A Home Program of Sensory and Neuromuscular Electrical Stimulation With Upper-Limb Task Practice in a Patient 5 Years After a Stroke

Background and Purpose. This case report describes a person with upper-extremity (UE) hemiparesis who participated in a home program that included sensory amplitude electrical stimulation (SES) to his involved arm and performance of task-specific exercises with the assistance of neuromuscular electrical stimulation (NMES). **Case Description.** The patient was a 67-year-old man with stable sensory and motor deficits 5 years after a stroke. Sensory amplitude electrical stimulation was delivered for 2 hours per day. A daily, 15-minute course of NMES was used to help him perform UE tasks. This home program was carried out for 18 weeks and included 6 physical therapist home visits. **Outcomes.** The patient's UE score on the Stroke Rehabilitation Assessment of Movement (STREAM) improved from 10/20 to 17/20. The score on the Action Research Arm Test (ARAT) improved from 27/57 to 42/57. The patient reported that he was now able to button buttons, use a knife and fork, and tie simple fishing knots. **Discussion.** A home program combining SES and NMES may be an effective method to increase UE function even 5 years after a stroke. [Sullivan JE, Hedman LD. A home program of sensory and neuromuscular electrical stimulation with upper-limb task practice in a patient 5 years after a stroke. *Phys Ther.* 2004;84:1045–1054.]

Key Words: *Neuromuscular electrical stimulation, Sensory amplitude electrical stimulation, Stroke, Upper limb.*

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An independent home program of electrical stimulation and exercise for a patient with upper-extremity hemiparesis is described.

Each year, an estimated 700,000 Americans have a stroke.[1] Approximately 75% of them have weakness in their involved upper extremity (UE).[2] More than half of those with severe UE paresis following a stroke learn to compensate by using the less-involved arm for function.[3] Some physical therapists are concerned that shortened rehabilitation stays, combined with a focus on functional activities that are critical for a safe return home, may result in a de-emphasis on therapy for the involved UE.[4] Improved function in the paretic UE recently has been reported in people with chronic stroke following an intervention that consisted of constraining the less-involved UE and intense practice of tasks with the involved UE.[5–9] To date, success following this intervention has been limited to subjects who have moderately good initial UE function and engage in intense supervised practice.[4–9] Although intense practice appears to be a critical element of successful interventions to improve function in the hemiparetic UE,[10,11] active practice is sometimes not possible following a stroke due to the severity of motor and sensory deficits. Interventions are needed to enable active practice for people who demonstrate limited UE movement following a stroke.

Neuromuscular electrical stimulation (NMES) may be an appropriate intervention to enable active practice following a stroke. Studies examining the use of NMES have demonstrated improvements in passive range of motion (PROM),[12–15] active range of motion (AROM),[16,17] force production,[18] and electromyographic (EMG) output[19] and reduction of abnormally high "muscle tone" (as measured by EMG stretch reflex latency and magnitude,[20] Ashworth score[21]). In these studies, NMES was delivered in the context of single-segment exercise (eg, repetitive wrist extension). Studies[22–24] also suggest that targeted functional practice is key to improving function following a stroke. Majsak[25] suggested that "embedding" the movements to be trained into task practice improves the quality of those movements after a stroke. In addition, better performance—as measured by increased number of repetitions,[26] increased joint range of motion (ROM),[27,28] shorter movement time, less total limb displacement, smoother trajectory, and higher and earlier peak velocity[29,30]—was seen during training that incorporated a purposeful activity including everyday objects. Recently, NMES was used to help a subject to practice reaching and moving everyday objects such as plates, utensils, and cans.[31] The subject reported increased ability to participate in homemaking activities and was reported to have improved selective shoulder flexion with elbow extension.[31]

Impaired motor function following a stroke may result from deficits in the sensory system as well as the motor systems.[32,33] For example, a patient with a lesion in the somatosensory cortex may not be able to accurately interpret afferent inputs. Diminished function in the sensory systems may further reduce motor output.[32] Reduced use of an extremity may result in a decline in the quality and quantity of afferent inputs to the primary sensory cortex. Cortical representation areas are constantly modified by experience-induced afferent input.[34–37] Following a cortical lesion, the cortical representation of the hand was reported to shrink in primates that did not receive training or encouragement to use the involved limb.[38] In contrast, cortical representation areas can be increased by training that is specific, requires attention, and is repeated over time.[39] Neuromuscular electrical stimulation can be used to enable such practice.

