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The effect of EMG triggered electrical stimulation ± task practice on arm function in chronic stroke patients with moderate-severe arm deficits.

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Abstract

Purpose: We examined the feasibility and outcome of electromyographically triggered electrical muscle stimulation (EMG-ES) plus unilateral or bilateral task specific practice on arm function in chronic stroke survivors with moderate-severe hemiplegia. Transcranial magnetic stimulation was used to examine inter-hemispheric inhibition (IHI) acting on the stroke-affected hemisphere in a subset of eight participants.

Methods: Twenty-one stroke survivors (14 males; mean time post stroke 57.9 months) participated in this pilot investigation. Participants underwent a six-week program of daily EMG-ES training with random assignment to concurrent task practice using the stroke-affected hand only or both hands. The upper-extremity subscale of the Fugl-Meyer (FMUE) and the Arm Motor Ability Test (AMAT) were completed at baseline, 0-, 1-, and 3-months post-intervention.

Results: Following the intervention, FMUE ($F_{(3, 57)}=3.89$, $p=.01$, $\eta^2=.17$) and AMAT ($F_{(3, 57)}=12.6$, $p=.01$, $\eta^2=.39$) scores improved, and remained better than baseline at three months re-assessment. The difference between groups was not significant. A non-significant decrease in IHI was observed post-intervention.

Conclusions: An intensive program of EMG-ES assisted functional training is feasible, well tolerated, and leads to improvements in moderate-severe deficits of arm function post stroke. Larger placebo controlled studies are needed to explore any advantage of bilateral over unilateral EMG-ES assisted training.

1. Introduction

Stroke is a major cause of death and disability worldwide (Feigin et al. 2009). Of particular note is the burden of disability associated with poor recovery of the stroke affected arm: only 12- 15% of stroke survivors regain normal arm function (Kwakkel et al. 2003; Hendricks et al. 2002). Current evidence-based therapies are primarily aimed at improving arm function in those who have mild-moderate deficits after stroke and therapeutic options for those with little or no distal movement are very limited (for a review see Sirtori et al., 2009). Stinear et al. (2007) have explored factors contributing to the recovery of arm function after stroke and proposed an algorithm for the selection of individualized rehabilitation strategies, based on the severity of corticospinal tract damage. Those with more severe deficits are likely to rely more on activation of the contralesional cortex (Stinear et al., 2007). It is proposed that therapeutic interventions which engage both hemispheres, such as bilateral training, augmented by electrical stimulation of the affected arm, may be useful in this group of stroke survivors (Cauraugh et al., 2005; Cauraugh & Summers 2005).

Two recent systematic reviews have suggested that unilateral and bilateral training are similarly effective (Coupar et al., 2010; Van Delden et al., 2012a). However, the studies which contributed most to the effect of unilateral training used constraint induced movement therapy (CIMT) or modified CIMT. In these investigations the CIMT groups engaged in considerably more time practicing movements of the affected limb than controls (Van Delden et al., 2012a). The importance of practice of sufficient intensity has previously been highlighted (Kwakkel et al., 2004). It is has

been suggested that the additional practice time in CIMT studies may underlie the effectiveness of such unilateral training protocols (Van Delden et al., 2012a).

Bilateral upper limb training devices allow for greater training intensity than many other interventions (Van Delden et al., 2012b). A variety of bilateral training paradigms incorporating customized equipment, with or without rhythmic auditory cueing, have been shown to be associated with improved motor performance of the stroke affected arm and, in some cases, with improved excitability of related cortical areas (see Van Delden et al., 2012b for review). Indeed, there is some evidence to show that bilateral training paradigms are associated with a reduction in the hyperexcitability in the non-affected primary motor cortex (M1) following stroke (Stinear and Byblow 2004; Summers et al., 2007). The hyperexcitability of the non-affected M1 is thought to be due to an imbalance of interhemispheric inhibition (IHI) acting between the two primary motor cortices. It is well established that abnormal IHI adversely impacts recovery of function in the stroke affected arm (Liepert et al., 2000; Murase et al., 2004; Duque et al., 2005; Takeuchi et al. 2010) and it has been suggested that the reduction in hyperexcitability of the non-affected M1 following bilateral training paradigms is due to the normalization of abnormal IHI (Summers et al., 2007). Most bilateral devices however do not allow task specific practice, as they focus on ‘in-phase’ (symmetrical) or ‘anti-phase’ (alternating) cyclic movement which is very stereotypical in nature (Van Delden et al., 2012b). Many functional tasks require the use of both arms, and there is a need to place greater emphasis on training of bilateral motor skills in a more task specific context (McCombe Waller & Whittall 2008).

