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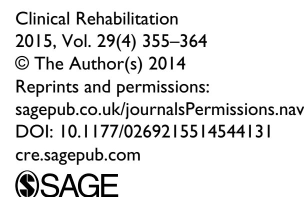

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Efficacy of electrical stimulation as an adjunct to repetitive task practice therapy on skilled hand performance in hemiparetic stroke patients: a randomized controlled trial

Nevein MM Gharib[1], Ahmed M Aboumousa[2], Abeer A Elowishy[1], Soheir S Rezk-Allah[3] and Fatma S Yousef[1]

Abstract

Objective: To assess the effects of additional electrical stimulation to hand muscles combined with repetitive task practice therapy on skilled hand performance in stroke patients.

Design: A randomized controlled study.

Setting: Neurological physical therapy outpatient clinic.

Subjects: Forty stroke patients of both sexes (45-65 years - 16 females and 24 males).

Methods: Participants were randomly assigned into two equal groups: experimental and control groups. All patients received repetitive task practice. Those in the experimental group received additional electrical stimulation for specific hand muscles and patients in the control group received sham electrical stimulation. Treatment was provided three times/week for two months.

Main outcome measures: Patients received baseline and post-treatment assessments using three-dimensional motion analysis (to evaluate range of motion of fingers abduction and extension), motor assessment scale (to assess hand motor function) and time to complete Jebsen Taylor Test (to assess hand skills).

Results: Patients in the experimental group showed a significant improvement as compared with those in the control group. Motor assessment scale score was 4.25±0.63 for the experimental group and 3.35±0.74 for the control group (t=-3.50 and p= 0.0001). Time to complete Jebsen Taylor Test was 180.90±7.04 for the experimental group and 192.80±6.87 for the control group (t=4.50 and p= 0.0001). There was a significant improvement in fingers abduction and extension in both groups (in favor to the experimental group).

[1]Department of Physical Therapy for Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Cairo University, Giza, Egypt
[2]Department of Neurology, Faculty of Medicine, Cairo University, Giza, Egypt
[3]Department of Basic Science, Faculty of Physical Therapy, Cairo University, Giza, Egypt

Corresponding author:
Nevein MM Gharib, Department of Physical Therapy for Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Cairo University, Giza, Egypt.
Email: neveinmohammed@yahoo.com

Conclusion: Repetitive task practice therapy combined with electrical stimulation can improve skilled hand performance in terms of hand motor function, skills and range of motion in stroke patients.

Keywords

Stroke, repetitive task practice therapy, electrical stimulation, hand skills, three-dimensional (3D) motion analysis

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Introduction

Approximately 60% of stroke survivors experience arm dysfunction limiting participation in functional activities.[1] Impaired hand function is among the most frequently persisting consequences of stroke. [2] In fact, finger extension is the motor function most likely to be impaired. [3] This distal limb impairment is especially problematic, because proper hand function is crucial to manual exploration and manipulation of the environment. Indeed, loss of hand function is a major source of impairment in neuromuscular disorders, frequently preventing effective occupational performance and independent participation in daily life.[4]

A very large number of interventions have been used to improve hand function in stroke survivors. [5–7] However, many of these emerging therapies require long intensive therapy sessions or expensive equipment, which make them difficult to implement in the present health care environment. Interventions emphasizing structured, active and repetitive movement are of high value in treating impairment and enhancing functional recovery following stroke. These increase strength, accuracy and functional use when applied to subjects with paresis due to stroke.[8] One approach for providing such therapy is task specific training. This kind of physiotherapy involving repetitive practice of meaningful daily activities is more effective than traditional approaches for rehabilitation of upper limb dysfunction after stroke.[9] Less intense but task-specific training regimens with the affected limb can produce cortical reorganization and associated meaningful functional improvements.[10]

Electrical stimulation of the upper limb is another technique that has received considerable attention as a therapeutic modality in post-stroke rehabilitation.[11,12] In a systematic review, de Kroon and colleagues[11] concluded that electrical stimulation may have a beneficial effect on motor control and strength of the affected upper limb, mainly in patients with mild residual motor function. Sheffler and Chae [12] arrived at a similar conclusion in their review as electrical stimulation can enhance upper limb motor relearning of stroke survivors and its effect may be more clinically relevant for acute conditions and for those with milder impairments. Nevertheless, the effect of electrical stimulation on arm-hand abilities and dexterity remains ambivalent, without strong evidence and further research is needed.