Electrical stimulation may enhance afferent input to the cortex in multiple ways. Traditionally, in rehabilitation

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for patients following stroke, NMES has been used to increase voluntary muscle contractions. The subsequent movement may enhance afferent information. Cutaneous input is delivered during electrical stimulation, whether at a motor or sensory threshold, even though there are no specific sensory receptors for electrical stimuli. Perhaps this afferent input could contribute to heightened sensory information and adaptation of cortical representation.

One way to maximize the amount of sensory input is via sensory amplitude electrical stimulation (SES), which, unlike NMES, is not limited by muscle fatigue. In one study,[40] when SES was delivered to the hand of subjects without neurological impairments, functional magnetic resonance imaging (fMRI) showed increased blood flow in the areas of the primary and secondary motor cortices as well as the primary sensory cortex. In other studies, the application of SES to patients following a stroke resulted in improvements in skin sensation and somatosensory evoked potential normality classification,[41] a reduction in abnormally high "muscle tone" (as measured by joint stiffness,[42] reflex torque onset,[43] and modified Ashworth Scale[44]), and reduced inattention and neglect.[45–47] Sensory amplitude electrical stimulation also has been incorporated as part of a comprehensive program for UE sensory re-education following a stroke.[48] Utilizing both sensory amplitude electrical stimulation and task-specific practice with NMES training could potentially have a greater cumulative benefit than with either intervention alone.

The purpose of this case report is to describe the use of a home program of SES and task-assisted NMES for a patient whose UE hemiparesis was stable following a stroke. We expected that a sensory and motor electrical stimulation program combined with task practice would decrease the patient's impairment and improve function of the upper limb.

Case Description

Patient Description

Informational flyers about our intervention were sent to groups for patients with stroke and to physical therapists and physicians practicing in neurology in the metropolitan Chicago area. Inclusion criteria included chronic stroke (more than 6 months) with UE dysfunction. Volunteers were excluded if they had acute stroke (less than 6 months), bilateral hemiparesis, diabetes, Parkinson disease, an open wound on the involved UE, cardiac arrhythmia, or a cardiac pacemaker. One person was selected from 10 volunteers. This person was chosen because he was the first volunteer who had clinically meaningful sensory and motor deficits and appeared willing and able to carry out the home program. Before participating in the intervention, the patient was informed about the intervention and signed an informed consent form approved by the Institutional Review Board, Office for the Protection of Research Subjects, at Northwestern University.

The patient was a 67-year-old, right-handed, Caucasian man who was otherwise healthy until he had a stroke with left-sided (nondominant) hemiparesis 5 years ago. The stroke was caused by an infarct to the middle cerebral artery resulting in a moderate-sized lesion involving the posterior frontal, anterior-superior temporal, and anterior parietal regions. The patient was medically and neurologically stable and took no medication aside from one 81-mg aspirin per day for stroke prophylaxis. He was not involved in formal rehabilitative therapy, but he participated in a weekly aquatics program for senior citizens and used an overhead pulley daily at home. The patient was independent in activities of daily living with the help of equipment (small-base quad cane, tub bench) and reported that he rarely used his involved UE for functional activities. Movement in that extremity was characterized by a flexor synergy pattern. He had increased resistance to passive stretch in the distal flexor musculature. Tactile sensation was severely impaired throughout the UE.

