Augmenting Rehabilitation after Stroke: A Flexible Platform for Combining Multi-channel Biofeedback with FES

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Abstract— **The use of functional electrical stimulation (FES), has been gainfully used for decades in stroke therapy but has been limited by its tendency to cause pain and fatigue during extended use. The use of EMG biofeedback for rehabilitation of sports injuries and other muscle disorders is well established. The use of such biofeedback in post-stroke therapy is, however, often hindered by patients having poor attention and endurance, particularly in cases of severe impairment.**

This paper describes a versatile upper limb rehabilitation platform (called "SynPhNe") which provides multi-channel biofeedback and allows a seamless, need-based integration with FES. This combination may have several benefits leading to more effective repetitive practice and hence, better recovery. The design of the biofeedback-FES interface and possible application scenarios are enumerated.

I. Introduction

It is widely acknowledged that recovery of functional use of the hand is one of the most important factors in independent living. The average recovery rate of functional use of the hemiplegic hand after stroke, however, languishes at 6-12% worldwide [1]. This problem is heightened with the increasing pressure on hospitals to discharge patients early and the rapidly decreasing number of therapist hours available per patient during hospital stay and after [2], [3].

Systematic reviews in literature demonstrate that FES has a marked positive effect on recovery of hand movement. In many studies, however, the effect on functional recovery is far more limited [1], [4]. One of the reasons cited for this was the inability to do extended functional task practice due to onset of pain and fatigue [5], [6]. FES is also frequently used to independently contract a muscle irrespective of whether the antagonist muscle elongates simultaneously or co-contracts. Thus it does not train the patient in appropriate agonist-antagonist muscle use strategy, which may be key to recovery of function.

Muscle biofeedback, on the other hand, is a modality used extensively for recovery of muscle co-ordination and efficiency after injury. It leverages the ability of a human to self-regulate the contraction and relaxation of muscle. In severe impairment after stroke, however, the ability to self-regulate is reduced and persistent failure by the patient to elicit sufficient movement may lead to frustration and truncated repetitions. In addition, multi-channel biofeedback equipment is time consuming to set up and requires the services of an expert.

This study explores the possibility of combining a simplified multi-channel biofeedback system with FES to help augment rehabilitation of hand function after stroke.

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II. System Description

A. Hardware system design

Fig 1 shows the components of "SynPhNe" or synergistic physio-neuro rehabilitation platform, which is being developed in Singapore as a low cost, wearable solution for recovery of hand function after stroke.

Fig. 1. SynPhNe Rehabilitation Platform

The portable device in Fig. 1 is a 16-channel data acquisition and storage device which can be waist mounted and has a memory card for storing electroencephalography (EEG) captured by the headset and surface electromyography (SEMG) data captured by the arm glove. Biofeedback can be provided for muscle as well as attention training, and EEG-SEMG profiles and metrics can be recorded for tracking progress real-time or offline. The details of the design and a pilot study with stroke patients have been reported previously by the authors [7], [8]. The biofeedback system has now been integrated with a commercial FES system (RehaStim 8 channel FES system by Hasomed GmbH, Germany), using LabView 2011 software (National Instruments, USA).

B. Software driven processes

The patient follows a therapy protocol which is a sequence of actions demonstrated via a video on the computer monitor. For each action, the appropriate muscle to be sensed and stimulated is automatically assigned through the software programming, which in turn, is mapped to a FES channel. The communication protocol allows direct control of 8 channels of the stimulator from an external PC via USB 1.1 standard interface.

III. Methods

Here, we limit our explanation to a simple set up for a exercise routine using two-channel FES stimulation. The routine includes wrist and finger extensions and flexions followed by opening and closing grasp activity. The ideal locations for FES stimulation of wrist and finger extensors and flexors were located on healthy subjects and the standard 50mm x 50mm FES electrode patch was placed. These patches had previously been modified to include two holes 12mm in diameter, set 28mm apart. A customized template was then created for repeated use, as shown in Fig 2(A). This template was placed on the subject's arm (Fig 2(B)) and connected to the FES machine over 2 channels for extensors and flexors.

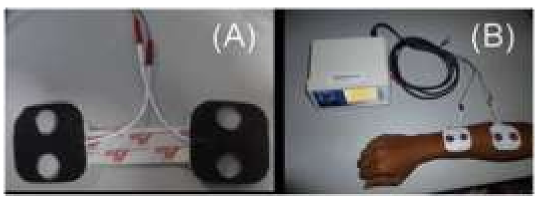

Fig. 2. FES electrode set up customization

Next, the SEMG arm glove, which is a spring loaded C-Clip design (Fig 3(A)) was simply placed over the FES patches in such a way that the dry SEMG sensors locate in the holes cut-out on the patches. There is insulation between the FES patch and the sensor in such a set up. The complete set-up using 3 C-Clips is shown in Fig 3(B), covering wrist and finger extensors and flexors.

Fig 3. Combination of Biofeedback Glove and FES

The subjects then went through a SEMG calibration which automatically calculated thresholds to establish three levels of difficulty for therapy, which the therapist could use to personalize therapy. FES parameters like current and pulse width were set in the software and saved for the particular subject.

IV. Results & Discussion

The subjects were instructed to use only biofeedback initially to get a feel of manipulating their own muscle activation and relaxation. The objective was to cross agonist muscle SEMG thresholds (as calculated during calibration) while performing the actions, maintaining low antagonist contraction at the same time. The biofeedback GUI guided the subjects. When the subject could no longer achieve the threshold consistently due to fatigue, the system was switched on-the-fly to a new threshold for triggering FES support. Therapy then progressed with the subjects achieving a smaller SEMG peak which then triggered the FES to complete the range of motion. Such a peak could be as low as 10% of original biofeedback threshold. In the trials with healthy subjects, the system was able to support a mix of modalities for increasing quality and duration of repetitive task practice. A very low current FES effectively gave tactile sensory feedback to the subject on whether the correct muscle was being activated during biofeedback. This can apply to stroke patients who are mildly affected. Obviously, in the case of a severely impaired arm, the system can also deliver passive FES.

V. Conclusion

Employing biofeedback integrated with FES may help increase quality and quantity of repetitions and augment therapy in a clinic setting and later at the patient's home. The entire set up is quick and can be done with one hand. Futher details of the system can be published in a full paper. The SynPhNe system is currently undergoing trials with stroke patients in Singapore.

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