

Restoration of Reaching and Grasping Functions in Hemiplegic Patients with Severe Arm Paralysis

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Materials and Methods

1.1 Participants

The study was conducted with hemiplegic patients having unilateral upper extremity paralysis. When the program began, each patient was unable to voluntarily: 1) flex, extend, abduct, adduct, or rotate the shoulder; 2) flex or extend the elbow; 3) pronate or supinate the forearm; 4) flex, extend, abduct or adduct the wrist; and 5) move any fingers. The participants were recruited for the study in the third week after being admitted to the stroke unit at the Toronto Rehabilitation Institute (acute patients), or 12 months after rehabilitation was completed (long-term patients).

After being recruited, the participants were divided randomly into two groups: **Group A** - *patients that were trained with the neuroprosthesis*; and **Group B** - *the control group*, that only had standard physiotherapy and occupational therapy. The control group was used to assess the success of the neuroprosthesis treatment as compared to the use of standard physiotherapy and occupational therapy alone. Thus far four patients have been recruited into the program. Three were assigned to Group A and one to Group B. This research program received ethics approval in 2002 from the ethics boards of the University of Toronto and the Toronto Rehabilitation Institute. All participants in the study signed letters of consent.

1.2 Neuroprosthesis Hardware used in the Study

The Compex Motion electric stimulator, developed by Popovic and Keller in collaboration with Swiss based company Compex SA [1], was used as a hardware platform for the neuroprosthesis for reaching and grasping. This fully programmable functional electrical stimulation (FES) system applies surface stimulation technology and provides the means for developing highly sophisticated, custom-made, neuroprostheses. Each patient had his/her own stimulation protocol and, as the patient's reaching and grasping functions improved because of the treatment, the stimulation protocol evolved and changed during treatment. On average, the stimulation protocol was changed/adjusted weekly or biweekly.

1.3 Stimulation Protocols used in the Study

The neuroprosthesis treatment consisted of a functional training program carried out in the following way. The participant was asked to voluntarily perform a task using the paralyzed arm. The participant would then voluntarily try to execute the requested task. If the subject was unable to complete a part of the task, the neuroprosthesis would assist the subject in completing the task. In the early stages of treatment, the arm/hand tasks were performed by the neuroprostheses alone. As the patient improved, assistance from the neuroprosthesis was reduced to the necessary minimum and eventually removed from the treatment protocol. During a treatment session, the participant was asked to repeat the same arm/hand task 30 to 50 times; a treatment session lasted up to 45 minutes. The patient had one treatment session per day, business days only. During the arm/hand movements, the physiotherapist guided the movements and assisted the patient in performing the desired task with the neuroprosthesis. This assistance ensured that all movements were carried out in a physiological way.

Standard self-adhesive surface stimulation electrodes were applied in this study. These electrodes were placed on the patient's skin above the following muscles and nerves: 1) flexor digitorum superficialis m. and the flexor digitorum profundus m.; 2) median nerve or thenar m., and flexor pollicis longus m.; 3) extensor digitorum m.; 4) flexor capri radialis m. and flexor capri ulnaris m.; 5) extensor capri radialis longus and brevis m. and extensor capri ulnaris m.; 6) biceps m.; 7) triceps m.; and 8) anterior and posterior deltoid m. Stimulation parameters used were: 1) balanced, biphasic, current regulated electrical pulses; 2) pulse amplitude from 8 to 50 mA (typical values 17-26 mA); 3) pulse width from 100 to 250 μ s (typical values 200-250 μ s); and 4) pulse frequency from 20 to 40 Hz (typical value 40 Hz).

In stroke patients, the neuromuscular recovery starts proximally followed by the recovery of the distal neuromuscular compartments. Therefore, the decision was made to begin the neuroprosthesis treatment by training the shoulder and upper arm muscles. The first anterior deltoid m. and the biceps m. were stimulated simultaneously to produce the arm movement that resembled a feeding movement. Once the hand reached the mouth, the posterior deltoid m. and the triceps m. were stimulated simultaneously to produce an arm extension movement and place the arm in a relaxed position next to the body. As soon as the patient showed signs of recovering both the voluntary extension and the flexion of the shoulder, the extensor digitorum m. was stimulated together with the triceps m. In this way the patient was trained to extend the fingers when the elbow was fully extended. This stimulation protocol promoted finger extension in the arm much more than if the stimulation was done for another arm configuration. This stimulation protocol also helped reduce spasticity and tonus in the fingers allowing patients to control finger flexion and extension better. The most difficult and time-consuming task was to train patients to voluntarily extend or relax their fingers. This function is essential for patients to be able to voluntarily grasp and release objects. Once the patients were able to voluntarily extend or relax the fingers, the flexor digitorum superficialis m., the flexor digitorum profundus m., the median nerve (or thenar m.), and the flexor pollicis longus m., were stimulated to generate palmar and/or pinch grasp.

1.4 Tests

The following tests were administered to all participants in the study (both Groups A and B). All tests, except the administrative test, were carried out before and after the treatment. The administrative test was conducted at the time of admission.