Another intervention that has shown some promise for improving motor performance of the stroke affected arm is electrical muscle stimulation. Electrical muscle stimulation has been utilized for more than three decades to facilitate recovery of movement in the arm post stroke (Baker et al., 1979). More recent research suggests that stimulation paradigms which use EMG triggering to initiate stimulation are superior to those where the onset of muscle stimulation is driven by the device (Woldag and Hummelsheim 2002). While there are some reports that EMG triggered electrical muscle stimulation (EMG-ES) of wrist extensors produces functional benefits in hemiplegic subjects post-stroke, a recent meta-analysis failed to find a statistically significant effect in favour of EMG-ES over conventional stimulation across a range of measures (Meilink et al., 2008). However, one meta-analysis of bilateral training reported that a combination of EMG-ES and bilateral training showed the largest effect sizes with respect to improving upper limb function (Cauraugh et al., 2010). The seven studies included, however, represented samples with a wide range of chronicity (mean time since stroke ranging 15 months to 8.2 years) and treatment durations (the total duration of bilateral training ranged from 5 to 19 hours), leaving many aspects of the most effective combined EMG-ES – bilateral training protocols, and the most suitable subjects for this type of treatment, to be determined.

In light of evidence that EMG-ES may increase activation of the stroke affected motor cortex (Shin et al., 2008) and that bilateral training can reduce hyperexcitability in the non-affected M1 (Stinear and Byblow 2004; Summers et al., 2007), the combination of EMG-ES and bilateral training might be an effective method for improving arm function in stroke patients with severe motor deficits.

The present study therefore examined the feasibility and effectiveness of an intensive program of EMG-ES plus unilateral or bilateral training on recovery of arm function and IHI in a group of chronic stroke survivors with moderate-severe motor deficits. This investigation took the novel approach of incorporating ‘real-world’ functional task-specific practice during the EMG-ES training, rather than stereotypical cyclic wrist and finger extension, as has been used in a number of previous investigations (Cauraugh & Kim 2002; Summers et al., 2007; Cauraugh et al., 2005; Cauraugh et al., 2009) and included follow up at one and three months post cessation of training to explore the durability of any change in arm function.

2. Methods

2.1 Subjects

Subjects were recruited via a stroke database, community based stroke support groups and media advertisement. Sixty subjects were screened for suitability and 24 subjects were randomized to EMG-ES plus unilateral or EMG-ES plus bilateral training. Subjects were eligible if they had a medically confirmed stroke >6 months previously resulting in moderate to severe hemiplegia (scoring not greater than 80% on the FMUE scale but able to trigger the EMG-ES device with their affected wrist/finger extensors), and were able to commit to the daily training requirements. Exclusions included inability to passively extend the fingers with the wrist in a neutral position and severe stretch induced muscle overactivity (sustained clonus) on rapid passive wrist/finger extension. Ethical approval was obtained from the Sir Charles Gardiner Hospital and the University of Western Australia Human Ethics Committees. All participants provided written informed consent.

2.2 Intervention

Subjects were randomly allocated to either EMG-ES plus functional practice using only the affected arm or EMG-ES plus functional practice using both arms. Subjects undertook a six week home program of at least 30 minutes/day EMG-ES plus functional practice using either the affected arm or both arms, according to group allocation. Over the first two weeks, participants used only cyclic stimulation, with the functional practice introduced in week two. By week three the EMG triggered function was commenced. A research physiotherapist visited subjects once each week to modify their practice regime. Training was customised to the individual subject's ability and goals. Tasks included grasp and release of a cup, pouring water into a cup, sorting cards, opening an envelope and unscrewing a jar/bottle lid. Subjects or their carers completed a training diary to record training times and any problems encountered during the training program. This was verified by the researcher at each visit.

