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Effects of home-based sensory and motor amplitude electrical stimulation on arm dysfunction in chronic stroke

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Objective: To examine the effects of a home-based arm exercise programme of sensory and motor amplitude electrical stimulation.
Design: Non-concurrent, multiple-baseline, single-subject design.
Subjects: Ten adults with chronic arm hemiparesis following stroke. Subjects ranged in age from 38 to 74 years and were 2–16 years post stroke. Three subjects had right-sided involvement; seven had left.
Intervention: Subjects completed an eight-week, individualized, home programme of neuromuscular and sensory amplitude electrical stimulation. All subjects engaged in stimulation-assisted task-specific exercises for 15 minutes 2–3 times daily. Participants with sensory deficits received an additional 15 minutes of sensory amplitude stimulation twice daily. The Action Research Arm Test was used to examine arm function; the Stroke Rehabilitation Assessment of Movement was used to examine movement quality; and the Modified Ashworth Assessment of Spasticity was used to examine muscle tone.
Results: A statistically significant improvement was demonstrated by six of the 10 subjects on the Action Research Arm Test, and five subjects on the Stroke Rehabilitation Assessment of Movement. Four subjects had $\geq 10\%$ improvement on the Modified Ashworth Assessment of Spasticity. Two subjects demonstrated significant improvement on all three outcome measures; six subjects improved on two or more measures; and seven subjects improved on one or more measure. Subjects who improved on two or more measures tended to have had more recent onset of stroke, were older and had higher baseline motor and functional capacity.
Conclusion: Subjects with chronic stroke can experience impairment and functional improvements following a home-based programme of motor and sensory amplitude electrical stimulation.

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Introduction

Following stroke, many individuals contend with substantial functional limitations.[1] Approximately 75% of individuals who have had a stroke experience weakness in the involved arm.[2] Arm dysfunction following stroke has been associated with a low level of subjective well-being[3] and poorer ratings of health-related quality of life.[4] More than half of those with severe arm paralysis after stroke are only able to function by developing compensatory strategies using their uninvolved arm.[5]

In today's health care environment, individuals who have experienced a stroke have considerably shorter periods of hospitalization than in the past.[6] Goals during inpatient rehabilitation are typically directed at ensuring that individuals can safely navigate the home environment and perform basic self-care. This focus may not address optimal functioning of the involved arm and may contribute to the development of compensatory arm strategies.[7] A recent study reported that after stroke, patients in acute rehabilitation spend less than 17% of physical therapy time working on the involved arm.[8] Because of the need for complex arm control in daily tasks, an individual with limited arm recovery may not successfully reincorporate this extremity into daily activities.[5]

Electrical stimulation delivered at both sensory and motor amplitude has been reported to reduce impairment and improve arm function following stroke. Studies examining neuromuscular electrical stimulation use by individuals following stroke report improved force production,[9,10] selective activation of muscles,[11–14] passive range of motion,[15] and reduction of abnormally high muscle tone.[16,17] Sensory amplitude electrical stimulation has been reported to enhance sensorimotor recovery following stroke.[18] Improvements in arm function have been described following motor[10–12,19] and sensory amplitude electrical stimulation.[18,20]

Traditionally, neuromuscular electrical stimulation has been delivered during single-segment exercise.[21,22] However, the benefit of training in a functional context and of manipulating objects during functional activities has been demonstrated following stroke.[23] Recent studies have described participants who practised electrical stimulation-assisted tasks involving object manipulation and reported improved selective movement and function in the arm and hand following stroke.[12,14]

The purpose of this case series is to describe the outcomes of a home programme of electrical stimulation-assisted task performance with additional sensory amplitude electrical stimulation in 10 subjects with chronic arm hemiparesis following a stroke. It was hypothesized that this intervention would result in a decrease in impairment and improvement in function in the involved arm.

Methods

Informational flyers about this study were sent to stroke support groups, physical therapists and physicians practising in rehabilitation in our area. Inclusion criteria targeted individuals over 21 years of age with unilateral arm dysfunction following a stroke that occurred more than six months prior to the onset of the study. Volunteers were excluded if they had acute stroke, bilateral involvement, diabetes, Parkinson's disease, an open wound on the involved arm, an uncontrolled seizure disorder, cardiac arrhythmia, or a cardiac pacemaker. Prior to participating in the intervention, all participants were provided with information about the study and gave informed consent according to the process approved by the Institutional Review Board at our institution.