Administrative test: Collecting demographic information, and participants' medical and stroke histories.

Neurological test: The Canadian Neurological Scale was used to assess the neurological profiles of the participants, including levels of consciousness, orientations, speech, motor functions, and facial weaknesses.

Functional tests: 1) Functional Independence Measure (FIM); 2) Barthel Index (BI); 3) Chedoke McMaster Stages of Motor Recovery (CMSMR); 4) Fugl-Meyer Assessment (FMA); and 5) Rehabilitation Engineering Laboratory Hand Function Test for Functional Electrical Stimulation Assisted Grasping (REL).[2]

Results

In Group A, one patient was a long-term patient, and two were acute patients. In Group B, the patient was acute. The following are the results achieved with these participants (see Figures 1 and 2):

Group A:

Patient No. 1: This 76-year-old, male, hemiplegic, patient was introduced into the program approximately 18 months after his rehabilitation program was completed. After four weeks of treatments, he was able to: 1) voluntarily flex, extend, adduct and abduct the shoulder against gravity and resistance; 2) extend and flex the elbow against gravity and resistance; 3) flex and relax all five fingers against gravity and resistance; and 4) the arm was no longer spastic. Functionally, the patient was able to voluntarily touch his forehead, place the arm in 50 % of its workspace, and grasp and release various objects.

Patient No. 2: This 31-year-old, male, hemiplegic, patient joined the FES program four weeks after onset of stroke. After eight weeks of neuroprosthesis treatment the patient could: 1) voluntary move both shoulder and elbow against gravity and resistance; 2) voluntarily flex thumb and fingers against gravity and resistance; and 3)

except for finger flexors, the arm was no longer spastic. Functionally, the patient was able to voluntarily touch his forehead, place the arm in 60 % of its workspace, and grasp and release various objects.

Patient No. 3: This 49-year-old, female, hemiplegic patient started FES treatment three weeks after onset of stroke. After four weeks of neuroprosthesis treatment, she could: 1) voluntarily contract the deltoid m. (could move the arm against gravity); 2) voluntarily contract the biceps m. (could move the forearm against gravity); 3) voluntarily contract the triceps m. (extend the elbow in the absence of gravitational force); 4) could voluntarily contract finger flexors; and 5) had significantly reduced tone in the arm. Functionally, the patient was able to voluntarily touch her chin and contralateral shoulder, and place the arm in 30% of its workspace.

We have observed that the initial improvements in the reaching and grasping functions, due to the neuroprosthesis training, strongly motivated patients to continue participating in the program. Furthermore, the reinforced motivation and the regained functions encouraged patients to increase active use of the paralysed arms and hands in activities of daily living (ADL); the increased activity promoted recovery and gradually eliminated the “no use pattern” typical for these patients. After FES treatments were completed, all patients reported that they felt significant improvements in the way they looked and the way their arms behaved. They all reported that after FES treatments their arms “followed” the natural movements of their bodies.

Group B:

Patient No. 4: This 46-year-old, female, hemiplegic patient started standard occupational therapy and physiotherapy treatments three weeks after onset of stroke. After six weeks of standard occupational therapy and physiotherapy her condition remained unchanged.

Discussion

Hemiplegic patients who have unilateral upper extremity paralysis rarely improve their arm and hand functions to the point of effective use in ADL. Established occupational therapy and physiotherapy, which are commonly applied to rehabilitate these patients, seldom facilitate significant improvements in reaching and grasping functions. As a result, these patients frequently exhibit a “no use pattern” and are often released home with a paralysed arm. In recent years a constrained induced therapy has been introduced, which suggests that if the “healthy” arm of a hemiplegic patient is constrained (not allowed to move) and the patient is forced to use the disabled arm, the function of the disabled arm improves considerably. However, this technique has one shortcoming, a patient subjected to this therapy must have a mild or moderate paralysis of the arm so that at least some movement can be initiated in the arm or hand. Hence, this treatment is not appropriate for patients who have severe upper extremity paralysis.

Studies carried out by Popovic et al. [4], and Cauraugh and Sangbum [3] suggest that if FES is applied to patients with mild to moderate upper extremity hemiparesis (both long term and acute patients) these patients considerably improve control of their wrists and fingers, and expand their motor repertoire. These results indicate that FES might facilitate changes in representational organization in the motor cortex and can help hemiplegic patients to restore grasping function. However, these two studies were limited to patients who already had good shoulder and elbow functions, and had only mild to moderate hand paralysis.