A NeuroTrac™ ETS (VerityMedical Ltd. Hampshire, UK) device was used to record EMG activity and to stimulate wrist and finger extensors of the affected arm via surface electrodes over the extensor muscles. The EMG target threshold was set at 40% of the maximal contraction of the wrist/finger extensors for each individual so that they could successfully trigger the device. When a pre-set target level of activation was achieved, stimulation commenced to assist wrist/finger extension movement. The threshold was evaluated on a weekly basis and modified as required. The duration of each session was also customised to the individual, according to the quality of the practice, and their ability to continue to trigger the device effectively.

2.3 *Functional Measures*

Assessment of upper limb function

Baseline assessments of arm function were undertaken on three separate occasions prior to commencement of training. Data presented are an average of the second and third baseline assessments. Measures were collected weekly during the six week intervention period, immediately after, and at one and three months post cessation of training by the research therapist, during regular home visits. Data are presented here for only the one and three month follow up functional assessments, as any lasting effects of the intervention were of primary interest.

Two functional measures were used to examine motor performance. The primary outcome measure of motor control in the arm was the Fugl-Meyer Upper Extremity subscale (FMUE; Fugl Meyer et al., 1975), administered as per the instructions outlined in Deakin et al (2003). This scale, rated from 0-66 points, is the most commonly used scale in research concerned with upper limb recovery following stroke (Sullivan et al., 2011; Page et al. 2012) and is highly associated with other commonly used measures of arm function after stroke (Lin et al., 2009). Importantly, it includes assessment of reflex activity as well as voluntary movement (performance of actual tasks) making it suitable for lower functioning individuals. Data on minimal detectable change (MDC) for the FMUE range from 4.74 to 6.6 points dependent on baseline functioning (Page et al., 2012; van der Lee et al., 2001). In the present study, the MDC for the FMUE was considered to be 5 points.

The Arm Motor Ability Test (AMAT) was utilised as a secondary outcome measure (Taub et al., 1993; Kopp et al., 1997). This battery of simulated activities of daily living assesses a range of everyday tasks (such as drinking from a cup, tying shoelaces) and was selected as it includes a number of bilateral tasks. To our knowledge, the MDC for the AMAT has not been reported, consequently for the present study the MDC was considered to be 10% of the total score (14 points).

2.4 *Neurophysiological measures*

Paired-pulse transcranial magnetic stimulation (TMS) was used to assess IHI prior to commencement of training, immediately after completion of training and again at least three weeks later. Assessors were blinded to group allocation.

In each TMS session, subjects sat comfortably in a slightly reclined position with their neck and head supported and their forearms resting on the arm rests of the chair. EMG activity was recorded from the relaxed extensor carpi radialis (ECR) muscle with Ag-AgCl electrodes placed in a belly-tendon configuration. The EMG signal was amplified (1000x), band pass filtered (10-1000 Hz), and digitized at 4000 Hz for 100 ms beginning 50 ms before the TMS pulse was delivered. A paired-pulse protocol was used to measure IHI acting from the non-affected hemisphere on the affected hemisphere. Two Magstim 200 stimulators were used to generate single-pulse stimuli. Stimuli were delivered through figure-of-eight coils placed tangentially to the scalp with the handle pointing backward and at a 45° angle away from the midline. The coil used for stimulation of the affected hemisphere was 90 mm in diameter and the coil used for stimulation on the non-affected hemisphere was 70 mm in diameter.

Suprathreshold pulses were delivered over M1 at a number of sites to determine the optimal site for stimulation for ECR (for both hemispheres). The optimal site was defined as the site at which five successive suprathreshold pulses produced the largest mean ~~Motor-motor e~~Evoked ~~Potential-potential~~ (MEP) amplitude in ECR and all TMS pulses were applied at this site throughout the experiment. A cap marked with the International 10-20 system was used to identify the optimal sites and to ensure the precision of coil placement within a testing session. The TMS intensity, for both single and double pulses, was set as the intensity that elicited a MEP of approximately 1mV (SI_{1mV}) in ECR.

