Use of an upper limb FES device for a drinking task: 2 case studies

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Abstract

Two stroke patients performed a drinking task with and without an upper limb FES device assisting with hand opening upon grasp and object release. The number of correct triggers of the device, time to complete the task, and movement smoothness were used to evaluate the effectiveness of the device. Results suggest that these patients benefited from the device when performing the drinking task.

1 Introduction

Stroke affects approximately 2 in 1000 people in the UK per year [1] and impaired upper limb function is reported to be a major problem [2]. At 3 months post stroke only 20% of patients have normal upper limb function [3] and less than 15% with paralysis may regain complete function [4]. Voluntary extension of wrist and fingers is often reduced, resulting in difficulties when grasping or releasing objects.

FES devices stimulate peripheral nerves to cause purposeful muscle contraction. For example the 'dropped foot stimulator' (e.g. ODFS) assists with dorsiflexion of the foot during the swing phase of gait. Stimulation onset and termination is typically triggered by pressure sensitive resistors or foot-switches.

In contrast, control of upper limb FES systems is more challenging since movements are non-cyclic, have no obvious events (e.g. heel strike) and various motion trajectories can bring the hand from a fixed start point to a target. Control through EMG [5] or EEG [6] signals is possible but external noise and information transmission rates can cause difficulties.

FES control through the motion of the contralateral shoulder has shown to successfully trigger stimulation in patients with higher level spinal cord injury (Freehand System). However, for stroke patients with a lower level of unilateral impairment, use of the unaffected limb to control the impaired hand is not ideal. Artificial trigger movements of the hemiplegic arm, such as an exaggerated elbow motion, can be used to trigger hand opening [7] but this is cosmetically not desirable.

The ultimate goal of our project is to use the natural motion of the forearm, as measured with an accelerometer, to trigger an implantable FES device that initiates wrist extension and hand opening during grasp and release. In this paper we present the first results of our current prototype (an external surface stimulator) and show its effect on a reach and grasp task performed by two stroke patients. Our outcome measures are: 1) number of correct triggers for the FES device; 2) time to complete the task; 3) smoothness of the wrist joint centre trajectory as a measure of motor performance [8].

2 Methods

2.1 Patients

Two medically-stable stroke patients gave informed consent and participated in this study (see Table 1). Both could use their hemiplegic arm to reach towards objects placed at a comfortable distance but had limited active hand-opening. However, their hemiplegic hand responded well to surface stimulation of the wrist and finger extensors, and thumb abductors. They suffered from no other neurological condition and had no fixed contractures of elbow, wrist and fingers. Muscle spasticity in the flexors of the hand, wrist and elbow was 3 or less on the Modified Ashworth Scale. Note that the patients' general medical treatment modalities were not withheld.

2.2 FES Hardware & Software

In order to apply stimulation to the hemiparetic arm, we employed a 2-channel Odstock surface stimulator that was modified to receive

Table 1 Patient Information.

	Patient 1	Patient 2
Age	60	63
Gender	Male	Male
Time since Stroke	4 years	6 month
Dominant Side	Right	Right
Hemiplegic Side	Left	Left
Time since Botox	3 months	----
Use of exercise stimulation prior to testing	10 weeks, 1x20 min per day	2.5 weeks, 2x15 min per day
Ability to grasp glass	Limited	None

commands from a PC via USB. The surface stimulator could therefore be triggered in two different ways: 1) manually by laboratory staff; 2) automatically by pattern recognition software that, throughout task performance, interprets kinematic data from a 3D accelerometer located on the dorsal surface of the forearm.

The particular algorithm we employed was based on a Finite State Machine (FSM) with state transitions triggered by acceleration along a given axis crossing a given threshold [9]. The 'best' axis and threshold for each state transition were determined during training. The training data consisted of acceleration profiles collected during manual triggering where laboratory staff labelled state transitions in real-time using the keyboard. This training could be completed within minutes and tested on the patient within the same data collection session.

2.3 Data Collection & Processing

Reflective 6mm markers, attached to the medial and lateral process of the styloid, were tracked in 3D with a 10 camera Vicon motion analysis system in order to record the motion of the wrist during trials. The midpoint of the styloid markers, filtered in Matlab using a low-pass Butterworth filter with a cut-off frequency of 6 Hz, defined the wrist joint centre position. Its velocity was then computed as the first derivative of its position.

