequency of between 1 and 5 days/week. Session times varied, ranging from 15 min to one hour. The experimental group received either biofeedback only (3 trials) or biofeedback plus usual therapy (19 trials). In the three trials where the experimental group received biofeedback only, the control intervention was nothing (1 trial) or usual therapy only (2 trials). In the 19 trials where the experimental group received biofeedback plus usual therapy, the control group received placebo plus usual therapy (2 trials), or usual therapy (17 trials).

Outcome measures: For standing up, weight distribution between the lower limbs was measured (2 trials). For standing, the measures used were directional control during reaching in standing (3 trials), Berg Balance Scale (3 trials), Rivermead Mobility Index (1 trial), gross function subscale of the Rivermead Motor Assessment (1 trial), and the balance component of the Fugl-Meyer-Lindmark (1 trial). For walking, all trials measured gait parameters such as step/stride length or width of base of support or speed (11 trials). Outcomes were measured after intervention (20 trials) and from 1 to 5 months after cessation of intervention (11 trials).

Effect of biofeedback

The short-term effect of biofeedback on activity limitations was examined by pooling data after intervention from 17 trials comprising 411 participants using a fixed-effect model. Biofeedback improved lower limb activities compared with usual therapy/placebo (SMD = 0.41, 95% CI 0.21 to 0.62) (see Figure 2 on the eAddenda for the detailed forest plot). There was, however, substantial statistical heterogeneity (I^2 = 65%), indicating that the variation between the results of the trials is above that expected by chance. The results of a sensitivity analysis revealed that the heterogeneity was best explained by the quality of the trials. When low quality trials (ie, seven trials with PEDro score 3 and 4) were excluded from the analysis, the magnitude of the effect was similar (SMD = 0.49, 95% CI 0.22 to 0.75) but with less heterogeneity (I^2 = 43%) (Figure 3, see Figure 4 on eAddenda for the detailed forest plot).

Table 3. Summary of included trials (n = 22).

Trial	Design	Participants	LL activity	Intervention	Outcome measures during activity
Aruin et al (2003)	RCT Bfbk+UT vs UT	n = 16 Age (yr) = 65 (SD 4) Gender = 11 M, 5 F Time since stroke = < 1 mth	Walking	Exp = Step width from distance sensor via auditory fbk 70 min/day x 10 day Con = no Bfbk during walking practice 70 min/day x 10 day Both = usual therapy	• Step width • Follow-up = 0, 10 day
Bradley et al (1998)	RCT Bfbk+UT vs plac+UT	n = 23 Age (yr) = 71 Gender = 12 M, 11 F Time since stroke = 1 mth	Walking	Exp = LL mm activity from EMG via auditory + visual fbk 3/wk x 6 wk Con = placebo Bfbk during walking practice 3/wk x 6 wk Both = usual therapy	• Speed, step length • Follow-up = 0, 6 wk, 3 mth
Chen et al (2002)	RCT Bfbk+UT vs UT	n = 41 Age (yr) = 57 (SD 11) Gender = 13 M, 28 F Time since stroke = 3 mth	Standing	Exp = wt distr from force platform via visual fbk 20 min x 5/wk x 2 wk Con = no Bfbk intervention Both = usual therapy	• Smoothness of weight distribution • Follow-up = 0, 6 mth
Cheng et al (2001)	RCT Bfbk+UT vs UT	n = 54 Age (yr) = 63 (SD 8) Gender = 33 M, 21 F Time since stroke = 3 mth	Standing up	Exp = wt distr from force platform via visual + auditory fbk 20 min x 5/wk x 3 wk Con = no Bfbk intervention Both = usual therapy	• % BW thru paretic lower limb • Follow-up = 0 wk, 6 mth
Cheng et al (2004)	Q-RCT Bfbk+UT vs UT	n = 52 Age (yr) = 61 (SD 17) Gender = 32 M, 20 F Time since stroke = 3 mth	Standing	Exp = wt distr from force platform via visual fbk 20 min x 5/wk x 3wk Con = no Bfbk intervention Both = usual therapy	• Smoothness of weight distribution • Follow-up = 0, 3 wk, 6 mth
Colborne et al (1993)	CT-RCT Bfbk vs UT	n = 8 Age (yr) unknown Gender unknown Time since stroke = 17 mth	Walking	Exp = Ankle joint angle from elgon via visual + auditory fbk 30 min x 2/wk x 4 wk Con = usual therapy 30 min x 2/wk x 4 wk	• Speed, step length • Follow-up 0, 5 wk
Cozean et al (1988)	RCT Bfbk+UT vs UT	n = 18 Age (yr) = 55 Gender = 10 M, 6 F Time since stroke = unknown	Walking	Exp = Ankle muscle activity from EMG via visual + auditory fbk 30 min x 3/wk x 6 wk Con = placebo Bfbk during walking practice 30 min x 3/wk x 6 wk Both = usual therapy	• Stride length and cycle time • Follow-up = 0, 6 wk
Engardt et al (1993, 1994a, 1994b)	RCT Bfbk+UT vs UT	n = 40 Age (yr) = 65 (SD 8) Gender = 25 M, 15 F Time since stroke = 1 mth	Standing up	Exp = wt distr from force platform via auditory fbk 45 min x 5/wk x 6 wk Con = no Bfbk during standing up practice 45 min x 5/wk x 6 wk Both = usual therapy	• % BW thru paretic lower limb • Follow-up = 0, 6 wk