Three outcome measures were employed. The Action Research Arm Test[24] was used to measure arm function; the upper extremity subscale of the Stroke Rehabilitation Assessment of Movement[25] was used to measure the quality of arm and hand voluntary movement; and the Modified Ashworth Assessment of Spasticity[26] was used to measure muscle tone in each of 15 muscle groups in the involved arm and hand.

In addition to these primary outcome measures, sensory status was also examined. In subjects a–d, sensory examination was performed with the subjects' eyes closed. The examiner provided fingertip tactile stimuli to various arm and hand sites in a random pattern. The subject was asked to identify and localize the stimuli by pointing with the uninvolved hand to the site of stimuli. The authors became aware of the Nottingham

Stereognosis Assessment,[27] a more objective examination of sensation, and this outcome measure was used to examine sensation in subjects e–j.

All tests were administered in our department. Outcome measure testing consisted of two phases: baseline and intervention phases. Each subject randomly drew a baseline testing period from an envelope with slips of paper indicating the numbers 3, 4 or 5 weeks. Baseline testing was conducted in an effort to determine the stability of the subject's sensory, motor and functional status. In order to proceed to the intervention phase of the study, the participant's baseline test scores on the primary outcome measures (Action Research Arm Test and the Stroke Rehabilitation Assessment of Movement) were required to all be $\leq 10\%$ from the mean baseline score. If necessary, the baseline phase was extended until baseline stability was achieved. The Action Research Arm Test and the Stroke Rehabilitation Assessment of Movement were administered weekly during the baseline phase and every other week during the intervention phase. Sensory examination and the Modified Ashworth Assessment of Spasticity were administered at pre and post test. Testing was administered by one of the authors or by a physical therapy student supervised by the authors. The testers were aware of the subjects' participation in the study but were masked to the specific details of the intervention. All testing was videotaped and reviewed by the authors for consistency.

Data from the Action Research Arm Test and the Stroke Rehabilitation Assessment of Movement were analysed using a two-standard-deviation (2SD) band method.[28] Data from the Nottingham Stereognosis Assessment and Modified Ashworth Assessment of Spasticity were analysed by identifying a positive 10% change in score as a minimal clinically important difference (Ottenbacher, personal communication, 2001).

The intervention consisted of two components: motor amplitude electrical stimulation-assisted task practice and sensory amplitude electrical stimulation. All participants engaged in stimulation-assisted task practice. Subjects demonstrating sensory deficits on baseline testing also received sensory amplitude stimulation. The subjects used a Rehabilicare EMS +2 Muscle Stimulator with Stimcare+electrodes (Rehabilicare, New Brighton, Minnesota, USA). A symmetrical biphasic current with a phase duration of 250 μs was delivered at a frequency of 35 Hz.

Stimulation practice tasks were individually chosen for each participant based on ability. Desirable tasks were those that were functional, involved various objects, and were challenging for the subjects, yet could only successfully be performed with the assistance of stimulation. Electrode placement was individualized based on those muscles necessary for task success. One to two stimulation channels were used, depending on the subject's abilities and the task. Stimulation ramp and fall times were selected based on the speed of movement required to successfully complete the task. Examples of stimulation-assisted tasks include writing or drawing on a piece of paper, hitting a ball, and grasp and/or release of objects. Subjects were instructed to begin each session by attempting the task voluntarily, without stimulation. They were then instructed to adjust the stimulus amplitude for that session to the level that was necessary to allow them to successfully complete the task. Subjects used a hand or heel switch to activate stimulation only when assistance was required to complete the task. Hand switches were used for unimanual tasks and heel switches were used for bimanual tasks. Participants were instructed to practise the stimulation-assisted tasks for two or three 15-minute sessions daily (depending on fatigue), seven days/week.

Sensory amplitude electrical stimulation was provided to the nine subjects who demonstrated sensory deficits on baseline testing (all except subject f). For those participants, stimulation was delivered for 15 minutes, twice daily via four electrodes (two channels) on the palm of the hand and tips of the fingers/thumb. Subjects were encouraged to vary the location of the electrodes at each session. Stimulation parameters for sensory amplitude electrical stimulation were identical to those for motor stimulation with two exceptions. Stimulation amplitude was adjusted at each session to the point at which the subject could just perceive the stimuli, but below the level that produced an observable or palpable muscle contraction. A duty cycle of 10 seconds ON : 10 seconds OFF was employed to minimize sensory habituation.