Investigation of the potential for stimulation-induced increases in cortical excitability to improve upper limb function following stroke has recently begun. [13] Techniques such as peripheral and cortical stimulation[14] and transcranial direct current stimulation[15] have been applied to small numbers of chronic stroke patients with promising results. However, despite evidence that both stimulation-induced and exercise-induced plasticity can be beneficial for recovery in hemiplegia, published studies in this regard are relatively scarce and are based on small and heterogeneous samples of stroke patients. The goal of this study was therefore to investigate whether additional peripheral electrical stimulation combined with repetitive task training of the hand could improve motor recovery and subsequently hand skills as compared to repetitive task training programme alone in stroke patients.

Material and methods

Patients were recruited from the neurological physical therapy outpatient clinic of the Faculty of Physical Therapy, Cairo University, after agreeing

to participate in the study. All the patients were diagnosed with stroke and confirmed with computed tomography or magnetic resonance imaging. Patients were enrolled if they met the following criteria: (1) first ever stroke, hemorrhage or infarction with duration of illness ranged from six to eighteen months post stroke; (2) between 45 and 65 years old; (3) the degree of spasticity of the muscles of the affected hand (wrist and fingers flexors) was grades 1 and 2 according to modified Ashworth scale [16]; and (4) the active range of antigravity motion of the affected side was at least 60 degrees shoulder elevation and 10 degrees wrist extension.

Exclusion criteria for all participants were having any other neurological or orthopedic diseases that may affect upper limb movement (e.g., parkinsonism, ataxia, rheumatoid arthritis, carpal tunnel syndrome), blindness, deafness, cognitive impairment (not being able to follow simple verbal commands and instructions during tests and training), and an uncontrolled seizure disorder, language deficits that impair patient's cooperation, or any contraindication to electrical stimulation (e.g., cardiac pacemaker). Patients meeting the enrollment criteria were randomly allocated to one of two groups: the experimental group who received electrical stimulation and structured task training or the control group who received the same task specific training exercise programme in addition to sham electrical stimulation.

Random assignment of patients was conducted through two stages. Stage one involved instructing two physical therapists who were working in the neurological physical therapy outpatient clinic to report all patients who fulfilled the inclusion criteria of the study (registration diagnosis, age, duration of illness, degree of spasticity, active range of motion of the upper limb) and had no exclusion criteria. The second stage involved randomly assigning the patients to either the experimental group or the control group by using sealed envelopes. The randomization process was carried out by a registration clerk who was not involved in any part of the study. A written informed consent form giving agreement to participation and publication of results was signed by the patients. In cases of writing disability, one witness confirmed the subject's informed consent. The study was approved by the ethics committee of the Faculty of Physical Therapy, Cairo University.

All patients (in both groups) were evaluated two times, pre treatment and post treatment (after eight weeks from the start of the treatment programme) by the same examiner who was blinded to which group each patient was in. Hand motor function and skills were assessed by Motor assessment scale [17] and Jebsen Taylor Test of Hand Function (JTHFT). [18] Motion analysis system was used for measuring fingers abduction and extension.

For evaluation of motor function of the hand, the hand section of the motor assessment scale was used. This section has six tasks and it is recorded on a scale of 0 to 6. If the patient could not complete any task, a score of zero (0) was given and if he/she was able to do the sixth task, a score of 6 was given. These tasks are: wrist extension, radial deviation, pronation/supination, forward reach, pick up and thumb opposition. The patients were asked to repeat each task three times and the highest score was taken (the best performance). Each patient was encouraged without any feedback about his/her performance. [17]

JTHFT was used to assess hand motor skills.[18] It was scored by the summed times to complete seven common tasks. The scoring method is the time necessary to complete each subtest (rounded the nearest second). The results were measured by using a stop watch. The tasks are: writing a sentence, simulated page turning, picking up small objects and placing them in a can, simulated feeding (picking up small objects with a teaspoon and placing them in a can), stacking checkers, picking up large light cans, and picking up large heavy cans. The first task, writing a sentence, was not used because it is dependent on hand dominance and education level.[19] Patients were instructed to perform the tasks as fast and accurately as possible.[18] Patients were allowed frequent breaks to avoid fatigue during familiarization and testing. Partial subtest JTHFT times and total JTHFT time were recorded for analysis. Feedback on

