FEEDBACK STIMULATION TRAINER FOR HEMIPLEGIC WRIST

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ABSTRACT

A new treatment modality for facilitation of wrist extension incorporating isotonic exercise, positional feedback and electrical stimulation is presented. The effectiveness of this treatment was compared to conventional therapy training in 30 adult hemiparetic patients lacking functional wrist extension control. Patients were randomly placed in two groups with 15 patients in each group. In one group conventional treatment was provided while in the other group feedback stimulation training was provided twice per day, five days per week, for four weeks in addition to conventional treatment. Patients treated with the Feedback Stimulation Trainer (FST) showed isometric strength four times and selective range of motion three times their starting levels. Control patients showed no change in strength and only a 50% increase in selective range of motion. The Feedback Stimulation Trainer is designed to be easy to operate and is automated, thus requiring little therapist time to administer the treatment.

INTRODUCTION

It is well documented that electrical stimulation of paralyzed muscles has desirable long-term effects. Reports that the clinical use of Functional Electrical Stimulation (FES) increases muscle strength was first reported by Liberson[1] and has been substantiated by others.[2-4] Inhibition of antagonistic activity,[1,2,5-7] ranging stiff joints and success in pulling out contractures[8-10] have also been reported.

Of special interest are descriptions of hemiplegic patients relearning to use paralyzed muscles through the use of electrical stimulation. The phenomenon of regaining control of a paralyzed muscle for some period of time after stimulation -- commonly referred to as "carry over" -- has been described

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by numerous investigators.[1,3,6,11-12] Facilitation of the patients' own muscle response has been documented by Vodovnik and Reberšek,[6] and Gračanin and Marincek.[11] Gračanin[2] observed that some patients with footdrop, unimproved after six months' therapy, gained nearly normal dorsiflexion function after six weeks of FES. Similar results are reported on patients more than one-and-a-half years after the occurrence of cerebral vascular accident.[13] Kralj, et al[14] reported increased motor function and control of other muscles in the lower extremities with multi-channel stimulation timed to excite the proper muscles during the periods they would normally contract, thereby facilitating and reinforcing the normal gait pattern.

Biofeedback training has also been reported successful in the rehabilitation of hemiplegic patients. The oldest and most common form of biofeedback used for patients with neurologic disorders has been electromyography (EMG). Andrews[15] reported that stroke hemiplegic patients who had shown no progress with traditional rehabilitation therapy and who were at least one year post onset made significant gains following minimal EMG training. Johnson and Garton[16] reported good improvement of muscle function in hemiplegics using EMG feedback for foot dorsiflexion and proposed that the use of electromyographic devices would be helpful in re-educating muscles about many joints. Other investigators also report similar results when using EMG biofeedback.[17-18]

While EMG biofeedback has been shown effective, it is evident that a great deal of therapist time is required to properly use it in treating the patient.[19] In addition, the therapist must have specific training and background in the use of EMG biofeedback. Often a single channel of EMG is not adequate for, in addition to the patient learning to contract an agonistic muscle about a joint, he must simultaneously learn to relax the antagonist muscle. For the hemiplegic patient with spasticity, this can be a major problem.

The purpose of this study was to combine both electrical stimulation and feedback therapy to enhance muscle re-education in an automated treatment and clinically compare this treatment to conventional therapy.

MATERIALS AND METHODS

Equipment

The feedback stimulation training equipment consisted of three parts -- an adjustable isotonic resistance training table, a feedback display unit, and an electrical stimulator (Figure 1).