Measures of IHI were obtained (in each session) from a single measurement block of 30 trials; 15 single-pulse TMS trials delivered to the affected hemisphere and 15 double-pulse trials with the conditioning stimulus delivered to the non-affected hemisphere and the test stimulus delivered to the affected hemisphere with an inter-pulse interval of 10 ms. Both conditioning stimulus and test stimulus intensity was set to SI_{1mV} . Single and double trials were delivered at randomly selected between-pulse intervals of five, six, or seven seconds.

2.5 *Data Analysis*

Functional measures. Complete datasets were available for 21 subjects. One subject withdrew from the study due to unrelated health complications, in one subject non-compliance with the EMG-ES regime was identified from the training diary and one subject had suffered a stroke more than 20 years previously and was subsequently considered inappropriate to include in the dataset. Repeated measures analysis of variance (ANOVAs) were used to test for a difference in function (FMUE and

AMAT) from baseline to post-intervention for the two groups (bilateral, unilateral). Bonferroni adjusted pairwise comparisons were used for post-hoc comparisons.

Inter-hemispheric Inhibition. Two of the 21 subjects were unable to be screened using TMS (one aneurysm clip, one due to a history of seizures). Data are reported for 8 of nineteen subjects (three female) for whom consistent MEPs could be elicited in ECR with single-pulse TMS.

The peak-to-peak amplitude of MEPs in ECR contralateral to the affected hemisphere (in mV) was obtained from 40 ms of EMG activity beginning 10 ms after TMS pulse to the affected hemisphere. IHI was quantified by expressing the mean MEP amplitude from double-pulse trials as a ratio of the mean MEP amplitude from single pulse trials. Repeated measures ANOVA was used to test for a difference in IHI from baseline to post-intervention for the two groups (bilateral, unilateral). Correlational analyses were performed to examine associations between each subject's change in IHI from baseline to post-intervention and their change in the functional measures.

3. Results

Demographic data are summarised in Table 1. Training diaries indicated that participants were compliant with the six week training program, with most subjects undertaking an average of 30 minutes EMG-ES per day for 6-7 days/week, and some subjects using the stimulator for two 30 minute sessions per day. Subjects frequently experienced difficulty early in the training schedule with consistently triggering the stimulator, presumably related to muscle fatigue. However from week three onwards,

participants were reporting completing at least 15 EMG-ES assisted repetitions over the 30 minute training period.

3.1 Functional measures.

Data for the functional measures are represented in Table 2. A repeated measures ANOVA with group (bilateral, unilateral) as a between subjects factor and time (pre, immediate post, post 4-weeks, post 12-weeks) as a within subjects factor revealed a main effect of time for the FMUE ($F_{(3, 57)}=3.89$, $p=.01$, $\eta^2=.17$) and the AMAT ($F_{(3, 57)}=12.6$, $p=.01$, $\eta^2=.39$). There was no significant main effect of group and no significant interaction of time and group for either the FMUE or the AMAT. Bonferroni adjusted pairwise comparisons of the FMUE revealed a significant difference between pre and immediate post scores ($t_{(20)}=-1.88$, $p=.007$) and pre and 4 weeks post scores ($t_{(20)}=-2.89$, $p=.009$) and pre and 12 weeks post scores ($t_{(20)}=-3.17$, $p=.005$). Bonferroni adjusted pairwise comparisons of the AMAT (task) scores revealed a significant difference between pre and immediate post scores ($t_{(20)}=-5.54$, $p<.001$), pre and 4 weeks post scores ($t_{(20)}=-3.79$, $p=.001$), and pre and 12 weeks post scores ($t_{(20)}=-4.44$, $p<.001$). These results show that, regardless of group, there was a significant improvement on both FMUE and AMAT scores pre to post intervention for a 12 week period (Table 2). However, mean change was not greater than estimated MDC for either of the functional measures (Table 2).

Based on previous literature, initial sample size estimates indicated a required total sample of 26 participants (13 per group) to detect group differences for functional measures.