Trial	Design	Participants	LL activity	Intervention	Outcome measures during activity
Eser et al (2008)	RCT Bfbk+UT vs UT	n = 41 Age (yr) = 61 (SD 12) Gender = 25 M, 16 F Time since stroke = 6 mth	Standing	Exp = wt distr from force platform via visual fbk 15 min x 5/wk x 3 wk Con = no Bfbk intervention Both = usual therapy	• Rivermead Mobility Index • Follow-up = 0, 4 wk
Geiger et al (2001)	RCT Bfbk+UT vs UT	n =13 Age (yr) = 60 (SD 16) Gender = 9 M, 4F Time since stroke = 4 mth	Standing	Exp = wt distr from force platform via visual fbk 15 min x 2–3/wk x 6 wk Con = no Bfbk during standing practice 15 min x 2–3/wk x 6 wk Both = usual therapy	• Berg Balance Scale • Follow-up 0, 4 wk
Gok et al (2008)	RCT Bfbk+UT vs UT	n = 30 Age (yr) = 57 (SD 8) Gender = 17 M, 13 F Time since stroke = 18 mth	Standing	Exp = Wt distr from unstable platform via visual fbk 20 min x 5/wk x 4wk Con = no Bfbk intervention Both = usual therapy	• Smoothness of weight distribution • Follow-up 0, 4 wk
Grant et al (1997)	RCT Bfbk+UT vs UT	n = 16 Age (yr) = 65 (SD 3) Gender = 10 M, 6 F Time since stroke = 1 mth	Standing	Exp = Wt distr from force platform via visual fbk 30 min x 5/wk (inpt) and 2/wk (outpt) x 8 wk Con = no Bfbk during standing practice 30 min x 5/wk (inpt) and 2/wk (outpt) x 8 wk Both = usual therapy	• Berg Balance Scale • Follow-up = 0, 8, 12 wk
Intiso et al (1994)	RCT Bfbk+UT vs UT	n = 16 Age (yr) = 57 (SD 15) Gender = 9 M, 7 F Time since stroke = 10 mth	Walking	Exp = Ankle muscle activity from EMG via auditory fbk 30 sessions/2 mth Con = no Bfbk during walking practice 30 sessions/2 mth Both = usual therapy	• Speed, step length • Follow-up = 0, 2 mth
Jonsdottir et al (2010)	RCT Bfbk vs UT	n = 20 Age (yr) = 62 (SD 11) Gender = unknown Time since stroke = 4 yr	Walking	Exp = Ankle muscle activity from EMG via auditory fbk 45 min x 3/wk x 7wk Con = usual therapy 45 min x 3/wk x 7wk	• Speed, stride length • Follow-up = 0, 7, 13 wk
Kerdoncuff et al (2004)	RCT Bfbk+UT vs UT	n = 25 Age (yr) = 60 (SD 14) Gender = 15 M, 10 F Time since stroke = 1 mth	Standing	Exp = Wt distr from force platform via visual fbk 15–20 min x 5/wk x 3 wk Con = no Bfbk during standing practice 15–20 min x 5/wk x 3 wk Both = usual therapy	• Fugl-Meyer-Lindmark Scale (balance component) • Follow-up = 0, 3 wk
Lin & Chung (1998)	RCT Bfbk+UT vs UT	n = 20 Age (yr) = 57 Gender = unknown Time since stroke = > 6 mth	Walking	Exp = Wt distr from force platform via visual fbk 40 min x 3/wk x 4 wk Con = no Bfbk intervention Both = usual therapy	• Speed, step length, cadence, step width • Follow-up = 0, 4 wk
Mandel et al (1990)	RCT Bfbk vs nothing	n = 37 Age (yr) = 57 (SD 13) Gender = 25 M, 12 F Time since stroke = > 6 mth	Walking	Exp = Ankle muscle activity from EMG via auditory + visual fbk 24 sessions/12 wk Con = no intervention	• Speed • Follow-up = 0, 12 wk, 3 mth