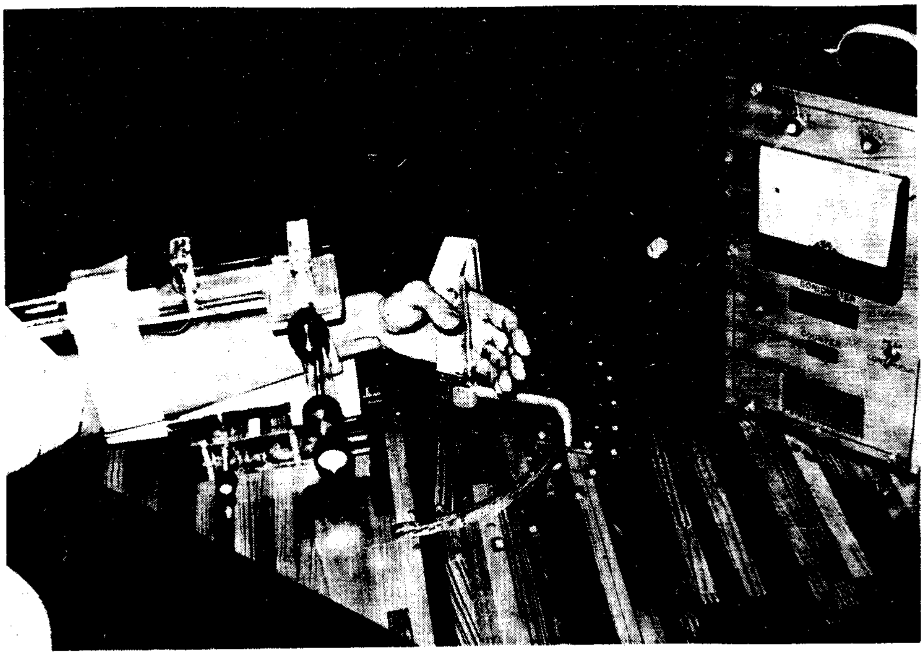

Figure 1. Feedback Stimulation Trainer for Wrist

An adjustable brace mounts on top of the training table allowing only wrist motion. Resistive weights may be added to a cable providing for repetitive isotonic exercise. Wrist motion progress is provided to the patient via a feedback display unit and electrical stimulator.

The training table included an adjustable brace which locked the forearm and upper arm while allowing the wrist joint to move in a gravity eliminated position. The hand was strapped to a lever arm by means of a metacarpal bar. A pulley and cable arrangement underneath the table connected to the lever arm allowed the addition of weights to apply constant resistance to wrist extension motion.

The feedback display unit provided visual and audio feedback of wrist position (Figure 2). A "START" light signaled that the patient should initiate

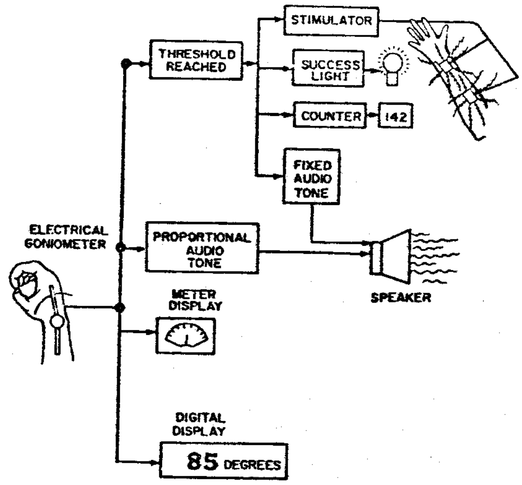

Figure 2. Block Diagram of Operation of Feedback Displays
Joint motion is visually facilitated by a meter and digital display. An audio tone increases pitch as joint angle increases. When a threshold angle is reached, a "success" light appears, a counter increments, the audio tone becomes interrupted, and electrical stimulation of the extensor muscles is provided.

an extension effort. As the patient extended his wrist, a meter needle changed deflection and an audio tone increased in pitch. In addition, a continuous digital reading of joint angle was provided. When a joint angle was attained above a threshold angle set on the back of the unit, a "GOOD" light was displayed, a digital counter incremented, the audio tone became intermittent and a cycle of electrical stimulation was triggered. Upon completion of the stimulation cycle, a rest cycle began after which the "START" light signaled for another effort by the patient.

The electrical stimulator applied 35 constant current pulses per second at a 200 microsecond pulse width. Each stimulation cycle began with an exponential rise in stimulus amplitude (rise time of 3 seconds) up to the pre-set value. The stimulus was applied through commercially available carbon-impregnated silicone rubber electrodes using a transmission gel recommended by the electrode manufacturer.

Subjects

Thirty patients with minimal active wrist extension from the hemiplegic patient population of Rancho Los Amigos Hospital volunteered for this study. All patients had unilateral hemiplegia as a result of either thrombotic or embolic cerebral vascular accidents of at least three weeks but not more than four months duration. Each patient had a minimum of five degrees but not more than 30 degrees patterned or selective extension motion at the wrist, with full passive range of motion. Each patient also had sufficient cognition to follow instructions and to give an informed consent to take part in the study. Patients were placed in control or experimental groups by the flip of a coin to assure random placement.