The intervention was reviewed with each participant, and each provided an appropriate return demonstration of the procedure. Videotapes of the

instructional session, photos of electrode placement and written instructions were given to each subject. Subjects were instructed to record the date, time and duration of each session in a logbook. They were instructed to replace electrodes and batteries twice a week or more frequently as needed.

Results

The first 10 volunteers who met the inclusion/exclusion criteria participated in the study. Subject characteristics are listed in Table 1. All participants demonstrated stability in baseline measures ($\leq 10\%$ change) during the baseline testing period. All participants completed the eight-week intervention period. None reported any adverse response to the intervention.

Table 2 summarizes results across all 10 subjects for the four outcome measures. Six subjects demonstrated a statistically significant improvement on the Action Research Arm Test. These subjects had higher mean baselines scores than those who did not demonstrate significant improvement (22.7 versus 16.9). Figure 1 shows an example of a 2SD graph for a subject with a statistically significant improvement on this outcome.

Five subjects demonstrated statistically significant improvements on the Stroke Rehabilitation Assessment of Movement. The mean baseline scores for those who improved were higher than for those who did not improve (11.2 versus 6.8). Figure 2 is an example of graph for a subject who did not have a statistically significant improvement on this test. The baseline data points were variable and resulted in a wider 2SD band without a significant improvement.

Four subjects demonstrated $\geq 10\%$ change from pre test to post test on the Modified Ashworth Assessment of Spasticity. The results on sensory examination for subjects a–d were inconclusive. The Nottingham Stereognosis Assessment was used to examine sensory status for six subjects (e–j). Subject f had a normal score on this test at baseline and at the end of the intervention. Data from subject g were not usable secondary to communication difficulty. The remaining four participants demonstrated $\geq 10\%$ change from pre test to post test on the Nottingham Stereognosis Assessment (Table 2).

Two of the subjects (a and d) demonstrated a significant improvement on three primary outcome measures. Four subjects (b, f, g and h) improved on two primary outcome measures; one subject (i) improved on only one outcome measure. The remaining three subjects (c, e and j) did not demonstrate significant improvement on any of the primary outcome measures. A Mann–Whitney *U*-test was used to examine differences between those subjects who experienced improvement and those who did not. There were no statistically significant differences between subjects who improved and those who did not with respect to age, length of time since onset of stroke, and baseline motor or functional capacity scores; however, subjects with improvement on at least two outcome measures tended to have had more recent stroke (mean [SD] length of time since stroke was 3.1 [1.2] versus 8 [5.9] years) and were older (mean [SD] age 53.6 [12] versus 49 [9.5]). Those who improved on two or more outcome measures had higher baseline Stroke Rehabilitation Assessment of Movement scores (mean [SD] 9.4 [2.5] versus 8.4 [5]) and Action Research Arm Test Scores (mean [SD] 21.1 [15.8] versus 18.8 [10.1]).

We were unable to analyse compliance data due to incomplete and missing logbooks. Only one subject provided a completed logbook for the entire eight-week intervention period.

Discussion

For those nine subjects who received both motor and sensory amplitude electrical stimulation, the individual contributions of each component of the intervention to participant outcomes cannot be determined. As has been previously demonstrated, the use of motor amplitude electrical stimulation alone may have resulted in improvements in force,[9,10] passive range of motion,[15] selectivity,[11–14,19] and abnormal tone.[16,17] The inclusion of sensory amplitude electrical stimulation provided an opportunity for non-fatiguing afferent input that has been suggested to have a beneficial impact on sensory status post stroke.[12,18]

Table 1 Subject characteristics and baseline test scores on the Action Research Arm Test (ARAT), Stroke Rehabilitation Assessment of Movement (STREAM), Modified Ashworth Scale of Spasticity (MASS), and Nottingham Stereognosis Assessment (NSA)