task performance was not provided. JTHFT measurements before (pre), after intervention (post) were calculated as the average of 3 trials. Motion analysis was conducted in the motion analysis laboratory, Basic Sciences Department, Faculty of Physical Therapy, Cairo University with a ProReflex Qualisys Motion Capture System (Goteborgsvgen 74, SE - 43363 Savedalen, Sweden). The system consisted of three ProReflex infrared high speed cameras to perform multi camera measurements and have a capture capability of 120 frames/sec. The basic principle of the system was to expose ball shaped reflective markers, positioned on the body, to infrared light from camera flashes and to detect the light reflected by the markers, and only those markers are displayed on the computer image. The markers used in this study were silver in colour and 12 mm in diameter.

The software programmes including Qualisys trac and Qualisys tools (provided by Qualisys Company) were used to capture and to analyze hand movement of the affected side. The location of cameras and their spatial orientation remain unchanged during the study. All markers were placed on all subjects by the same examiner for placement consistency.

The examiners involved in this study were trained and instructed in the use of the Qualisys Motion Capture System prior to commencing testing. They undertook a period of training and familiarization in its use to ensure competency and efficiency. The system was used to measure fingers abduction (for ring, middle, index and thumb fingers) and extension for metacarpophalangeal and proximal interphalangeal joints for index, ring and middle fingers. Each patient was positioned in comfortable sitting position with the elbow flexed 90 degree, wrist in neutral position. Small and light weight reflective markers were placed on the patient's joints' centers after determining them.

For measuring fingers abduction, one marker was placed over the distal interphalangeal joint of the measured finger and two markers were placed on the distal interphalangeal joint and the metacarpophalangeal joint of the reference finger. The reference fingers were the index (for measuring thumb abduction) and middle finger (for measuring index and ring fingers abduction). For measuring thumb abduction, the markers were placed on the first metacarpophalangeal joint, the interphalangeal joint of the thumb and the metacarpophalangeal joint of the index. For measuring extension of the proximal interphalangeal joints, the markers were placed on the head of middle phalanx, the head of proximal phalanx and the head of the metacarpal bones. For measuring extension of metacarpophalangeal joints, the markers were placed on the head of proximal phalanx, the head of the metacarpal bones and the mid carpal bones. [20]

The camera system was calibrated at the beginning of each 3D capturing session to enable the cameras to pick up the positions of the markers in the trajectory field. The positions of the cameras and their spatial orientation remain unchanged during capturing. Any relocation of the cameras required re-calibration. The cameras were arranged to cover the entire measurement volume which was marked out with the skin markers. The monitor window of the software was used to make sure that all markers are seen by all three cameras.

Patients in the experimental group received electrical stimulation for specific hand muscles followed by repetitive task training. On the other hand, patients in the control group received sham electrical stimulation followed by the same repetitive task training programme.

Electrical stimulation by using Phy-Action apparatus (787) was applied to: dorsal interossei muscles (1st, 2nd, 3rd, 4th) and abductor pollicis brevis muscle by the use of percutaneous fine needles for elimination of skin resistance, greater muscle selectivity (specially for small deep muscles) and lower stimulation currents. [12] The electrodes were connected to the exposed needle shaft. The stimulation parameters were: square-wave electrical pulses of 0.1 ms duration and a carrier frequency of 2500 HZ which is modulated to 20 Hz. Patients sat in a comfortable armchair with both arms supported and relaxed. For stimulation of dorsal interossei, the active electrode was placed in the muscle belly and reference electrode was on middle of the

dorsal surface of the forearm. For stimulation of abductor pollicis brevis muscle, the active electrode was placed in muscle belly and reference electrode was on the middle palmer forearm. The stimulus intensity range was 10 – 30 mA for each muscle, at a level just sufficient to evoke a visible motor response. The patients were instructed to pay attention to the stimulated hand and this was reinforced regularly during the session to assist in focusing their attention on the stimulated paretic hand. Stimulation lasts for 30 minutes, three sessions per week for eight weeks.

Before repetitive task training programme, patients in the control group received sham electrical stimulation. It was used with the same preparation and application like the experimental group except that the stimulus current was zero and patients were told: "You are about to receive weak electrical pulses to your finger and thumb that you may or may not feel." Patients were again asked to focus their attention on the paretic hand, and this instruction was repeated regularly during the session. All patients believed that they received the real stimulation. Sham stimulation lasts for 30 minutes, three sessions per week for eight weeks.