Training

Patients in the control group received conventional therapy treatment of the hand and wrist five days per week for four weeks. Patients in the experimental group received Feedback Stimulation Training for 30 minutes twice daily, five days per week for four weeks in addition to standard therapy treatment.

Training in the experimental group proceeded according to the patients' progress. The table brace was adjusted to each patient's arm and resistance adjusted weekly to the patient's tolerance. Threshold was adjusted to be approximately 5 degrees below the maximum voluntary ability of the patient. The stimulation ON time was adjusted to 6 seconds if the patient had minimal or no flexor spasticity and to 8 seconds if there was moderate flexor spasticity. The rest period was set to 20 seconds.

The patient was instructed to continue to repeat the exercise a predetermined number of repetitions which ranged from 20 to 100, depending upon his ability. The number of successful repetitions was monitored by a counter and displayed to the patient.

Evaluation

Control and experimental patients were compared for their active patterned and selective range of motion at the wrist. Pre-program as well as weekly measures of range of motion during the program were performed by an Occupational Therapist who was not involved with the treatment of any of the patients, and was unaware of which patients were control and experimental. Pattern extension range was measured with the wrist in the normal posturing angle for the patient. Selective extension range was measured with the wrist in a gravity eliminated position. In both cases an electrical goniometer with digital readout in degrees was used to measure range. Three trials were made for both pattern and selective range and a mean and standard deviation calculated.

All patients were also tested for isometric strength of the wrist extensors using an electrical torque transducer with a digital readout. Isometric measurements were taken with the wrist positioned in 30 degrees of flexion and in 30 degrees of extension.

In addition to the above tests, experimental patients were tested weekly in the training table to determine their ability to isotonically extend against incremented resistance. Four resistance levels were used including Zero Resistance and a Maximal Resistance which the patient could not move in pre-tests. The remaining two levels of resistance were equally spaced between Zero Resistance and Maximal Resistance.

Results

The average change in wrist extension torque with the wrist positioned in 30 degrees of flexion is shown in Figure 3. Although both control and experimental groups started with nearly equal torque, by the end of the four weeks of treatment a significant difference between the groups was noted. The control group, shown by the dotted line, changed very little while the experimental group, shown by the solid line, improved an average over 1 newton meter of torque representing a 75% increase over their starting value. Statistical significance between the two groups occurred in weeks two, three and four.

Similar results were observed when measuring torque with the wrist positioned in 30 degrees of extension as shown in Figure 4. Over a 1.2 newton meter average change was observed in the experimental group which represented a level over four times their initial torque while the controls made minimal improvements. A statistically significant difference between groups appeared in the third and fourth weeks of treatment.

In reporting on changes in wrist active movement, motion was defined as the difference between the natural resting position of the wrist and the point of the patient's maximum extension ability. While starting out in pre-tests with essentially equal abilities to extend their wrist in pattern, that is while allowing motion at other joints, the experimental patients increased in

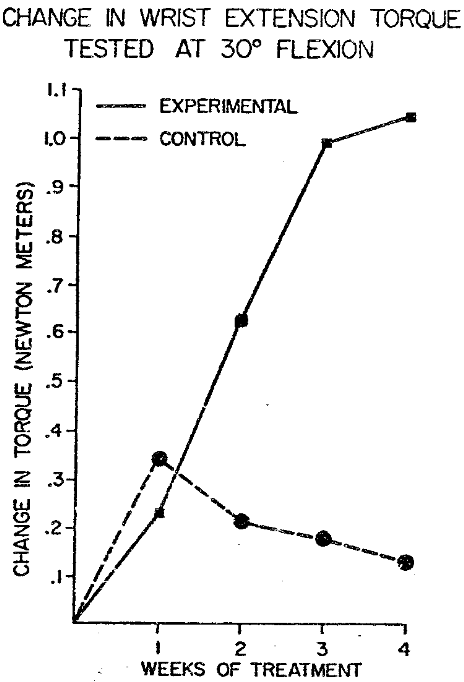

Figure 3. Average Change in Wrist Extension Torque Positioned in 30° Flexion

Over a 1 newton meter change in torque was observed in the experimental patients while only a minimal change was observed in the controls. The experimentals' torque at the end of the program was 75% higher than their starting value.

