Functional Electrical Therapy (FET): Intensive exercise augmented with functional electrical stimulation

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Abstract

We suggest that the optimal method for promoting recovery in individuals after a cerebro-vascular accident is intensive exercise augmented with functional electrical stimulation. This results from a thorough review of literature, and our clinical studies that analyzed the recovery of reach and grasp, and walking abilities. The suggestion is also based on evidences that cortical plasticity is promoted by intensive exercise and electrical stimulation. Clinical findings from reach and grasp studies in individuals with moderate disability are: 1) 3-week of FET during the acute phase of disability greatly promotes long-term recovery, 2) 3-week of FET in chronic phase results with small, statistically significant improvement. Identical FET in acute hemiplegic individuals with major disability promoted recovery; yet, the follow-up evaluation suggested only marginal differences between the FET and control groups. Results from a pilot clinical trial where FET was used in severely disabled hemiplegics for 4-week intensive walking exercise suggest: 1) major relative improvement in the maximum speed and symmetry, 2) carry over effect after 6 months.

1. INTRODUCTION

Plasticity of the CNS has been recognized as a part of the structural and physiological substrate for the recovery of function after a central nervous system injury. Corticomotor reorganization could occur as a response to: altered inputs to the sensory cortex, as an adaptation to the injury of the central or peripheral nervous system, or as a consequence of the motor task performed, and may be either short or long lasting. Dynamic remodeling processes occurring in the sensorimotor cortex of human and experimental animals have been demonstrated after peripheral deafferentation. Modification of the sensory representation has been shown for the fingering digits of violin players. However, not for the digits of the bow hand, indicating thus that a long-lasting change in the sensory cortex has occurred in response to the repetitive performance of complex and highly skilled motor tasks.

More recently the conclusion was reached that the task related intensive exercise augmented with electrical stimulation could greatly promote the recovery of sensory-motor systems. The intensive exercise augmented with assistive system which applies functional electrical stimulation was termed Functional Electrical Therapy (FET) [1].

2. FUNCTIONAL ELECTRICAL THERAPY

The FET is a new method for training motor function. It enables individuals with disability to use their paralyzed/paretic extremities during the period when they are unable to do so on their own; hence, provide function that otherwise would be impossible or very difficult. This functionality motivates the users to activate all preserved sensory-motor mechanisms. The use of the affected organ enhances the awareness regarding the ability to fulfill functional needs, and further promote active extremity use and integration into the overall motor control.

The functional sensory information generated by FET was hypothesized to result in intensive functional brain training of the activities performed. Data from our studies indicate that the functional support and maximized sensory feedback to the central nervous system make FET more effective in regaining functions when compared with results of other treatments [1, 2].

2.1. Instrumentation for FET

The FET applies a multi-channel programmable stimulator that is capable of stimulating
sensory-motor systems (e.g., Handmaster [3], Compex [4], Actigrip [1], UNA-FET [5]). The stimulation pattern delivered by these devices must generate functional movements that are otherwise compromised. One can envision the implantable systems that are easy to implant and remove (e.g., BION technology [6]).

The control of reaching and grasping requires the use of at least 8 channels. Control of grasping can be obtained by a 4-channel system. Effective assistance of walking needs at least 4-channel stimulation system. The number of stimulation channels can be reduced if the ability to function is preserved; yet, we discuss here individuals with substantial disability.

It is possible to combine electrical stimulation and external bracing in order to support some functions that are otherwise not achievable with electrical stimulation. Specifically, it is possible to control stiffness and resistance of some joint movements with relatively simple orthoses. The use of robots further increases the chances for creation of functional movements in severely disabled individuals [7]. The combination of electrical stimulation and external orthotics was termed Hybrid Assistive Systems [8].

### 2.2. The FET Procedures

Here we describe the FET through two examples:

1) **FET procedure in upper extremities.** The FET was organized in 30-minute daily sessions during three consecutive weeks. The FET used therapeutic functional electrical stimulation (tFES) to assist exercise of functional use of various objects (e.g., can, pen, comb, toothbrush, etc.). The exercise consisted of the following phases: reach, grasp, manipulate the object, bring back the object to the original post, and release it. The stimulation pattern of tFES was designed to mimic the activity of prime movers used typically for grasping and releasing in healthy individuals. A typical stimulation pattern for lateral grasp is shown in Fig. 1. The typical stimulation parameters were: 50 pps, duration 250 μs, and intensity between 10 and 45 mA.