The training program given to the patients in this study involved repetitive practice of everyday tasks. Tasks were standardized and repeatable and included: 1- wrist and fingers extension against resistance, 2- writing, 3- grasp and release objects in a box, 4-pushing: extend fingers from fist position to push pen while the therapist supported the wrist of the patient. The patient fisted his hand and asked to push the pen with extended fingers. In accordance with the principles of motor learning,[21] patients were given feedback of their performance and tasks were progressed as performance improved, which helped to maintain interest and motivation. Sessions lasted for 45 minutes and were conducted by an experienced physiotherapist.

Statistical analysis

All data were analyzed by the SPSS software, version 16.0. Mann–Whitney signed-rank test was used to compare the baseline assessment of the degree of spasticity between the two groups. Both between- and within-group comparisons were made. As the two groups were equal in size, homogenous and tested two times (baseline and post-treatment), paired *t* test (a parametric statistical evaluation) was used for all variables except motor assessment scale scores, which was analyzed using the Wilcoxon ranked-sign test. For the between-group comparisons, independent sample *t* tests were used for all variables except MAS scores, which were evaluated using the Mann-Whitney *U* test. Change scores were calculated by subtracting the baseline data from the post-treatment data. Significance was set at $p<0.05$.

Results

For this study, 61 stroke patients were identified as potential participants (Figure 1). Of these, 12 were excluded because they failed to fulfill the inclusion criteria and 9 patients refused to participate in the study. Thus, of the original pool, 40 hemiparetic stroke patients included in the study: 16 females and 24 males with a mean age of 54.42±6.25 years.

The demographic and clinical characteristics of participants in both groups are listed in Table 1. There were non-significant differences in the demographic and clinical characteristics between the experimental group and the control group.

There was a statistically significant difference between the mean values of baseline and post treatment of all variables in both groups including motor assessment scale scores, JTHFT mean time (in experimental group only), extension range of motion of metacarpophalangeal and proximal interphalangeal joints for index, middle and ring fingers and abduction range of motion of thumb, index, middle, and ring fingers. On the other hand, there was a non significant difference in JTHFT mean time of the control group. The changes in the mean values of all variables tested are shown in Table 2. All comparisons at post treatment between the two groups were statistically significant.

Discussion

The main findings of the present study were that patients who received repetitive task practice therapy combined with electrical stimulation (experimental group) showed a significant improvement