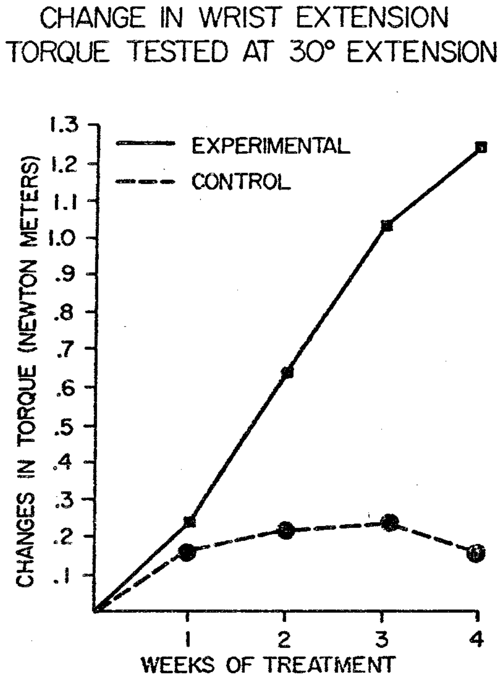

Figure 4. Average Change in Wrist Extension Torque Positioned in 30° Extension

Over a 1.2 newton meter change in torque was observed in the experimental patients while only minimal changes were observed in the controls. The experimentals' torque at the end of the program was over 4 times their starting value.

motion an average of over 35 degrees, which more than doubled their average starting value (Figure 5). The controls (dotted line) showed minimal improvements. Statistical significance occurred in the fourth week.

Looking at average changes in selective motion (Figure 6), that is wrist motion without movement at other joints, again controls made minimal improvements

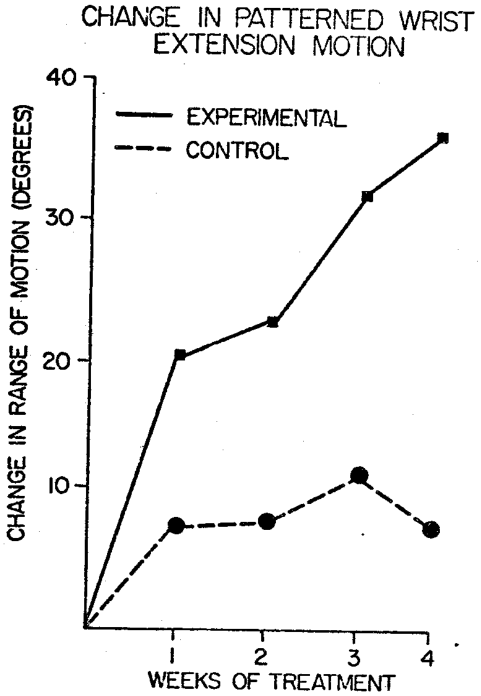

Figure 5. Average Change in Pattern Wrist Extension Motion

Experimental patients increased patterned motion over 35°, more than doubling their starting value while controls showed only minimal improvements.

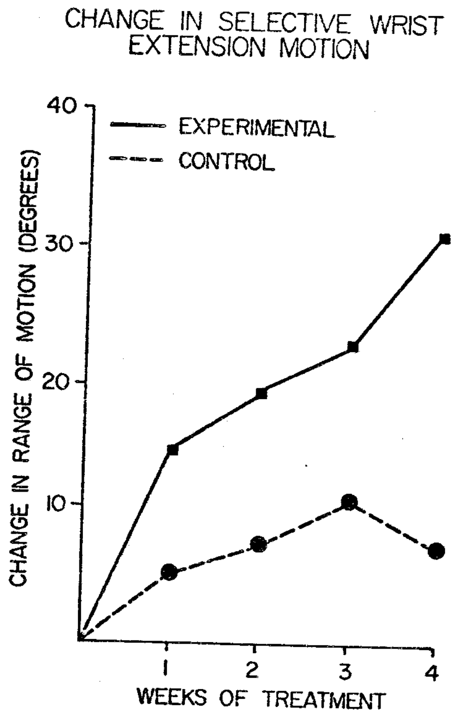

Figure 6. Average Change in Selective Wrist Extension Motion

Experimental patients improved over 30°, more than tripling their starting value. Controls improved about 5°.