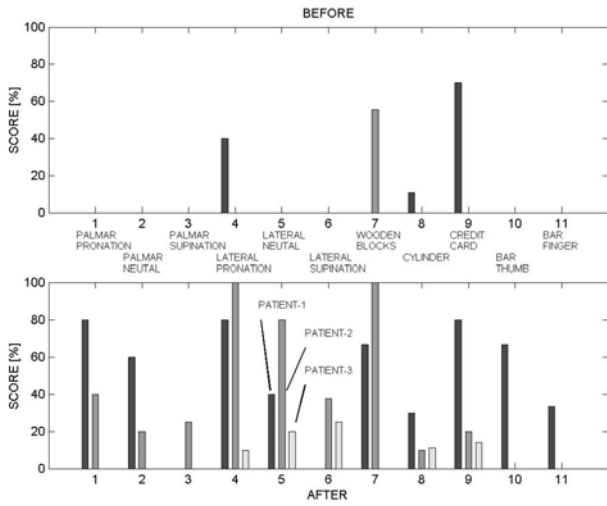
Our study differs from previously published results. First, our patients were not able to move their paralysed arms at all, and as such were not good candidates for constrained induced therapy or the FES therapy proposed by Popovic et al. [4], and Cauraugh et al. [3]. In our study the needed “active motor learning”, which is a precursor of representational plasticity in the primary motor cortex, was provided by FES. Second, the functional improvement achieved with our treatment produces radical improvements in function, not incremental improvement as observed by constrained induced therapy or the FES therapy proposed by Popovic et al. and Cauraugh et al. [3,4]. We believe that our results provide compelling evidence that FES therapy can be used successfully, not only to treat mild and moderate arm paralysis in hemiplegic patients, but also to treat patients with severe paralysis. Our treatment protocol stresses the importance of applying surface FES treatments that

can be tailored/adjusted to patients' needs on a daily basis, and evolve as the patients' functions improve. Our findings suggest that applying intensive, active, motor training of reaching and grasping functions using FES, promotes functional reorganization of cortical maps in stroke survivors and consequently, subjects with arm paralysis will be able to regain partial or complete voluntary functional control.

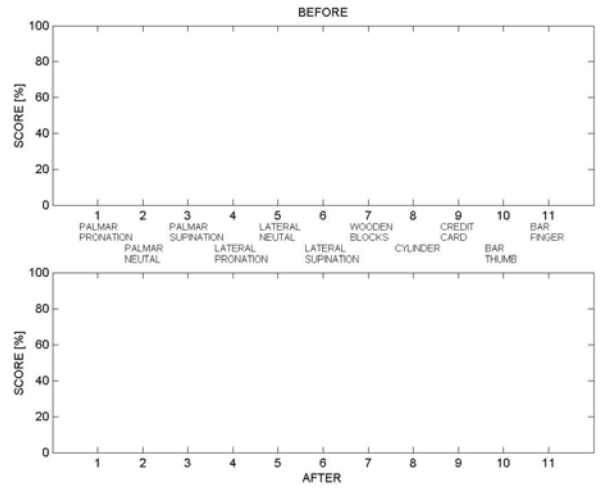
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Acknowledgments: The author wishes to acknowledge the Toronto Rehabilitation Institute for primary sponsorship of this research and Ms. Zina Bezruk for editing.

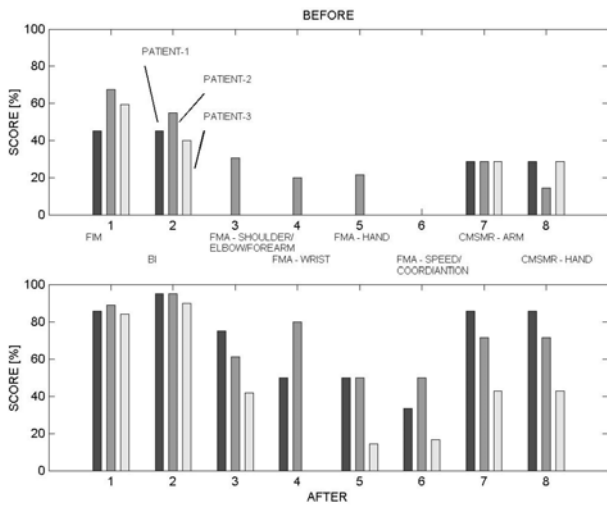


a) Group A

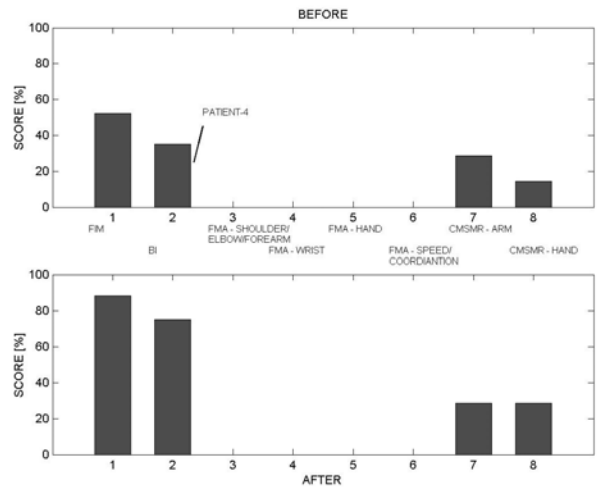


b) Group B

Figure 1: Average REL test results for Groups A and B before and after the treatment



a) Group A



b) Group B

Figure 2: Average FIM, BI, FMA and CMSMR test results for Groups A and B before and after the treatment