Measurements

Two primary outcome measures were used: the Action Research Arm Test (ARAT) and the Stroke Rehabilitation Assessment of Movement (STREAM). The ARAT was used to measure UE function. This test was designed for use with people following a stroke.[49] The test comprises 4 subscales, (grasp, grip, pinch, and gross movement). Each of the 19 test items is scored on a 4-point ordinal scale (0=can perform no part of the test, 1=performs the test partially, 2=completes the test but takes an abnormally long time or has great difficulty, and 3=performs the test normally). The total possible score is 57. The ARAT has been correlated with the Fugl-Meyer Assessment Scale (r=.94).[50] In a study using the ARAT with people following a stroke, intrarater reliability was r=.99 and interrater reliability was r=.98.[50] We chose this test as an outcome measure because the validity and reliability of data obtained with the test had been studied and it could be administered in the patient's home.

The STREAM examines voluntary movement and mobility after a stroke.[51] The test has 3 subscales: upper extremity, lower extremity, and basic mobility. A 3-point scale is used to score movement quality (0=unable to perform the movement, 1a=able to complete only part of the movement with marked deviation from the normal pattern, 1b=able to perform only part of the movement but in a manner that is comparable to the unaffected side, 1c=able to complete the movement but only with a marked deviation from the normal pattern, and 2=fully able to complete the movement in a manner comparable to the unaffected side). When calculating the total score, items scored as 1a, 1b, and 1c have a value of 1. Intrarater reliability of data for the STREAM with patients following a stroke was reported to be .995 using direct observation and .999 using videotaped observation. Internal consistency was reported to be .984, as demonstrated by Cronbach alphas.[51,52] The STREAM score was reported to be associated with the score of the Barthel Index of Activities of Daily Living (rho=.67) and Fugl-Meyer Assessment Scale (rho=.95).[53] We used the UE scale of the STREAM to examine voluntary movement because its reliability and validity have been studied.

Secondary outcome measures included PROM, tactile sensation, and resistance to passive muscle stretch. Passive range of motion was examined using standardized goniometric technique.[54] Sensory examination was performed with the patient's eyes closed. The examiner provided fingertip tactile stimuli to various UE sites, both proximal and distal, in a random pattern. The patient was asked to identify and localize the stimuli by pointing with the uninvolved UE to the site where the stimulus was delivered. Tactile sensation was scored as the number of correct responses divided by the total number of sites tested. Resistance to passive muscle stretch was examined by passively moving each UE joint at slow speeds and then at progressively more rapid speeds. This resistance to passive muscle stretch was graded in each muscle group as minimal, moderate, or severe based on the amount of resistance. We did not estimate the reliability of data for any of our secondary outcome measures.

Measurement Procedures

All tests were administered in the patient's home. Two baseline testing sessions were conducted to determine the stability of the patient's sensory, motor, and functional status. Testing during the intervention phase was done after 3 days, 6 weeks, and 18 weeks. The baseline sessions were conducted by a physical therapist student supervised by both authors, whereas the intervention and posttest outcome measures were administered by one of the authors (LDH).

Intervention

The intervention consisted of 2 concurrent components: (1) sensory stimulation (stimulation to sensory threshold without motor contraction) and (2) NMES during the assisted task practice. The intervention was initiated during the second visit (following the second baseline test). Sensory stimulation was carried out for 2 hours per day, and NMES was carried out for 15 minutes twice a day. All intervention was performed by the patient in his home.

Figure 1.
The patient used a hand switch to activate neuromuscular electrical stimulation while lifting a 250-mL can.

During pretesting, the patient performed all UE manipulation tasks with his wrist in a flexed position. When the wrist and finger flexors are maximally shortened, a state of active insufficiency is created and the ability to generate force is compromised. Increased wrist extension increases the length of the wrist and finger flexors and is associated with increased force generation.[55] We believed that increasing the patient's active wrist extension would increase his grip effectiveness; therefore, practice should involve active wrist extension while gripping objects.

