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Peripheral Nerve Stimulation in Neurological Rehabilitation

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Abstract: **An injury to the central nervous system can result in a permanent loss of the voluntary motor function and sensation. However, the peripheral motor and sensory nerves below the level of lesion often remain intact, and so do the muscles. Functional Electrical Stimulation (FES) is a technique to restore motor and sensory functions after such injuries. The forces generated in muscles activated by FES can be graded by varying the stimulus pulses, but the relationship of the force to the stimulus pulse varies in a complex manner that depends on, for example, muscle length, electrode-nerve coupling, and activation history. Several studies have shown that the application of closed-loop control techniques can improve the regulation of the muscle activation. Natural sensors such as those found in the skin, muscles, tendons, and joints present an attractive alternative to artificial sensors for FES purposes because they are present throughout the body and contain information useful for feedback control. Moreover, the peripheral sensory apparatus is still viable after brain and spinal cord injuries. Electrical signals can be recorded using long-term implanted nerve cuff electrodes in the human peripheral nerves. Reliable detection of sensory nerve signals is essential if such signals are to be of use in sensory-based functional electrical stimulation neural prosthetics as a replacement for artificial sensory (switches, strain gauges, etc.) In this paper the signal characteristics of the sensors, the nerve interface, signal processing, and example of human applications to restore motor functions are described [Sinkjær et al., 1999; Sinkjær et al., 2003]. In the second part of this presentation, stimulation of sensory nerves in CNS injured persons to improve their motor functions through neurorehabilitation will be addressed. Neurorehabilitation is a term relating to methods and technologies for maximising the functioning of impaired sensory-motor mechanisms in human after central nervous (CNS) injury (e.g., spinal cord injury and stroke). Maximising function relates to developing new sensory-motor mechanisms. This is focused on functional electrical therapy (FET) to promote recovery. The FET comprises two elements: 1) electrically induced activation of both afferent and efferent neuronal pathways on impaired extremities by a neural prosthesis device, and: 2) repetitive exercise of paralysed extremities [Popovic et al., 2002; Popovic and Sinkjær, 2000].**

Keywords: **FES, functional electrical therapy, cortical plasticity, neurorehabilitation.**

I. INTRODUCTION

The adult mammalian nervous system has an ability to reorganise itself in an activity-dependent manner in response to increased or decreased sensory inflow. Manipulating peripheral sensory nerve activity by electrical stimulation, one can modulate in healthy human subjects the magnitude of cortical response and modulate motor pathway excitability, which can produce a mixture of excitation and inhibition at supra spinal levels.

Focal transcranial magnetic stimulation (TMS), EEG, and magnetic source imaging (MEG) studies in humans suggest that cortical reorganisation may be associated with the intensified use of the affected extremity after stroke [Taub et al., 1999]. Elbert et al. [1995] found that the cortical somatosensory representation of the digits of the left hand was larger in string players, who use their left hand for the dexterous task of fingering the strings than in non-musician controls. Moreover, the representation of the fingers of blind Braille readers who use several fingers simultaneously to read was both enlarged and disordered; the latter neurophysiological aberration was associated with a perceptual disturbance in which the subjects could not discriminate which of their fingers was being touched [Sterr et al., 1998]. A "massive" cortical reorganisation takes place after somatosensory deafferentation of an entire forelimb in primates [Pons et al., 1991]. The amount of cortical reorganisation is strongly correlated with the amount of symptomatology in a number of pathological conditions: phantom limb pain [Flor et al., 1995], and focal hand dystonia in keyboard musicians and guitarists [Elbert et al., 1998]. The hypothesis that extensive use of affected organs produces a large use-dependent cortical reorganisation in humans with stroke-related paresis of an upper limb was confirmed in several collaborative studies. Liepert and colleagues [2000] reported the treatment-induced plastic changes in the human brain after a treatment-induced movement in stroke patients.

Ridding et al. [2000], Hamdy et al. [1998], and Khaslavskaia et al. [2002] studied the effects of repetitive

electrical peripheral nerve stimulation and its association with changes in the motor response of the muscle elicited by focal TMS. They showed that short-term nerve repetitive electrical stimulation in healthy human subjects could lead to a long-term increase in the contralateral motor evoked potentials (MEP). The results allow speculating that it is possible to use repetitive electrical stimulation in the rehabilitation of patients with muscle weakness and spasticity.

Based on such findings we designed a treatment protocol termed Functional Electrical Therapy (FET). FET is a new method of treating the more affected arm in humans after a stroke by applying electrical nerve stimulation in an activity-dependent manner to the affected arm [Popovic et al., 2002]. It is an exercise that comprises simultaneous voluntarily and externally assisted reaching and grasping. FET assists the grasp based on control that mimics the patterns typically found in able-bodied subjects. The treatment is intensive exercise of daily functions (e.g., drinking, eating, writing) by the more affected arm/hand.

II. METHODOLOGY

Functional Electrical Therapy for Cortical Reorganising

The studies described above relating to use-dependent cortical reorganisation, suggest that the size of the cortical representation of a body part in an adult human depends on the amount of use of that part. It is likely that if appropriately guided, the cortical changes after cerebro-vascular accident can improve the functioning of a subject. This hypothesis was the basis for introducing the new therapeutic modality, that is, an assisted intensive use of the more affected arm. The motivation for intensive exercise comes from the externally assisted ability to function during the period that this functioning is otherwise impossible.