3.2 Inter-hemispheric Inhibition

The mean TMS intensity for evoking MEPs of approximately 1 mV (SI_{1mV}) was 72% of maximum stimulator output for the affected hemisphere and 58% for the unaffected hemisphere. The mean MEP amplitude to single pulse TMS delivered to the affected hemisphere at baseline was 0.70 mV.

Figure 1 shows IHI at baseline and immediately following intervention for bilateral and unilateral groups separately. For both groups, ~15% IHI was evident at baseline. Immediately following the intervention, both groups showed a reduction in IHI compared to baseline, however, the change in IHI was not statistically significant for either group ($F_{(1,6)}=0.99$, $P>.05$).

Figure 2 shows scatter diagrams of the relationships between each subject's change in IHI and change in the functional measures following the intervention. Correlational analyses showed no significant relationships between change in IHI and functional measures (FMUE: $r=0.22$; 95% confidence interval: -0.58, 0.80; AMAT: $r=0.17$; 95% confidence interval: -0.61, 0.78).

4. Discussion

The concept of tailoring therapy to the type and severity of upper limb deficit post stroke is increasingly promoted in the literature (Pomeroy et al. 2011; Stinear et al. 2012; van Vliet et al. 2012); however very few therapeutic interventions exist for stroke survivors with moderate to severe residual deficits of upper limb function

(Sirtori et al., 2009). Many of the participants in the present study would have been unable to perform the functional practice without electrical stimulation due to their very limited active wrist and finger extension. It has been suggested that EMG-ES might be a particularly useful therapy for those individuals who have very limited recovery of volitional control after stroke, to enable them to meet criteria for more active therapies (Pomeroy et al., 2011). Indeed, EMG-ES has been used to increase voluntary control of wrist/finger extension so that participants could be eligible for inclusion in a modified CIMT program (Page and Levine 2006).

This pilot investigation examined the feasibility and efficacy of an intensive six-week home program of EMG-ES combined with task specific bilateral or unilateral training in a cohort of chronic stroke survivors with moderate to severe deficits of the affected arm. The current results show that 30 minutes per day of EMG-ES assisted functional practice, using either the stroke affected arm alone or both arms, was associated with a statistically significant improvement in movement control of the stroke affected arm, which was maintained for up to three months post cessation of training. The observed gains, while small, are notable given the chronicity of participants (mean time since stroke = 57.9 months, range 11 - 180 months) and the severity of upper limb deficit (mean FMUE for the whole cohort at baseline = 34.5, range 7.5-52). The current results, however, do not provide any evidence of the superiority of EMG-ES paired with bilateral training compared to EMG-ES paired with unilateral training. This is in agreement with a number of recent reviews which have suggested that unilateral and bilateral training, using a range of protocols and devices, are similarly effective (Coupar et al., 2010; Van Delden et al., 2012a). The most important aspect of training may be the ‘dose’ of therapy, with more intensive

unilateral protocols, such as CIMT, having proven efficacy in producing functional gains in chronic (McIntyre et al 2012) and sub-acute stroke survivors (Sirtori et al 2009) with mild-moderate deficits of upper limb function. Some modes of bilateral upper limb training, such as those incorporating robotic assistance, or devices such as Bilateral Arm Training with Rhythmic Auditory Cueing (BATRAC), allow for greater training intensity, which may be an important component of their effectiveness in improving arm function (Van Delden et al., 2012b). In the present investigation the two groups undertook the same total amount of training over the same time period. It is possible that task specific training of an appropriate intensity, utilizing the principles of motor learning (graded challenge to ensure mastery, goal directed training to increase motivation and engagement, and provision of appropriate feedback), might have the potential to improve arm function after stroke, regardless of the mode of training. Indeed, several recent studies comparing different therapies delivered at the same intensity have failed to show a difference between groups for arm function (Whitall et al. 2011; Crosbie et al. 2012) or locomotor training (Dobkin et al. 2006; Duncan et al. 2011).