Trial	Design	Participants	LL activity	Intervention	Outcome measures during activity
Montoya et al (1994)	RCT Bfbk+UT vs UT	n = 14 Age (yr) = 62 Gender = 8 M, 6 F Time since stroke = < 6 mth	Walking	Exp = Step length from moving platform via auditory + visual fbk 45 min x 2/wk x 4 wk Con = no Bfbk during walking practice 45 min x 2/wk x 4 wk Both = usual therapy	• Step length • Follow-up = 0, 4 wk
Morris et al (1992)	Q-RCT Bfbk+UT vs UT	n = 26 Age (yr) = 64 (SD 11) Gender = 12 M, 14 F Time since stroke = 2 mth	Walking	Exp = Knee angle from elgon via auditory fbk 30 min x 5/wk x 4 wk Con = no Bfbk during walking practice 30 min x 5/wk x 4 wk Both = usual therapy	• Speed • Follow-up = 0, 4, 8 wk
Sackley & Lincoln (1997)	RCT Bfbk+UT vs plac+UT	n = 26 Age (yr) = 66 (SD 11) Gender = 20 M, 6 F Time since stroke = 5 mth	Standing	Exp = Wt distr from force platform via visual fbk 20 min x 3/wk x 4 wk Con = placebo Bfbk during standing practice 20 min x 3/wk x 4 wk Both = usual therapy	• Rivermead Motor Assessment (gross function subscale) • Follow-up 0, 4, 12 wk
Schauer & Mauritz (2003)	RCT Bfbk+UT vs UT	n = 23 Age (yr) = 60 (SD 12) Gender = unknown Time since stroke = 1.5 mth	Walking	Exp = Position of heel strike via auditory fbk 20 min x 5/wk x 3 wk Con = no Bfbk during walking practice 20 min x 5/wk x 3 wk Both = usual therapy	• Speed, stride length • Follow-up = 0, 3 wk
Walker et al (2000)	RCT Bfbk+UT vs UT	n = 32 Age (yr) = 64 (SD 14) Gender = 20 M, 12 F Time since stroke = 1 mth	Standing	Exp = Wt distr from force platform via visual fbk 30 min x 5/wk until D/C Con = no Bfbk during standing practice 30 min x 5/wk until D/C Both = usual therapy	• Berg Balance Scale • Follow-up = 0, D/C (5-8 wk), 10 wk

RCT = randomised clinical trial, Q-RCT = quasi-randomised clinical trial, CT = cross-over trial, Bfbk = biofeedback, UT = usual therapy, M/F = Male/Female, Exp = experimental group, Con = control group, BW = bodyweight, LL = lower limb, fbk = feedback, wt distr = weight distribution, inpt = inpatient, outpt = outpatient, EMG = electromyography, elgon = electrogoniometer

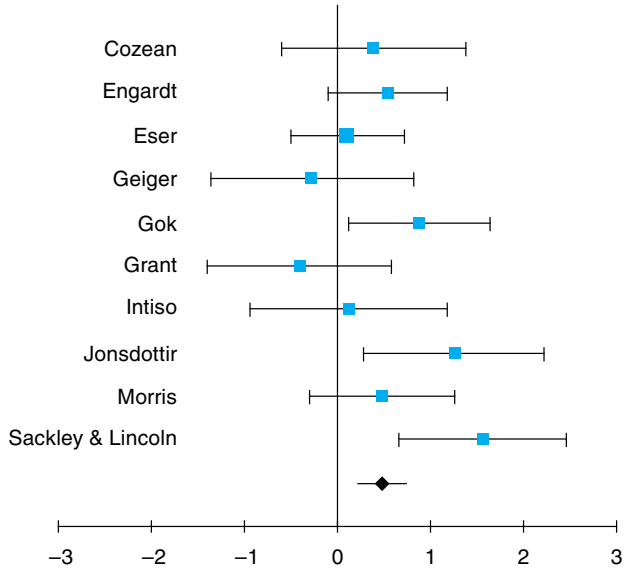

Figure 3. SMD (95% CI) of effect of biofeedback on lower limb activities after intervention by pooling data from 10 high quality trials (n = 241).