The patient was seated at a table with his forearm supported on a book in an initial position of wrist flexion. The NMES was delivered to the wrist extensor muscles while the patient grasped an empty, 17-cm, 250-mL aluminum can and lifted it from the tabletop as he extended his wrist (Fig. 1). He practiced the lifting task for 15 minutes, twice a day. A narrow can as used to accommodate the reduction in finger opening when the wrist was extended.

We used a Rehabilicare EMS+2 muscle stimulator with Stimcare Plus electrodes.* Electrodes (6.38 cm [1.25 in] in diameter) that were placed on the motor point of the common wrist extensors and approximately 2.54 cm (1 in) distally (Fig. 1). A symmetrical biphasic current with a phase duration of 250 microseconds and a ramp/fall time of 2 seconds was delivered at a frequency of 35 Hz. The patient used a hand switch to trigger stimulation when he determined that he needed assis-

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* Rehabilicare, 1811 Old Highway 8, New Brighton, MN 55112.

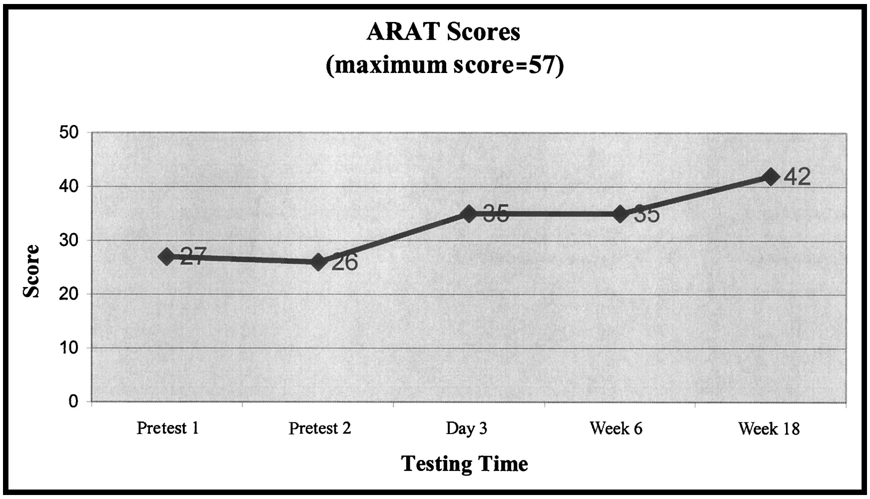

Figure 2.
Scores on the Action Research Arm Test (ARAT).

tance with the task. He adjusted the NMES amplitude each session to provide only as much assistance as was necessary to accomplish the task.

Because of our patient's severe sensory deficit, we believed that the additional application of sensory input might enhance his abilities to manipulate objects. The SES was delivered for 2 hours daily. The same electrode placement was used for SES and NMES to minimize complexity for the patient. Stimulation parameters for SES were identical to those for NMES with 2 exceptions. Stimulation amplitude was adjusted at each session to the point where the patient could just perceive the stimuli, but below an observable or palpable muscle contraction. A duty cycle of 10 seconds on and 10 seconds off was used to minimize sensory habituation.

We reviewed the intervention with the patient, and he demonstrated that he could independently perform the procedures. Videotapes of the instructional session, photographs of electrode placement, and written instructions were given to him. We instructed the patient to judge the success of his performance by comparing it with the instructional materials. He was instructed to replace the electrodes weekly or when they ceased to adhere consistently at the edges. He was instructed to replace the batteries biweekly or when responses to stimulation were less than in previous sessions regardless of amplitude setting.

After 3 days, stimulation was discontinued because the patient developed a superficial purplish discoloration at the electrode sites on the dorsum of the forearm. Three potential causes of this reaction were ruled out. Equipment malfunction was ruled out by testing the stimulator on an oscilloscope, which indicated that the stimulator was delivering the appropriate type of current. An allergic reaction to the electrodes was ruled out by applying them to other body areas, which did not produce a skin reaction. Finally, a clotting disorder was ruled out because of the normal values on the patient's blood tests.