The type of bilateral training may also play an important role in treatment outcomes. When both arms perform symmetrical movements, identical spatial parameters and timing tend to be elicited, particularly as the movement gets faster (Carson 2005). Cauraugh & Summers (2005) have suggested that this phenomenon of ‘symmetry constraint’ could be exploited in stroke rehabilitation via bilateral symmetrical movement training. It is important to note that the training in the present study was of a very different nature to many of the previously investigated bilateral training protocols using devices such as BATRAC (Whitall et al. 2000; Luft et al. 2004) and

robotic assistance (Hesse et al. 2003). These protocols involved repetitive, stereotypical movements of both arms/hands in synchrony or out of phase with each other. It is possible that this type of movement might ‘prime’ the brain for learning (Byblow et al. 2012) and, therefore, might affect inter-limb coordination, in an entirely different way from the task specific bilateral practice, for instance undoing the lid of a jar, which was used in this study.

The type of measures used in this study may have also influenced the ability to detect a difference between groups post training. Previous investigations have incorporated measures of impairment to assess the outcome of bilateral training, for example smoothness of arm extension movement (Stoykov and Corcos 2009; Lin et al. 2009) or reaction time and ability to sustain a contraction of the wrist/finger extensors (Cauraugh and Kim 2002; Cauraugh et al. 2009), rather than function. While such measures may be more sensitive to changes in muscle activation, they do not necessarily reflect the ability to use the affected arm/hand in everyday tasks, which is likely to be the most important patient perceived outcome of therapy. The primary outcome measure in the present study was the FMUE. Despite the fact that this tool is increasingly used to measure motor performance related to arm training after stroke (Sullivan et al., 2011); there is no agreed FMUE score which can be used to predict clinically important recovery of arm function, nor an agreed FMUE score that is associated with likelihood of ‘real world limb use’. Recent authors have claimed that “reporting the proportion of participants who have achieved improvement beyond the MDC (for a given measure) helps translate research findings into clinical practice” (Lin et al., 2009; p846). Published reports of MDC for the FMUE range between 4.74 and 6.6 points (Page et al., 2012; van der Lee et al., 2001). This

variance likely reflects the chronicity and severity of the limb deficit in different study populations. In the present study, improvements that were greater than a pre-defined MDC were seen in equal numbers of participants in both study groups (5/10 in the bilateral group and 5/11 in the unilateral group for the FMUE and 6/10 in the bilateral group and 5/11 in the unilateral group for the AMAT). The present data were used to calculate the future sample size required to detect significant group differences for the FMUE and the AMAT. A clinically relevant difference between the two groups on the FMUE (5 points) with an alpha of .05 and power of 85 would require 59 participants in each group. A clinically relevant difference between the two groups on the AMAT (10 points for the present data \approx 10%) with an alpha of .05 and power of 85 would require 62 participants in each group.

In addition to the functional measures obtained in the present study, paired-pulse TMS was used to measure IHI in a subgroup of participants in whom MEP²s were consistently detectable. While there was a trend towards a decrease in IHI following the intervention (from 15% IHI at baseline to 6% IHI post-intervention) this change was not statistically significant for either the unilateral or the bilateral group.

Previous research has shown that there is an imbalance of IHI following stroke, namely, there is increased inhibition acting on the affected hemisphere from the unaffected hemisphere (Liepert et al., 2000; Murase et al., 2004). Importantly, normalisation of IHI, that is, decreasing the amount of inhibition acting on the affected hemisphere from the unaffected hemisphere, has been shown to be correlated with improved functional outcome (Mansur et al., 2005). In the present study, no relationship was seen between change in IHI and change on functional

measures (Figure 2). Studies utilizing larger sample sizes are needed to determine the effect of EMG-ES paired with bilateral practice ~~in-on~~ IHI in chronic stroke survivors.

