Response To Upper Limb Functional Neuromuscular Stimulation and Robotics Following Stroke

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Abstract

Twelve moderately to severely involved chronic stroke survivors (>12mos) were randomized to one of two treatments: 1) functional neuromuscular stimulation and motor learning (FNS ML) or 2) Robotics and motor learning (ROB ML); Treatment was: 5hrs/day, 5ays/wk, for 12wks. FNS ML had 1½hrs/session devoted to FNS (surface electrodes) for wrist/hand flexors/extensors. ROB ML had 1½hrs/session devoted to robotics shoulder/elbow training. The primary outcome measures were the functional measure, the Arm Motor Assessment Test (AMAT) for the shoulder/elbow movements (AMAT S/E) and for wrist/hand movements (AMAT W/H). The secondary measure was the Fugl-Meyer upper limb coordination (FMUE). FNS ML produced gains in AMAT W/H and FMUE. ROB ML produced gains in AMAT S/E, and FMUE.

1. INTRODUCTION

Even after completing conventional rehabilitation, many stroke survivors demonstrate persistent and disabling upper limb motor deficits. Therefore, it is important to develop more effective methods for restoration of upper limb motor control following stroke. Two promising methods include robotics and functional neuromuscular stimulation (FNS). According to case series studies, use of upper limb robotics has produced improvement in muscle strength, coordination [1] and in active joint movement excursion. In a randomized, controlled trial of robotics therapy versus conventional exercise, there was an immediate post-treatment advantage of robotics according to a measure of joint movement coordination, that persisted at 6 month follow-up testing [2]. There is a dearth of literature regarding capability of robotics to produce functional gains in the involved limb [1]. The available studies of FNS intervention showed similar results. FNS produced improvement in the impairment measures of upper limb muscle tone [3,4] and strength and coordination [5,6]. For mild to moderately involved subjects in the chronic phase, a case series study of FNS intervention showed a significant improvement in a subscale of the Jebsen Hand Test (grasp/release movements required; [4]).

Therefore, the purpose of this study was to test response to FNS or robotics according to measures comprised of actual task components.

2. METHODS

2.1 Subjects

Twelve subjects were enrolled who were > 12 months after the stroke. Subjects were required to demonstrate at least a Trace (1 grade) muscle contraction in the wrist extensors and a score of > 10 in the upper limb Fugl-Meyer coordination measure. Subjects were stratified according to the Fugl-Meyer upper limb coordination score (FMUE) prior to randomization to one of the two following treatment groups: 1) functional neuromuscular stimulation and motor learning (FNS ML) or 2) Robotics and motor learning (ROB ML). FMUE was a 66-point scale categorizing severity as follows: 10-29 = severe; 30-49 = moderate; and >50 = mild (≥50, not accepted). FMUE measured movement either within or independent of synergistic patterns. FMUE is recommended for identifying severity levels after stroke.

Subjects were recruited from regional medical centers. The following subject characteristics were recorded: stroke type, stroke location, years since stroke, and age. Subjects provided informed consent in accordance with the Declaration of Helsinki, and the study was approved by the Institutional Review Board of the Medical Center.

2.2 Technology

FNS. FNS was provided, using the EMS+2 (Staodyn, Inc., Longmont, Colorado) with surface electrodes. The EMS+2 is a two-channel, portable stimulator operated with a 9-volt alkaline battery, that delivered a biphasic symmetric rectangular output for each of the two channels. The flexible PALS surface electrodes (Axelgaard Manufacturing Co., LTD; Falbrook, Ca) were constructed of electrolytic gel and a self-adhering surface.

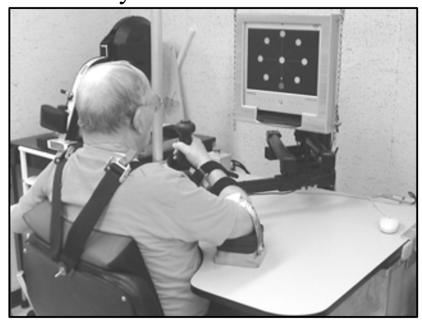
Robot. The InMotion2 Shoulder-Elbow Robot (Interactive-Motion Technologies, Inc.; Cambridge, MA) provided shoulder/elbow training, in the horizontal plane with a supported forearm. The robot utilized the QNX operating system, allowing for high performance control and integrated graphics. The robotics technology allowed for resisted, active, or assisted movement. The robot was a back-drivable impedance-controlled system, which allowed for smooth almost 'frictionless' motion. This 2-degree-of-freedom system functioned in the horizontal plane. The robot was capable of sensing and recording the position and velocity in the horizontal plane. The direct-drive 5-bar linkage system was driven by two brushless motors rated to 7.86 Nm of continuous stall torque with 16-bit resolvers for position and velocity measurements. The position data was measured by built-in precision potentiometers (0.9 Kohm/rad). The velocity data was measured by dc tachometers rated with a sensitivity of 1.75 V/rad/s.

2.3 Interventions

Both groups received treatment 5 hrs/day, 5 days/wk, for 12 weeks.