Subjects: The inclusion criteria were: more than two weeks and less than six months following first stroke ever, aged over 18, able to give informed consent, and cognitive status sufficient to learn how to use FET. The exclusion criteria were: dependent on care prior to stroke, severe medical condition, previous injury or disease or contracture, pre-existent neurological disease or injury, severe cognitive disability or aphasia, and electrical life support devices. 28 subjects who fit the inclusion criteria and signed informed consent forms (59.9 ± 9.3 mean age ± S.D.) participated in this randomised study. The subjects have been originally characterized as higher functioning group (HFG, 16 subjects) or lower functioning groups (LFG, 12 subjects) upon their ability to actively control the wrist and fingers when entering the study. This division is based on evaluation of constraint induced movement therapy [Taub et al., 1999]. The subjects were accepted in the clinical trial in average 7 ± 2 weeks after the onset of stroke. The study was blinded to evaluators.

Treatment modalities: We had two groups: The FET and control groups. Both groups received customary therapy and in addition were included in 30-minute daily exercise. In the FET group electrical augmentation of movement (FET) was applied for three consecutive weeks. The FET session consisted of 30-minute electrically assisted functional use of various objects (e.g., can, telephone receiver, comb, toothbrush, VCR tape). Details are explained elsewhere [Popovic et al., 2002]. The subjects from the control group received conventional therapy and were requested to exercise functional use of objects in the same way as the FET group, yet without the electrical stimulation.

Outcome measures: The effectiveness of FET was assessed at the point of entry to the trial, after the therapy, and at 6, 13, 26 weeks after the beginning. We used the following four outcome measures: 1) UEFT - Upper Extremity Function Test in order to assess the differences in the performance of eleven selected activities (combing hair, using a fork, picking up a VHS tape, drinking from a full can, drinking from a small bottle, writing with a pen, using the telephone receiver, brushing teeth, pouring from a full juice container, drinking from a mug, and eating finger food) before and after therapy; 2) Drawing for assessing the coordination of arm joint movements. The subjects were required to track a square (20 cm x 20 cm) on a digitising board. The movements were self-paced in clockwise and counter-clockwise directions. The outcome measure was the ratio between the surface area surrounded by the drawn line and the surface of the square (A = 400 cm^2) expressed in percent; 3) The Ashworth spasticity scale was used for assessing the tonus of key muscles of the upper extremities; and 4) Reduced Upper Extremity Motor Activity Log (RUE/MAL). This test is a structured interview examining how much and how well the subjects use their more affected arm outside of the laboratory setting. The subjects were rating the amount of use of their more affected arm ("Amount" Scale) and the quality of their movement during the functional activities indicated ("How Well" Scale). The best scores in "Amount" and "How Well" scales were 60, yet the worst was 0. The RUE/MAL questionnaire included the following 12 activities: pick up phone, open a door, eat finger foods, control the bathroom faucet, pick up a glass, bottle, or can, brush teeth, use a key to unlock the door, write on a paper, use the removable computer storage media, use utensils for eating, pick up a cup for handle, and

carry an object. For each of the endpoint variables (coordination, Ashworth, UEFT and RUE/MAL) we conducted the one-way ANOVA. The within-subject factor was the time (baseline, after the treatment, 6, 12, and 26 weeks after the baseline measurements).

III. Results

The Mann-Whitney rank sum test showed that the age (p_{HFG}=0.613, p_{LGF}=0.983), period between the onset of stroke and the beginning of the therapy (p_{HFG}=0.447, p_{LGF}=0.818), and the initial values of UEFT (p_{HFG}=0.721, p_{LGF}=0.1.00) in the FET/control groups match.

We also measured the time to track the square, and in most subjects the movement became much faster after the treatment. The LFG subjects could in average track the square in 9.1 ± 8.3 seconds (FET group) and 11.6 ± 8.6 seconds (control group) at the end of the study (week 26) compared with 18.4 ± 9.5 seconds (FET group), and 17.9 ± 11.7 seconds (control group) prior to treatment. The stroke subjects from the HFG FET could track the square in 4.1 ± 2.7 seconds at the end of the study (week 26) compared with 11.2 ± 6.8 seconds at the beginning. The controls in average could track the square in 7.3 ± 3.6 seconds at the end of the study (week 26) compared with 11.8 ± 7.9 seconds prior to treatment.

IV. Discussion and Conclusion

The results show a statistically significant difference in all outcome measures for the HFG submitted to FET. The data also show that the LFG FET subjects improve all outcome measures, yet this difference compared with the HFG is smaller. The muscle tonus was decreased in all subjects, yet the statistically significant change was found only in subjects from the higher functioning group that was subjected to FET. The important finding is that FET greatly improved the coordination of elbow and shoulder joints.

This study suggests that systematic electrical stimulation of peripheral nerves in a manner that generates life-like movement that is timed with the voluntary activity and integrated into a functional scheme leads to faster and greater reorganisation of the central nervous system after stroke; thereby speeds and promotes the recovery of reaching and grasping in acute stroke subjects.

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