There were several limitations in the methodology of the present study. Firstly, this investigation did not include a group who received training of the same intensity without EMG-ES assistance. As mentioned previously, this was because the intention was to explore a therapeutic approach to individuals with moderate to severe upper limb deficits post stroke, who could not undertake unassisted functional practice. However a larger study comparing EMG-ES assisted training with other forms of active-assisted training, such as utilizing a robotic device, would help to clarify the role of electrical stimulation in promoting recovery of arm function. ~~In addition~~ Secondly, due to difficulties in recruiting a more homogenous sample, the subjects studied were very varied in terms of severity and chronicity of hemiplegia. As a consequence of this, within-group variance in the data was large. The cohort studied was a mean of 4.8 years post stroke, which increases the likelihood of the presence of secondary complications, such as adaptive soft tissue shortening or spasticity, which may have limited the potential for a response to task specific training. Although muscle over-activity was assessed at baseline, and subjects with sustained clonus on rapid wrist extension were excluded, no measure of spasticity was included during or following the training regime. To our knowledge, no data exist regarding the influence of bilateral training on inappropriate muscle activation. It might be expected that EMG-ES to the wrist and finger extensors could be associated with reduction in stretch reflex excitability in the flexor muscles, which might have impacted on arm function, however, this is unable to be evaluated from

the present investigation. Finally, while blinded assessors were used to conduct IHI evaluations, assessors of functional outcomes were not blinded to group allocation.

5. Conclusions

The results of this pilot investigation show that an intensive six-week home program, consisting of daily EMG-ES plus task specific practice, is a feasible intervention for individuals with moderate to severe upper limb deficits post stroke²² and that such training was associated with statistically significant improvements in motor performance of the affected arm, which were maintained for up to three months post-intervention. The current results, however, do not provide any evidence of an advantage of pairing EMG-ES with bilateral training compared to EMG-ES augmented practice using only the stroke affected arm. Larger, placebo controlled, studies are needed to identify those most likely to benefit from EMG-ES assisted unilateral or bilateral task specific training, and to elaborate the mechanisms underpinning any differences in response to these types of training.

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Table 1. Participant characteristics measured at baseline.

	Unilateral group (n= 10)	Bilateral group (n=11)
Age (mean years \pm SD)	68 \pm 16.4	68.6 \pm 9
Gender: M:F	8:2	6:4
Side most affected R:L	5:5	6:5
Time since stroke (months) (mean \pm SD)	63.9 \pm 49.4	51.9 \pm 48.2
FMUE (mean \pm 95%CI)	38.04 \pm 5.9	30.55 \pm 7.9
AMAT (mean \pm 95%CI)	53.41 \pm 20.6	39.35 \pm 22.63

Independent samples t-tests revealed no statistically significant differences between groups for the AMAT or the FMUE at baseline (all *p*-values > .05).

Table 2. Mean (SD) and range of FMUE and AMAT scores at baseline and one- and three-months post-intervention for both unilateral and bilateral groups.

		Unilateral				Bilateral		
	Baseline	4-wk post	12-wk post		Baseline	4-wk post	12-wk post	
FMUE								
Mean (SD)	38.0 (9.6)	40.0 (9.2)	40.2 (9.7)		30.5(12.8)	32.5(11.3)	33.6(12.6)	
Range	21.5- 52	20 - 53	22 - 55		7.5 – 53	14 - 56	21 - 60	
Mean (SD) change from baseline		2.73 (4.82)	2.82 (4.87)			2.0 (3.83)	2.7 (5.89)	
AMAT								
Mean (SD)	53.4(33.3)	66.4 (35.2)	64.9(39.7)		39.3(36.5)	50.2(32.7)	48.5(36.1)	
Range	7 - 102	12 - 123	11 - 137		4 – 91	5 - 97	7 - 104	
Mean (SD) change from baseline		6.09 (9.54)	9.73 (13.10)			7.6 (7.09)	9.2 (8.61)	