A condition called *senile purpura* could not be ruled out. This is a skin condition common in fair-skinned, light-eyed people whose skin is more easily damaged by lifetime exposure to ultraviolet radiation. Radiation causes damage to the structural collagen that supports the walls of the skin's blood vessels, which makes these blood vessels more fragile. When combined with the thinning of the skin that occurs with aging, people with this condition are more likely to rupture vessels following a slight impact. The skin discoloration seen with senile purpura is purplish and appears superficial.[56] The patient met the criteria for this condition because of his age and coloring, and we observed that he applied excessive pressure over the electrodes to ensure that they were secure.

The skin discoloration resolved in 10 days without stimulation. Stimulation was then reinitiated with several modifications. The patient was reinstructed in electrode and skin care. The patient's NMES-assisted task practice was reduced from 2 to 1 daily 15-minute session. Finally, electrode placement for SES was changed to the volar surface of the forearm. This was done because senile purpura is more commonly seen on the dorsum of the forearms and hands. Electrode placement on the dorsum of the forearm was necessary during NMES, however, to activate the wrist extensors. No further skin discoloration recurred following the treatment modifications.

Outcome measurements were repeated after 6 weeks of intervention. The ARAT score improved from 27/57 to 35/57 (Fig. 2), and the STREAM score improved from 10/20 to 12/20 (Fig. 3). We believed that the increased resistance to passive stretch initially noted in the finger flexor muscles was reduced and the active wrist extension movement observed to be comparable to that of the less involved side. A different NMES-assisted task was used during the second phase of the intervention. The patient was seated, with his arm supported on a table and grasping an empty 2-L plastic bottle. The NMES was delivered to the finger extensor muscles while the patient released the bottle. It was possible to use a larger size object in NMES task practice because of an increase in finger opening with the wrist extended.

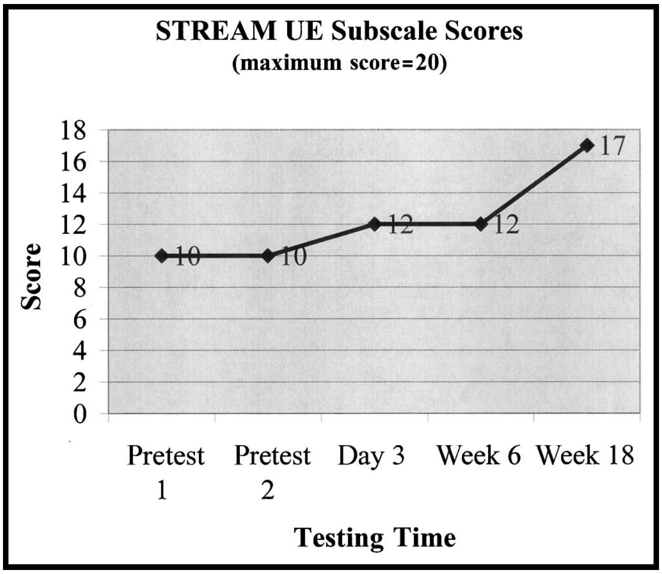

Figure 3.
Scores on the Stroke Rehabilitation Assessment of Movement (STREAM) Upper Extremity (UE) Subscale.