FNS ML. For FNS ML, during 1½ hrs of the daily treatment session, subjects utilized FNS for wrist/finger muscle activation. They practiced single and multiple joint movements using FNS. FNS-assisted coordination training included practice of the following movements: wrist flexion/extension; finger and thumb flexion/extension; and simultaneous wrist extension and finger flexion. The stimulus parameters were: 300microsecs pulse width; 30Hz; amplitude ranging from 1mA to the highest comfortably produced stimulus; and 10secs on/10secs off duty cycle. The remainder of each session (3½ hrs) was practice of task components and whole task practice without technology assistance, identical to that described in the previous section for the ROB ML group.

ROB ML. For ROB ML, during 1½ hrs of the daily treatment session, subjects utilized the robot and practiced shoulder/elbow movements, with the forearm and hand supported in a cradle and the wrist and hand in fixed positions (wrist, 20 degrees of extension; fingers resting around a cone-photograph below). The practice movements were between a center target and targets located on the periphery of a circle 14cm in diameter. The visual display provided on-line visual feedback of accuracy and coordination success.



The remainder of each session (3½ hrs) included practice of functional task components and whole task practice without technology assistance. This portion of the treatment protocol was identical for both groups.

2.4 Measures

The primary outcome measure was based on the Arm Motor Assessment Test (AMAT), a measure of functional capability [7]. Because each of our treatment groups targeted either shoulder/elbow or wrist/hand movements, respectively. Our primary outcome measures were AMAT S/E and AMAT W/H. Our secondary outcome measure was Fugl-Meyer Upper Limb Coordination (FMUE).

2.5 Data Analysis

Group comparisons prior to treatment were made, using the Mann Whitney U Test for the ordinal measures and t test for the interval-level measures. The following variables were tested for initial group differences: age, time since stroke, and the following study outcome measures: AMAT S/E; AMAT W/H ; FMUE. We made within-group pre-/post-treatment comparisons for the interval level measures using t test, and for the ordinal level measures using the Wilcoxan Rank Sum Test.

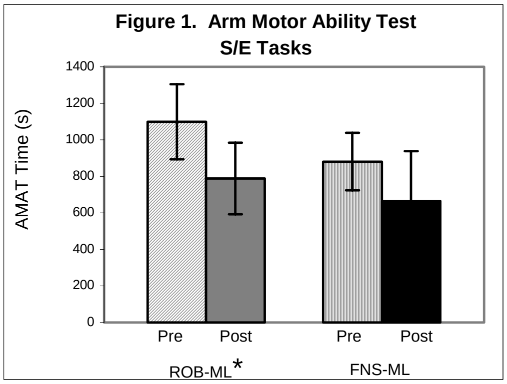
3. RESULTS

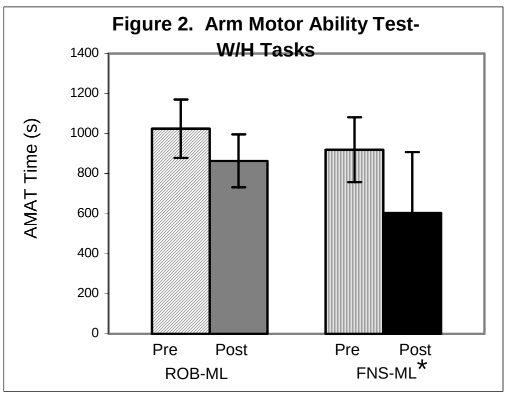
Prior to treatment both groups were comparable for subject characteristics or measures.

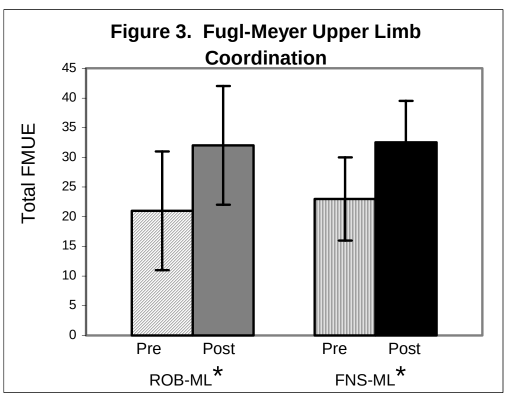
For the AMAT S/E measure, only the ROB ML group had a significant gain (Figure 1; asterisk indicates $p<.05$).

The AMAT W/H, showed that only the FNS ML group had a significant gain (Figure 2; asterisk indicates p<.05).

Both groups had gains in upper limb coordination (Figure 3; asterisk indicates p<.05).







4. DISCUSSION AND CONCLUSIONS

The results of the study extend the literature by providing evidence of statistically significant pre-/post-treatment gains in response to FNS ML, according to the AMAT(W/H), a parametric measure, objectively obtained, and comprised of actual functional tasks. The results also reflect statistically significant pre-/post-treatment gains in response to ROB ML, according to the AMAT(S/E).

Training specificity is a well-known phenomenon in able-bodied individuals [8]. This study extends the literature by providing evidence of training specificity for chronic stroke survivors with persistent upper limb motor deficits according to functional task components. First, significant gain in AMAT W/H was shown only for the FNS ML group, who received targeted finger/wrist FNS training for 1½hrs of each daily session; whereas for the ROB ML group, there was no gain. Second, significant gain in AMAT S/E was demonstrated only for the ROB ML group, who received targeted shoulder/elbow robotics training for 1½hrs of each daily session; whereas for the FNS ML group, there was no gain. In both cases, the intensely targeted treatment at specific joints produced the result for the functional task movements exclusively at those joints.

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Acknowledgements

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