Figure captions

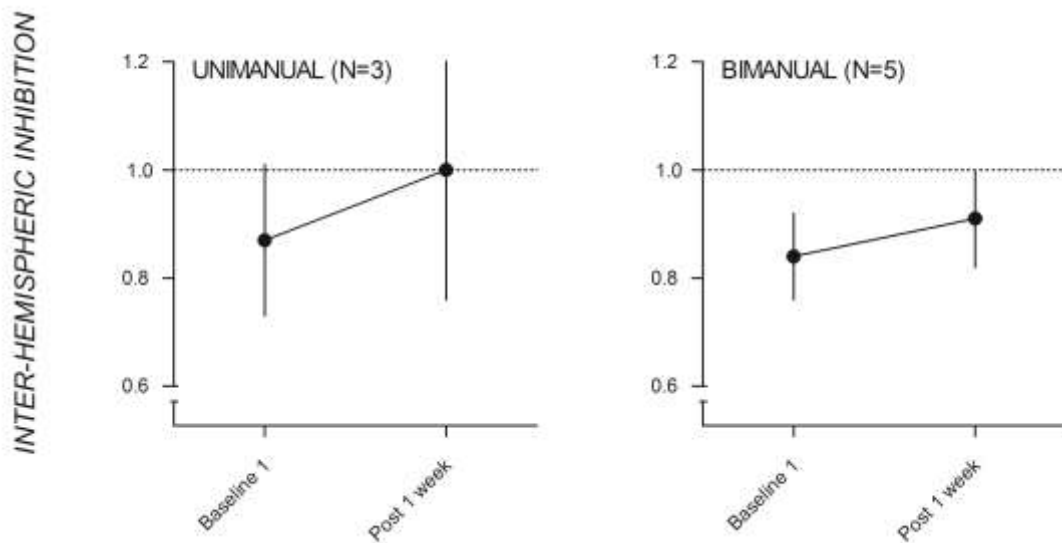


Fig. 1. IHI at baseline and immediately following intervention for both bilateral (left) and unilateral groups (right). Error bars show SEM. IHI decreased from baseline to immediately post-intervention, but this change was not statistically significant for either group.

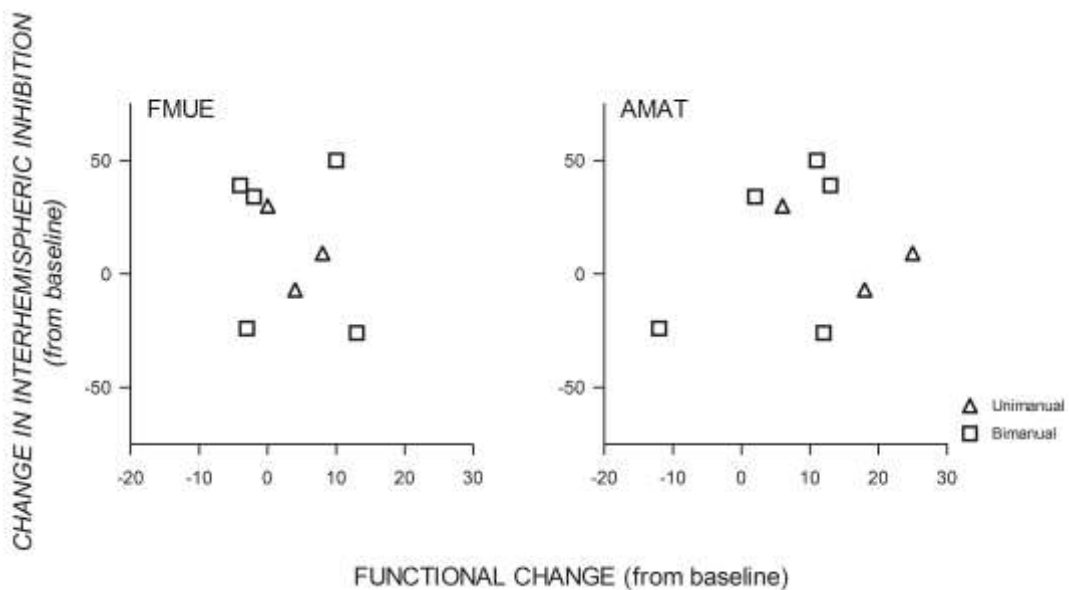


Fig. 2. Scatter diagrams showing relationships between change in IHI and change in functional measures from baseline to immediately post-intervention for subjects in the bilateral group (square symbols) and subjects in the unilateral group (triangle symbols). Y-axis: values greater than 0 represent a decrease in IHI following intervention and values less than 0 represent an increase in IHI following intervention; X-axis: values greater than 0 represent improved scores on functional measures following intervention and values less than 0 represent poorer scores on functional measures following intervention. Correlational analyses across all participants showed no significant relationships between subject's change in IHI and change in AMAT or FMUE.

Fig. 1.

Fig. 2.