Table 1.
Pretest and Posttest Scores on the Action Research Arm Test (ARAT) Subscale Tests

ARAT Subscale	Pretest Score	Posttest Score
Grasp	11/18	15/18
Grip	8/12	12/12
Pinch	3/18	6/18
Gross movement	5/9	9/9
Total	27/57	42/57

Outcomes

Following 18 weeks of home exercise that included 6 physical therapist home visits, outcome measures were repeated. The ARAT score improved from 27/57 to 42/57 (Fig. 2), with improvements in all 4 subscales (Tab. 1). The STREAM UE subscale score had improved from 10/20 to 17/20 (Fig. 3). Figures 4 and 5 illustrate the change in performance on the ARAT and STREAM. Tactile sensation improved from 2/19 to 11/18 correct responses to tactile stimuli. Correct responses were observed only in the left upper arm at pretest, whereas correct responses were at the upper arm down to the wrist at posttest. Passive range of motion improved at the shoulder and elbow (Tab. 2). At pretest, minimally increased resistance to passive stretch was noted in the left shoulder adductors and extensors, elbow, and finger flexors. At posttest, this remained unchanged at the shoulder and elbow, whereas in the finger flexor muscles, there was decreased resistance during passive stretch. The patient reported that he was pleased because he could now button buttons, use a knife and fork, and tie simple fishing knots.

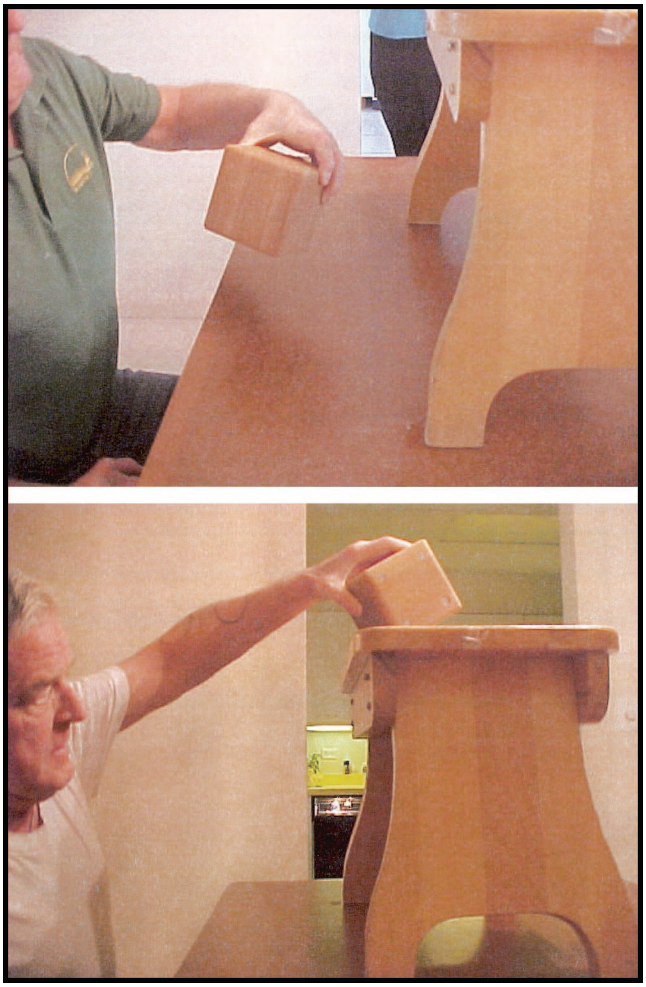

Figure 4.
(Top) Action Research Arm Test (ARAT) pretest. The patient attempts to lift a block; his wrist remains flexed. (Bottom) ARAT posttest. The patient lifts a block with his wrist in neutral position.

Discussion

Rapid initial improvements in the outcome measures following a stable baseline may have resulted from the patient's renewed attention to his arm. Continued improvements throughout the intervention period suggest the changes could have resulted from the intervention. The individual contributions of NMES and SES to the outcome, if any, could not be determined. Use of NMES might have resulted in improvements in PROM and AROM, resistance to passive stretch, and isolated movement. The inclusion of SES provided additional sensory input that may have been beneficial.