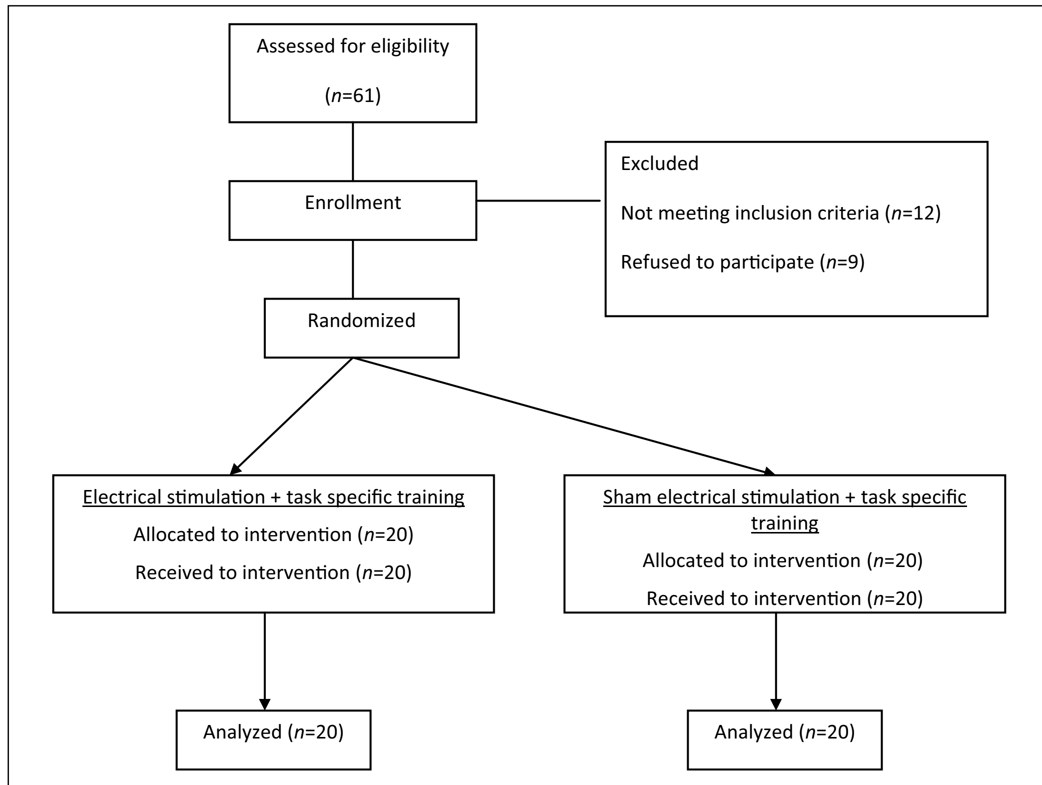

Figure 1. Flow diagram showing the patients participating in the study.

Table 1. Demographic and clinical characteristics of patients in both groups.

	Experimental group (*n*=20)	Control group (*n*=20)
Age (years)[a]	54.85±6.41	54±6.23
Gender[b]		
Male	13 (65%)	11 (55%)
Female	7 (35%)	9 (45%)
Duration of illness (months)[a]	10.95±4.81	11.40±4.60
Affected side[b]		
Right	13 (65%)	12 (60%)
Left	7 (35%)	8 (40%)
Modified Ashowrth scale[c]	1.40±0.5	1.60±0.5
Cause of lesion[b]		
Infarction	14 (70%)	15 (75%)
Hemorrhage	6 (30%)	5 (25%)

Values are mean±SD[a] or frequency (percentage)[b]. Method of statistical analysis is in the form of U Mann–Whitney signed-rank[c].

in hand motor skills compared with those who received training only (control group). Moreover, there was a significant improvement in fingers extension and abduction range of motion and motor

Table 2. Changes in outcome measures in the experimental and control groups (intragroup comparison).

	Experimental group (*n*=20)		Control group (*n*=20)		Change score	
	Baseline	Post	Baseline	Post	Experimental	Control
MAS scores	2.95 ± 0.82	4.25±0.63*	2.50±0.68	3.35±0.74*	1.30±0.73	0.85±0.81
JTHFT time (sec)	192.8±6.89	180.90±7.04*	192.90±6.76	192.80±6.87	11.90±1.58	0.15±0.36
Extension ROM of PIP joints						
Index	85.20±6.08	96.05±3.60*	84.40±5.80	90.75±5.67*	10.85±4.95	6.35±2
Middle	84.40±5.23	95.30±3.75*	87.45±5.77	91.55±5.62*	10.9±3.35	4.1±1.71
Ring	83.55±5.04	97.40±3.01*	82.30±5	88.35±5.16*	13.85±5.45	6.05±2.5
Extension ROM of MCP joints						
Index	87.70±5.32	101.85±4.14*	87.30±4.24	95.40±3.51*	14.15±3.81	8.10±2.51
Middle	89.30±4.02	106.70±3.81*	89.70±2.97	101.90±3.93*	17.40±4.47	12.20±2.26
Ring	88.50±3.77	105.25±3.4*	87.40±2.94	97.15±3.34*	16.75±4.55	9.75±2.95
Abduction ROM						
Thumb	16.12±5.88	26.90±7.48*	14.85±5.35	18.65±6.02*	10.77±4	3.75±1.7
Index	7.60±2.62	13.90±3.05*	6.45±2.54	9.50±2.50*	6.30±2.31	3.05±1.8
Middle	7±3.37	13.35±3.88*	7.95±2.45	10.85±2.45*	6.35±1.78	2.90±1.11
Ring	9.80±5.39	17±4.49*	10.95±5.18	13.30±5.23*	7.20±2.72	2.35±1.03

Values are mean±SD. Post: post-treatment assessment, MAS: motor assessment scale, ROM: range of motion, JTHFT: Jebsen Taylor Hand Function Test, PIP: proximal interphalangeal,
MCP: metacarpophalangeal. *Significant at $p<0.05$.

assessment scale scores in both groups (in favour of the experimental group).