The total time to complete the task was defined as the time from when the wrist velocity crossed 10% of its maximum at the beginning and end of the trial. The wrist joint centre's jerk (the 3rd derivative of its position) was also calculated in order to compute the Jerk Metric, defined by "dividing the negative mean jerk magnitude by the peak speed" [10]. Accordingly an increase in the Jerk Metric indicted increased smoothness.

2.4 Experimental Task

Patients reached forward to grasp an empty plastic glass that was placed at a comfortable distance in front of them. The position of the glass was marked so that it would always be returned to the same location. The task was conducted under the following three test conditions: 1) without FES (baseline) if possible; 2) with manual FES triggering by laboratory staff; 3) with automatic FES triggering via FSM software [9] interpreting forearm accelerations. Note that data from manual FES triggering served as training data for the design of the pattern recognition algorithm used in conditions 3.

3 Results

Five to twelve trials were recorded per patient per condition. The number of trials was limited by the test time: patients were to finish in 1.5 hours, including screening, set-up, breaks and algorithm training.

Condition 1, no FES: Patient 1 altered the task in 5 out of 12 trials in that the glass was either not lifted all the way towards the mouth or was not returned to its correct position on the table. It appeared that the grasp was not secure during those trials and the task therefore 'cut short'. Patient 2 did not provide any data for this condition due to limited active hand-opening, preventing the patient from grasping the glass.

Condition 2, manually triggered FES: Both patients completed all trials successfully as instructed (patient 1: 5 trials, patient 2: 7 trials). These trials were then used to train the algorithm for automatic triggering.

Condition 3, automatically triggered FES: For patient 1, stimulation assisted with both grasp and release in all 7 trials. For patient 2 this was only the case in 5/9 trials whereas 4/9 trials stimulation was triggered for the grasp only. No false triggering was observed for either patient.

Average movement time and smoothness of the wrist joint centre trajectory: Across 5 successful trials of each condition, patient 1's

movement time initially increased with manual FES triggering as compared to the No-FES condition but decreased below the time required without FES when stimulation was triggered automatically (Table 2). Moreover, movement smoothness improved with each condition for this patient (Table 3). It is noteworthy that without FES patient 2 was not able to perform the task at all. With FES, however, the patient was quicker to complete the task when the algorithm triggered the device automatically as compared to manual triggering (Table 2). Smoothness was slightly better in the manual triggering trials for this patient (Table 3).

Table 2 Mean time (sec) to complete task across 5 trials.

	Patient 1	Patient 2
No FES	16.19 (±1.79)	---
Manual Triggering	18.14 (±2.66)	13.96 (±1.18)
Automatic Triggering	15.01 (±0.94)	13.77 (±1.52)

Table 3 Mean Jerk Metric ($1/s^2$): more positive values indicate greater smoothness.

	Patient 1	Patient 2
No FES	-32.17 (±6.33)	---
Manual Triggering	-29.08 (±4.64)	-16.86 (±3.36)
Automatic Triggering	-23.39 (±2.23)	-17.47 (±3.09)

4 Discussion and Conclusions

With the pattern recognition software the FES device was correctly triggered 28 out of 32 times (87.5%) and only four times did the algorithm fail to trigger (Patient 2: object release). Moreover, for both patients movement time was shorter when the device was automatically triggered as compared to no-FES or manual triggering of the device. Finally, patient 1 showed a clear increase in smoothness during automatic triggering and it is also noteworthy that patient 2 was unable to perform the drinking task without FES device. We conclude that these patients benefited from the device when performing this task.

The absence of false triggers further suggests that the device is safe within this application and did not cause a false release of the glass. This is important since an untimely release of, for example, a cup of hot coffee would place the patient at risk of sustaining burns.

It is noteworthy that the more a patient is able to reproduce movement characteristics for a given task, the more reliably the device will assist. Cognitive performance in patients using such a device needs to be addressed in a larger study with a greater variety of patients and in conjunction with multiple tasks.

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