Changes in the primary outcome measures of ARAT and STREAM scores were consistent with our expectation that attended, repetitive, progressive practice of demanding tasks could improve the patient's ability to use his arm. This outcome is consistent with previous work that demonstrated the benefits of UE functional training incorporating objects.[26,27,29,30]

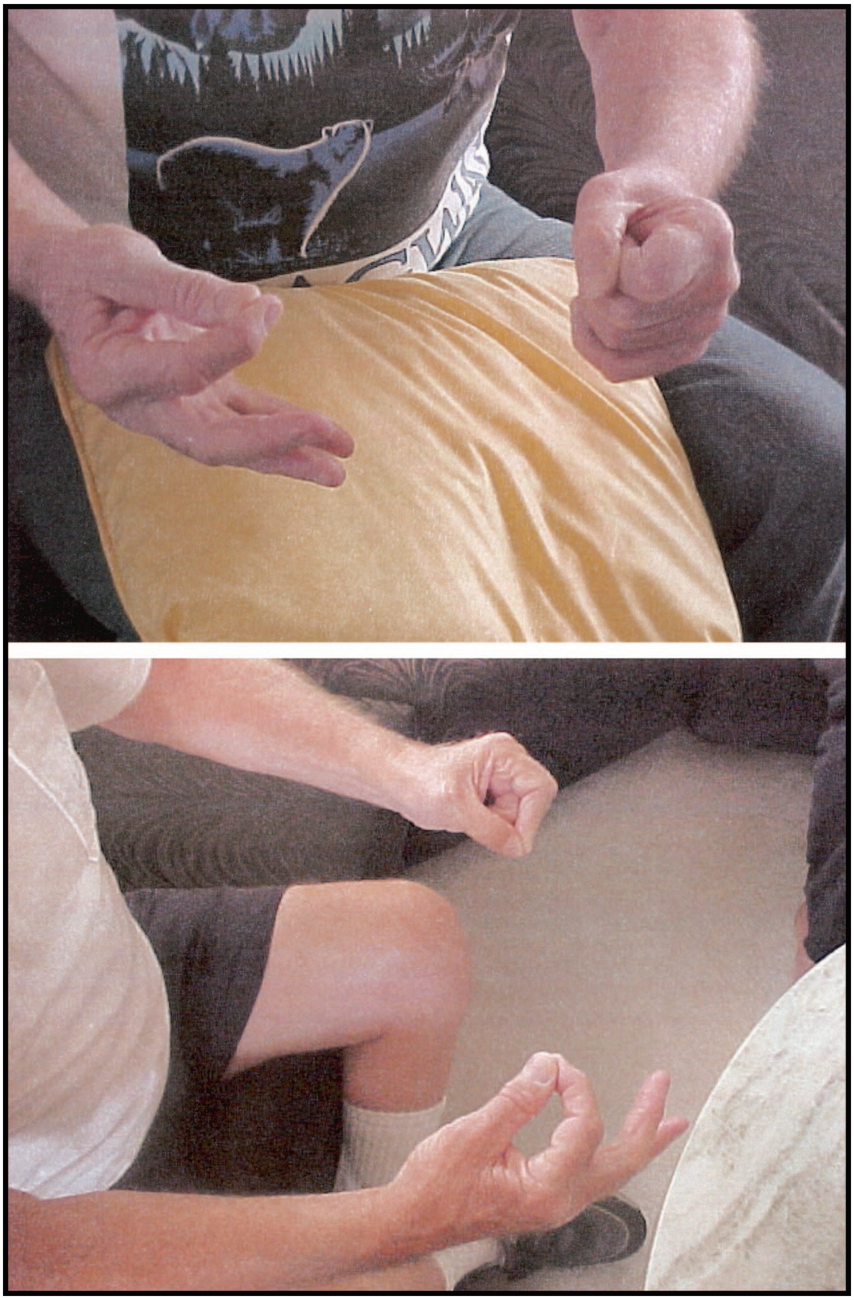

Figure 5.
(Top) Stroke Rehabilitation Assessment of Movement (STREAM) pretest. The patient attempts to oppose his thumb and index finger; the hand remains in a fist. (Bottom) STREAM posttest. The patient opposes his thumb and index finger successfully.