(as shown by the dotted line), while experimentals improved over 30 degrees which tripled their pre-program motion ability. What this meant was that the experimental patients were able to extend well beyond the neutral position, while the controls were still in a flexion position. Statistical significance occurred in the fourth week.

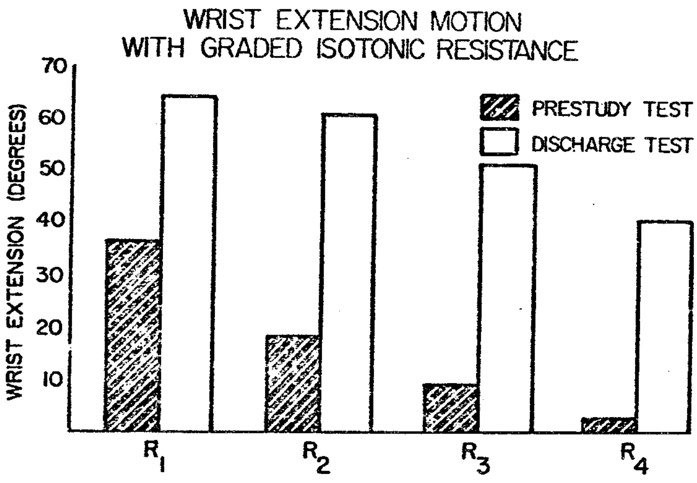

Figure 7. Wrist Extension Motion with Graded Isotonic Resistance

Significant differences were observed in experimental patients pre-study versus motion abilities upon discharge from the hospital at four different isotonic resistance levels. These differences were most notable at the greatest resistance level.

Experimental patients were tested for range of motion in the training table against four isotonic resistances (Figure 7). R_1 was no resistance, R_4 the minimal resistance that the patient was unable to move at all in pre-tests, and R_2 and R_3 resistances were evenly spaced between R_1 and R_4. Marked differences between pre-study tests (hatched columns) and discharge tests (solid columns) were observed for all four resistances with the greatest differences under high loads. By the end of the program, patients were moving a resistance they could not budge in the pre-test, further than they were able to move zero resistance in the beginning of the program.

DISCUSSION.

Although much has been documented on the therapeutic use of EMG biofeedback, little has been reported on the use of motion feedback for motor training the hemiplegic patient.[19] Certainly motion feedback can have no effect unless there is some motion present. When no motion is present, EMG biofeedback can be used to re-educate ability to contract the agonist muscle or to relax a spastic antagonist muscle effectively. Once the patient has re-learned to obtain some motion, however, it may be more appropriate to use positional feedback to facilitate that motion.

By combining electrical stimulation after a near maximal voluntary effort with positional feedback to form repetitive isotonic exercise, new possibilities of muscle re-education emerge. Positive feedback and goal attainment in this study was provided to the patient only when contraction of the agonist and simultaneous relaxation of the antagonist (in those patients with spasticity) resulted in joint motion. In addition to the audio and visual feedbacks provided, the patient received cutaneous, kinesthetic and proprioceptive input when electrical stimulation was triggered and the joint was moved through its full available range. Stimulation also helped increase strength and decrease antagonist tone.

This treatment offers an important advantage over classical facilitation techniques. Little therapist time is required to initiate treatment. The device is automated and allows the therapist to administer controlled therapy without her immediate presence. Other facilitation techniques require specially skilled therapists working one-on-one with the patient.

The same equipment has been used with a second training table and brace for facilitating the elbow. Results similar to those reported for the wrist have been observed at the elbow. Future studies implementing the same feedback-stimulation concept are under way using portable electrical goniometers for the elbow, wrist and fingers. Other possibilities include the use of similar equipment for training selective control about most joints by using multiple portable goniometers that would monitor not only a primary joint, but also secondary joints.

CONCLUSION

The Feedback Stimulation Trainer offers a form of treatment which is easy to apply and requires little therapist time. The therapist can set up a patient in the device in just a few minutes and have the patient perform a specified number of exercise repetitions in a controlled manner.

The program has been shown to have clinical significance. Patients receiving feedback stimulation treatment increased in isometric strength which was not matched by the control group of patients. In addition, the experimental patients increased in both pattern and selective active motion while the controls made only minor improvement.

Gains in the areas of strength and voluntary motion are major steps toward developing functional ability in the hemiplegic hand.

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