The muscles stimulated were: finger flexors and extensors, thumb extensor, and the Thenar muscle group. The subjects used a push-button switch to trigger “open and grasp synergy”, and “the release and relax synergy”. The stimulator incorporated several protocols for various exercise routines. The overall goal during a single FET session was to perform as many as possible functions. The objects for training sessions were selected to force the subjects to practice palmar, lateral and precision grips. The FET sessions were tailored according to individual abilities to perform functional movements during the three weeks of the treatment. A therapist assisted and instructed the subjects while they try to reach, grasp, and functionally use the objects during sessions. The assistance comprised holding of the object in the adequate orientation and position, if so was required.

2) **FET procedure for walking.** Four channels of electrical stimulation were applied to Glut. m., Quadric. m., Gastroc m., and Tib. Ant. m. in order to augment walking in hemiplegic individuals. The muscles were selected to provide: 1) support during the stance; 2) push-off at the end of the stance and better stability at the foot contact; and 3) foot clearance during walking.

![Fig. 1: An example of the grasp/release stimulation patterns for tFES. The subject controls the trigger, while the profiles are preprogrammed.](image1)

![Fig. 2: An example of the sensory driven control of walking. The top two traces are signals from the FSR sensors in the insole. The “Tr” indicates the trigger given by the therapist or the user. The four bottom traces are stimulation patterns for Tib. Ant. M. (TA), Gastroc. m. (GN), Quadriceps m. (QA), and Gluteus m. (GL). The IF-THEN rules were determined by machine classification.](image2)
the swing phase. The time sequence for the stimulation was developed by using the mapping between the muscle activities and gait patterns from healthy individuals. Fig. 2 shows one of the stimulation sequences used in clinical study. The stimulation parameters were similar to those described in the FET in upper extremities.

The stimulation sequence was triggered by a trained physical therapist or the user. The stimulation was triggered once per step. Since the timing of the required stimulation varies with the speed of walking we applied the rule-based control that is sensory driven. The sensory signals were from the heel and toes force transducers. The FET sessions lasted 30 minutes daily during four consecutive weeks. The task was to walk for as long as possible at comfortable speed. Subjects used different walking aids depending on their needs (rolling walker, cane, or other).

3. DISCUSSION

The common finding in FET clinical studies for promoting recovery of upper and lower extremities in acute and chronic hemiplegic individuals is that it has an immediate effect, that is, subjects accomplish more than they would do without electrical assistance. This finding fits into the expectations because orthotic effects of patterned electrical stimulation are well known. However, the studies also suggest long-term, carry over effects. The reach/grasp and walking were improved better in FET groups compared with controls: the functioning remained better at follow-ups at six months and later. The differences in all outcome measures between the control and FET groups were significant.

The findings from the studies are summarized in Fig. 3. The top panel in Fig. 3 shows the results from the FET in acute hemiplegic individuals who started their rehabilitation with limited, yet measurable functions. The time between the onset of hemiplegia and beginning of the treatment was in average about 4 weeks. The middle panel shows the results from the lower functioning group that was treated in the acute phase. The performance was improved, yet the level reached was still not good enough to encourage these individuals to continue effective use of the paretic extremities. This led to deterioration and disuse of the developed function. The result was best seen in upper extremities, especially if the non-dominant arm was paretic and treated. The pilot study of FET of walking comprised to small sample size to draw conclusions, but the trends in increasing of the speed of walking, and decreasing of the symmetry index were noticed in all subjects.
and the differences are significant.

In the lower functioning group the FET was not effective compared with the effects in the higher functioning group. The assistance likely needs to be much “stronger” in the lower functioning group in order to provide better support to many more sensory-motor systems if one expects to see effective functioning. The intensive exercising is viable if the function could be performed, and that is essential for motivation to adhere with the rehabilitation program.

The bottom panel in Fig. 3 shows the results from the FET in chronic subjects. The carry over effect could be categorized as marginal. However, all individuals were very enthusiastic, and very interested in continuing in the programs of FET if they are offered and organized. We are hypothesizing that the dose of three or four weeks is not sufficient; thus, the augmentation of the function is not good enough. Providing more assistance and longer treatment could lead to better results.

The FET is limited by the complexity of application. If more stimulation channels and sensory signals are needed, then the application becomes too demanding and the cost benefit function is being elevated at the levels not acceptable by rehabilitation institutions and disabled individuals. Many channels of stimulation and complex sensory system make the system very impractical. In such cases, the use of external orthotics (robots) could be a great complement in rehabilitation of functions.

References

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