Subject	Involved side	Age	Time since stroke (years)	Mean baseline ARAT score (total possible 57)[a]	Mean baseline STREAM score (total possible 20)[a]	Baseline MASS score (total possible 75)[b]
a	Right (dominant)	40	2	42	10	17
b	Left (non-dominant)	61	3	3.2	6.4	22
c	Right (dominant)	47	8	6.2	4.8	15
d	Left (non-dominant)	49	2.5	3	6.7	29
e	Left (dominant)	50	16.2	19.5	8.2	23
f	Left (non-dominant)	51	5.5	20.8	10.2	26
g	Right (dominant)	74	3	23.3	10	21
h	Left (non-dominant)	47	2.5	34.2	13.3	4
i	Left (non-dominant)	38	5.3	31	15.6	12
j	Left (non-dominant)	61	2.5	19	5	35
Mean		52	5.0	20.2	9.02	20.4

[a]Higher numbers correspond with improvement.
[b]Lower scores correspond with improvement.

Sensory input during stimulation-assisted task practice was provided by activation of cutaneous receptors, afferent input from the contracting muscles, and contact with the practice objects used in the task. We believe the combined motor and sensory amplitude electrical stimulation represented an increase in the amount of afferent input that subjects had previously been experiencing, which could have contributed to improvements.

Positive changes on the Action Research Arm Test scores for 6 of the 10 participants corresponded with expectations that enabling repetitive task-specific practice would improve object manipulation. The results of the present study are consistent with previous work that demonstrated enhanced arm function following motor amplitude electrical stimulation[10,12,14,21] and the benefits of stimulation-assisted training incorporating objects.[12,14] Improvements on the Stroke Rehabilitation Assessment of Movement for 5 of the 10 participants are consistent with previous reports of enhanced motor capacity following motor[12,19] or sensory amplitude stimulation[18,29] after stroke. Although only five subjects demonstrated a statistically significant improvement, three additional subjects (c, i and j) had higher scores during the intervention phase, although not at the level of significance. The variability in some subjects' baseline scores, while within the range of 10% determined for baseline stability resulted in a larger 2SD band. Figure 2 provides an example of a subject with variable baseline and a non-significant result, despite having a higher mean score during the intervention (5.75) than the baseline phase (4.8).

Improvements on the Modified Ashworth Assessment of Spasticity for four of the subjects concur with numerous previous reports of reduction of spasticity following electrical stimulation intervention after stroke.[16,17] However, some subjects in the present study experienced increases in spasticity. We believe this change may be related to environmental factors. Participants entered the study in the early fall and completed it during the winter. All subjects had to travel to the testing

Clinical messages

- Subjects with chronic stroke experienced motor, sensory and functional improvements following an individualized home-based programme of motor and sensory amplitude electrical stimulation.
- There was a trend towards better outcomes in those with more recent onset of stroke.
- Subjects with higher baseline ability experienced better motor and functional outcomes.

Table 2 Participants who demonstrated improvement on Action Research Arm Test (ARAT), Stroke Rehabilitation Assessment of Movement (STREAM), Modified Ashworth Scale of Spasticity (MASS) and Nottingham Stereognosis Assessment (NSA)

Subject	Number of primary outcome measures with significant improvement	Primary outcome measures			
		ARAT[a]	STREAM[a]	MASS[b]	NSA[b]
a	3	+	+	+	Not used
b	2	+		+	Not used
c	0				Not used
d	3	+	+	+	Not used
e	0				+
f	2	+	+		[c]
g	2		+	+	[d]
h	2	+	+		+
i	1	+			+
j	0				+

[a] + = significant improvement.
[b] + = ≥10% improvement.
[c] This subject had a normal Nottingham Stereognosis Assessment score at baseline.
[d] Data not usable secondary to communication issues.

site in extremely cold weather for their final testing period. Many subjects expressed concern that the cold weather had 'made them more spastic'.

The Nottingham Stereognosis Assessment was used to test stereognosis in six subjects. Data from one subject (g) was not usable and one subject (f) scored 20/20 on the test at pre test and post test. The remaining four subjects demonstrated ≥10% improvement on the test. These data contribute to the emerging body of literature suggesting that electrical stimulation intervention may enhance sensory status following stroke.[12,18,30]

We believe that the participants' active participation was a key element of the intervention. The authors of a recent review of studies using electrical stimulation to improve arm function following stroke concluded that positive results were more common when the stimulation was triggered by voluntary movement.[31] Better outcomes were reported in individuals who trained using electromyograph biofeedback-triggered stimulation compared with electrical stimulation alone following stroke,[32,33] possibly because of the active participation required when using biofeedback-triggered stimulation. In an attempt to maximize active participation in the present study, subjects were instructed to trigger stimulation only when they needed assistance with the task. In addition, stimulation amplitude was adjusted at each session to provide only as much assistance as was necessary for task completion.

