Electrode-Array Based Functional Electrical Stimulation for Upper-Limb Stroke Rehabilitation with Innovative Sensing and Control

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Introduction

Functional electrical stimulation (FES) has shown effectiveness in restoring movement post-stroke when applied to assist patients' voluntary intention during repeated, motivating tasks. However, most commercial upper-limb FES products assist only few muscles and do not use position sensor feedback to adjust the FES. Recent clinical trials have employed advanced controllers that precisely adjust stimulation applied to three muscle groups in order to assist functional reach and grasp tasks, giving rise to statistically significant reduction in impairment. This paper describes the system, focusing on the innovative sensing technology, electrode array based controller and associated hardware.

Methods

Stroke participants (N=4) undertook seventeen intervention sessions, each of one hour duration. During each session FES was applied to the anterior deltoid and triceps via single electrodes, and wrist/finger extensors via an electrode array to assist participants in performing functional tasks with real objects and virtual reality functional reaching tasks. These comprised: 1) pressing low or high light switches, 2) closing a drawer, 3) grasping-replacing-releasing an object. Kinematic data were extracted using a Microsoft Kinect and PrimeSense, and mechanical arm support was provided by a SaeboMAS. An advanced model-based iterative learning controller used kinematic data from previous attempts at each task to update the FES applied to each muscle on the subsequent trial. This produced stimulation profiles that facilitate accurate completion of each task while encouraging voluntary effort by the participant. Participants completed clinical assessments (Fugl-Meyer and Action Research Arm Test) pre- and post-intervention, as well as FES-unassisted tasks during each intervention session.

Results

Feasibility was established in preliminary tests with unimpaired participants (N=2) who provided no voluntary effort. These confirmed high levels of performance over a range of functional tasks. For the case of stroke participants, results showed that FES-assisted performance increased over the course of the intervention for a range of functional tasks. Statistically significant improvements were also observed in FES-unassisted tasks over the course of the intervention. In particular, range of movement (ROM) increased at the shoulder, elbow, wrist and index finger joints over a range of tasks; the high light switch demonstrated the most significant gain in shoulder flexion ROM, the contralateral reach in elbow extension ROM, the near reach in wrist extension ROM and the far reach in index finger extension ROM.

Conclusion

The feasibility of applying precisely controlled FES to multiple muscle groups in the upper limb using advanced sensors, controllers and array hardware was demonstrated. This technology is expected to lead to significant reductions in upper-limb impairment following chronic stroke. This compact low-cost rehabilitation technology also has potential for future transfer to patients' homes.