The significant improvement of fingers range of motion and motor assessment scale scores in the control group who received task practice therapy alone might be attributed to the opinion that specific training or repetitive exercise is known to increase corticospinal excitability and can lead to increased activation of the affected somatosensory cortex.[22] The somatosensory cortex has direct anatomic projections to motor, premotor, and parietal cortices.[23] These projections modulate neuronal activity in primary motor cortex and associated frontal and parietal areas, [24] providing a likely anatomic substrate for the findings described in the control group. Additionally, task specific training is suggested to recruit other functional brain areas such as basal ganglia, cerebellum and other areas of the cortex in planning and execution of the motor task.

The significant improvement of hand motor skills as measured by JTHFT performance in the experimental group and not in the control group might be attributed to the point that the experimental group received a period of electrical stimulation prior to each training session. Associative electrical stimulation has previously been shown to produce an increase in cortical excitability that lasts for approximately 1 hour. [25] Therefore, although not tested in the present study, it is likely that patients in the experimental group received their training at a time during which motor cortical excitability was increased. Increased motor cortical excitability has previously been shown to facilitate motor performance in stroke patients.[26] Therefore, the present findings suggest that training during a period of increased motor cortical excitability may lead to additional improvement of hand motor skills in the experimental group.

This explanation is supported by the opinion that performance of the JTHFT engages a distributed network of interconnected cortical regions including frontal and parietal cortices.[27] Electrical stimulation, which activates group Ia large muscle afferents, group Ib afferents from Golgi organs, group II afferents from slow and rapidly adapting

skin afferents and cutaneous afferent fibers, elicits an increase in motor cortical excitability of body part representations that control the stimulated body part (hand) and results in reorganization of the motor and somatosensory cortices.[28]

Another explanation that might justify the significant improvement of hand motor skills in the experimental group is the potentially beneficial effect of electrical stimulation on improving motor control and strength of the stimulated muscles and subsequently range of motion of hand joints.[29,30] Electrical stimulation may simply be a convenient method of repetitive contraction and stretching of muscle groups, and it is possible that simple passive range of motion or active assisted range of motion exercises would lead to the same results. However, it is possible that electrical stimulation has a combination of effects, including those at the level of the muscle, and also a central effect associated with improved motor relearning. [12,31]

Combining electrical stimulation and repetitive task practice therapy was able to show better improvement in motor assessment scale scores and range of motion in extension of metacarpophalangeal and proximal interphalangeal joints in index, middle and ring fingers and also the abduction range of motion of thumb, middle, ring and index fingers. These results are consistent with those reported by Ng and Hui-Chan [32] as they found that combining electrically induced sensory inputs through transcutaneous electrical nerve stimulation (100 Hz, 0.2 ms square pulses) with task training for 20 sessions in a home-based program would augment voluntary motor output in stroke survivors better than either treatment alone or no treatment. Additionally, it was reported that functional electrical stimulation that delivered alternating current modulated to bursts at 36 Hz combined with task specific training can enhance the recovery of upper extremity function even during early stroke rehabilitation than functional electrical stimulation alone.[33]

3D kinematic analysis provides quantitative and qualitative assessment of upper-limb motion and is used as an outcome measure to evaluate impaired movement after stroke.[34] The use of the 3D technique was of help to show the improvement in the range of motion of the paretic hand. Yet this was in concordance with the improvement in the other clinical parameters. This could raise the question of the relevance of using 3D assessment in clinical practice.

This study has several limitations. The small number of participants might limit the generalization of the study results. The patients who participated in the study were all aged between 45 and 65 years old. Further studies are recommended to be conducted on different ages to enable comparisons of the results across different age groups. The duration of illness of all patients who participated in this study was from six to eighteen months post stroke. Further studies are recommended to target duration of illness beyond eighteen months to enable comparisons of the results across different durations of illness. Additionally, the degree of spasticity was another limitation as all patients included in this study had a mild degree of spasticity (grade 1 and 2 according to modified Ashworth scale). This limits the generalization of our results and future studies are recommended to be done on higher degrees of spasticity. The total amount of training time that the two groups received was also different. This is because all patients received the same amount of repetitive task training therapy while the patients in the experimental group received additional time for training by electrical stimulation. The lack of follow-up for the patients in both groups might be considered another limitation of the study. We suggest future studies to control these potential sources of bias.

Clinical messages

- Combining repetitive task practice therapy with electrical stimulation can increase the chance of improving skilled hand performance than training alone in hemiparetic stroke patients.
- The improvement in hand function is accompanied by and may result from induced changes in the range of motion of hand joints.

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Conflict of interest

The authors declare that there is no conflict of interest.

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