The amount of practice time may have also contributed to the subjects' improvement; however, incomplete logbooks make it impossible to ascertain the actual amount of time each subject practised. Therefore, we are unable to speculate about the relationship of practice time and outcomes. Performing the stimulation at home enabled participants to schedule exercise flexibly

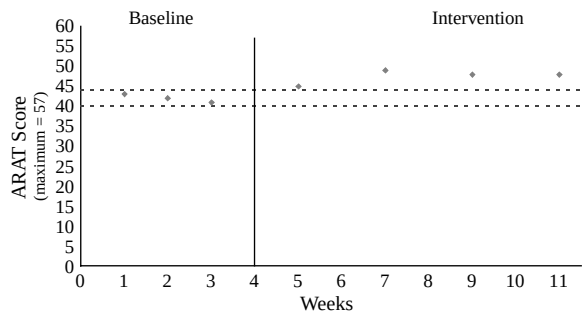

Figure 1 Two-standard-deviation analysis of Action Research Arm Test scores for subject a. Results are statistically significant since two consecutive data points in the intervention period fall outside the 2SD band.

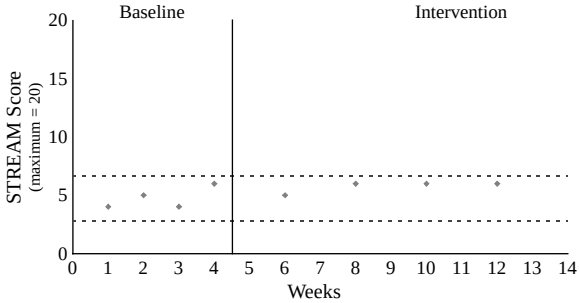

Figure 2 Two-standard-deviation analysis of Stroke Rehabilitation Assessment of Movement scores for subject c. Baseline scores are variable resulting in a wider two-standard-deviation band. Results are not statistically significant.

throughout the day. A comparable amount of practice may not have been possible in a clinic. The ability to rest between stimulation sessions may have minimized muscle fatigue and enhanced compliance. No subjects reported muscle fatigue or soreness.

The multiple baseline, single-subject design utilized in this study does not have a classical control group, such as found in a randomized control trial. This design does, however; have control elements.[28] Each subject was tested multiple times during the baseline period before the intervention began. It is assumed that the relatively stable baseline period would have continued had not the intervention been made, making each subject's baseline period his or her own 'control'.[28] In addition, the baseline phase was randomized across subjects (between three and five weeks) and the results showed that improvements occurred after the intervention was applied. The principle of unlikely successive coincidences allows one to infer with greater confidence a causal relationship between the intervention and the outcome measures.[28]

There were several limitations to this study. Sensory status was not examined using the same technique with all subjects. The Nottingham Stereognosis Assessment was identified as a clinically relevant, reliable measure of testing this impairment mid-way through the study and was used only with subjects e–j. Incomplete logbooks prevented an analysis of compliance related to outcomes. Postintervention follow-up testing would have provided information on retention of the improvements. Having a consistent examiner administer the outcome measures at all testing sessions would have strengthened the reliability of the results; however, videotapes of the testing sessions helped ensure consistent application of score criteria.

This study makes several important contributions to clinical practice. The results suggest that sensory and motor improvement may occur even for participants with chronic deficits secondary to stroke. Our study describes how electrical stimulation may be employed to enable voluntary, repetitive, task-specific practice in a format requiring minimal therapist involvement. Our results suggest that subjects with higher baseline ability may experience better outcomes following the combined application of sensory and motor amplitude electrical stimulation after stroke. Further studies of this intervention with larger sample sizes and using randomized controlled trials that analyse outcomes and underlying mechanisms of improvement should be considered. The use of a stimulator with a compliance meter could provide useful data about dosage relative to outcomes.

Competing interests

None declared.

Contributors

Both JES and LDH were involved in the study design, subject recruitment, data collection, data analysis, and manuscript writing. JES is guarantor.

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