We believe that the patient's active participation was a key element of the intervention. Better outcomes were reported in subjects following a stroke who trained using electromyograph biofeedback-triggered NMES (EMGBF-triggered NMES) compared with NMES,[57,58] possibly because of the active participation required when using EMGBF-triggered NMES. In an attempt to maximize active participation, we instructed the patient to use the hand switch to trigger NMES only when he needed assistance with the task. In addition, he was instructed to adjust NMES amplitude to provide only as much assistance as was necessary for task completion.

The SES was provided in an attempt to increase the afferent input to the sensorimotor cortex. We theorized that this additional input might contribute to enhanced function. Limited information is available from previous studies of sensory training following a stroke upon which to base specific characteristics of the intervention (eg, the amount of active attention given to the sensory stimulus and associated tasks). Future studies should attempt to determine the most effective electrode placement, treatment duration, and the amount of active subject participation required to produce individually meaningful and measurable changes in performance.

Improvements in the secondary outcome measures of PROM and resistance to passive muscle stretch also are consistent with previous reports of use of NMES use following stroke.[12–15,20,21] Furthermore, the change in the patient's sensation is consistent with recent reports of sensory improvement following SES in patients with stroke.[41] The relationship of secondary outcome measure changes to improvements in the primary outcome measures is not clear. It is possible that sensation would have improved simply with increased use of the UE without use of SES.

This case report has several limitations. The patient's sensory status was examined as is typically done in the clinic.[59–61] Several authors[59–61] have discussed the flaws in traditional sensory testing and concluded that a reliable, multimodal, user-friendly test of sensory deficits for use with individuals following stroke is not available. A standardized test of resistance to passive muscle stretch, such as the Modified Ashworth Scale,[62] might have provided more reliable information on this outcome. Another limitation was that the patient used a logbook to record actual stimulation time. Unfortunately, the logbook was collected for analysis at the time of the skin reaction and not returned to the patient. Follow-up testing after the intervention would have provided information on retention of the improvements. The exam-

Table 2.
Passive Range of Motion Results (in Degrees)

	Pretest	Mid-intervention	Posttest
Shoulder flexion	109	115	130
Shoulder abduction	95	100	130
Shoulder extension	42	60	60
Shoulder external rotation	28	20	60
Shoulder internal rotation	43	55	60
Elbow flexion	128	150	150
Elbow extension	−35	−35	−12
Pronation	80	80	80
Supination	23	65	80
Wrist flexion	92	80	80
Wrist extension	80	85	70
Finger flexion			
Metacarpophalangeal joint	90	90	90
Proximal interphalangeal joint	100	100	100
Distal interphalangeal joint	90	90	90
Finger extension[a]			
Metacarpophalangeal joint	0	0	0
Proximal interphalangeal joint	0	0	0
Distal interphalangeal joint	0	0	0
Thumb flexion			
Metacarpophalangeal joint	50	50	50
Distal interphalangeal joint	80	80	80

[a] Measured with wrist in neutral.

iners were not masked to the patient's participation in the intervention, and having an examiner consistently administer the outcome measures at all testing sessions might have strengthened the reliability of the measurements.

Because this is a case report, the results cannot be generalized and the intervention strategies must be evaluated using experimental research designs, including designs that will separate the effects of SES from NMES and task practice. We believe, however, that this case report does contribute to clinical knowledge. It describes the combined application of SES and NMES with an object-based, task-specific NMES activity. A description of an intervention that enabled active practice where practice previously was not possible is provided. The report also documents the occurrence of apparent senile purpura during electrical stimulation that resolved with treatment modification. Finally, this case report provides an example of an independent home program of electrical stimulation and exercise for a patient with UE hemiparesis, which required minimal physical therapist involvement.

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