The long-term effect of biofeedback on activity limitations was examined by pooling data after the cessation of intervention from 5 high quality trials comprising 138 participants using a fixed-effect model. Biofeedback improved activity compared with usual therapy/placebo (SMD = 0.41, 95% CI 0.06 to 0.75, I^2 = 42%) (Figure 5, see Figure 6 on the eAddenda for the detailed forest plot).

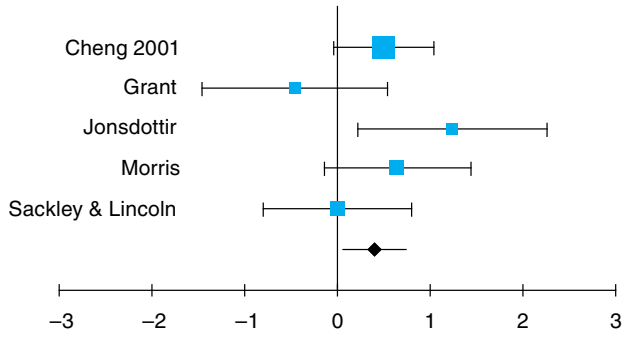

Figure 5. SMD (95% CI) of effect of biofeedback on lower limb activities 1-5 months after the cessation of intervention by pooling data from 5 high quality trials (n = 138).

Subgroup analysis by activity found that the short-term effect of biofeedback on standing up could only be examined in one high quality trial comprising 40 participants. Biofeedback tended to increase standing up compared with usual therapy (SMD = 0.54, 95% CI –0.09 to 1.17). The short-term effect of biofeedback on standing could be examined by pooling data after intervention from five high quality trials comprising 125 participants, using a fixed-effect model. Biofeedback increased standing compared with usual therapy/placebo (SMD = 0.42, 95% CI 0.05 to 0.78, I^2 = 69%, see Figure 7 on the eAddenda for the detailed forest plot) and the magnitude of the effect was the same using a random-effects model (SMD = 0.42, 95% CI –0.08 to 0.93). The short-term effect of biofeedback on walking could be examined by pooling data after intervention from four high quality trials comprising 76 participants, using a fixed-effect model. Biofeedback increased walking compared with usual therapy (SMD = 0.57, 95% CI 0.10 to 1.03, I^2 = 0%, see Figure 8 on the eAddenda for the detailed forest plot).

Discussion

This systematic review provides evidence that biofeedback has a moderate effect (Cohen 1988) in improving activities of the lower limb such as standing up, standing, and walking in the short term compared with usual therapy/placebo. Furthermore, the benefits are still present in the longer term although slightly diminished. This suggests that learning has taken place in addition to short-term improvements in performance. Biofeedback delivers feedback that is continuous, objective and concurrent with the activity, ie, knowledge of performance. In healthy populations, evidence suggests that concurrent feedback is beneficial to performance, but detrimental to learning (van Vliet and Wulf 2006). However, this review provides evidence that after stroke the provision of concurrent biofeedback during the practice of activities resulted in learning because lower limb activities were permanently improved.

The mean PEDro score of 4.7 for the 22 trials included in this review represents only moderate quality. However, in order to decrease the substantial amount of statistical heterogeneity, only higher quality trials (PEDro score > 4) were included in the final meta-analyses. This resulted in the 11 trials contributing to the findings having a mean PEDro score of 5.7, adding to the credibility of the conclusions. There was some clinical heterogeneity in these trials. Participant characteristics of age and gender were similar, and the time since stroke was generally subacute (70%), with three trials of participants whose time post stroke was chronic (10 mth, 18 mth, 4 yr). There was a range of duration of intervention (3 to 8 weeks), however the majority of trials examined interventions of 4 to 6 weeks in duration. Taken together, this suggests that the findings are credible and can be generalised cautiously.

Our subgroup analysis of lower limb activities suggests that biofeedback may be slightly more effective at improving walking (SMD 0.57) than standing (SMD 0.42). However, another explanation may be that the tools used to measure outcome were usually more congruent with the activity practised in trials of walking (eg, outcome of biofeedback of step length during walking practice measured as step length during walking) than in trials of standing (eg, outcome of biofeedback of weight distribution during standing practice measured with the Berg Balance Scale). In terms of walking, our result is similar to Tate and Milner (2010) who reported a moderate-to-large effect of all types of biofeedback on walking (7 trials, no meta-analysis). In contrast, Woodford and Price (2009) reported no effect of biofeedback on walking speed (SMD 0.13, 95% CI –0.55 to 0.80, 3 trials) and Langhorne et al (2009) reported being unable to draw conclusions. However, this may have been because these systematic reviews performed meta-analyses only on trials that measured exactly the same aspect of walking, eg, speed or step length, and this usually resulted in small numbers of trials available for analysis. In terms of standing, our finding is in contrast to Barclay-Goddard

et al (2009) and van Peppen et al (2006) who both reported no effect of biofeedback (force information via visual feedback) on standing, with Berg Balance Scale effects of MD –2, 95% CI –6 to 2 (2 trials) and SMD –0.20, 95% CI –0.79 to 0.39 (2 trials).

It is possible that some of the positive effect of biofeedback could be explained by the amount of practice carried out by the experimental group compared with the control group. When analysing only those trials where the control group practised the same activity for the same amount of time as the experimental group, with the only difference being the substitution of biofeedback for therapist feedback in the experimental group, the effect of biofeedback was still clinically and statistically significant (SMD 0.51, 95% CI 0.20 to 0.83, I^2 = 47%, fixed-effect model of 8 trials, see Figure 9 on eAddenda for detailed forest plot) and of a similar magnitude to the original analysis (SMD 0.49, 95% CI 0.22 to 0.75). This suggests that improvement in lower limb activities is due to the type of feedback (ie, biofeedback compared with therapist feedback during usual therapy) rather than the amount of practice. Why might biofeedback be more effective than therapist feedback? An observational study of therapist-patient interactions during therapy found that the content of feedback was motivational rather than informative, with specific feedback rarely given (Talvitie 2000). As early as 1932, Trowbridge and Casen demonstrated that the content of feedback is important, with feedback containing specific information regarding ways to improve future practice, enhancing learning more than motivational feedback. By its very nature, biofeedback provides specific information that can be used to adapt the next attempt at the task.

This review has some potential limitations. Several of these limitations may have led to an overestimate of the effect of biofeedback. First, there was a lack of blinding of participants and therapists since this is not always possible in trials of biofeedback. Second, even after including only high quality trials in the meta-analysis, the results are potentially affected by small trial bias, with an average number of 27 participants per trial (range 13–54 participants). Third, when multiple measures were reported, the measure used in the meta-analyses was the measure most congruent with the aim of the intervention, which may have introduced selection bias. On the other hand, the inclusion of trials that compared biofeedback only with usual therapy only does not distinguish the effect of biofeedback precisely, making the result from this systematic review a more conservative estimate of the effect. However, given that only one trial with this design was included in the meta-analysis, it is unlikely to have had a large impact. Additionally, as is usual with trials of complex interventions, the outcome measures were not the same. This meant that we had to calculate a standardised mean difference from the meta-analysis, which is less clinically useful than a mean difference. Finally, only half of the trials measured the outcomes some time after the cessation of intervention. There is a need for a large high quality trial with adequate power and follow-up to investigate the effect of biofeedback in this population.

In conclusion, this systematic review provides evidence that augmenting feedback through the use of biofeedback is superior to usual therapy/placebo at improving lower limb activities in people after stroke. Importantly, it appears superior to therapist feedback. Furthermore, these benefits are largely maintained in the longer term. Given that many biofeedback machines are relatively inexpensive, biofeedback could be utilised more widely in clinical practice. ■

Footnote: [a]MIX–Meta-Analysis Made Easy Version 1.61.

eAddenda: Table 1, Figures 2, 4, 6, 7, 8, and 9 available at jop.physiotherapy.asn.au

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