Iterative Learning Mediated FES in Stroke Rehabilitation

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Abstract

This study examined Stimulation Assistance through Iterative Learning (SAIL), a novel stroke rehabilitation system for the upper limb. Five hemiparetic stroke participants with reduced upper limb function undertook 18, 1 hour training sessions. Participants completed 3D tracking tasks in which they moved their impaired arm to follow a slowly moving sphere along a specified trajectory. The participants' arm was supported by a robot. Functional electrical stimulation (FES), precisely controlled by advanced iterative learning algorithms, was applied to the triceps and anterior deltoid muscles to assist accurate tracking. For assessment, participants completed unassisted tracking tasks in each session, as well as clinical assessments (ARAT and FMA) pre- and post-intervention. Results show that unassisted tracking performance and FMA scores improved over the intervention, and the amount of FES required to produce accurate tracking reduced over the same period. The technology employed by the SAIL system was designed to help stroke patients train their upper limb muscles, leading to improved motor control. The results from this study suggest that SAIL can accurately assist upper limb movement in stroke participants. The feasibility and effectiveness of SAIL in reducing upper limb impairments following stroke was demonstrated.

Keywords: *FES, upper limb, stroke rehabilitation, iterative learning control*

Introduction

Stroke is a leading cause of death and disability in the UK, with approximately 50% of stroke survivors being left disabled and dependent [1]. Upper limb impairment is a particularly common problem post-stroke that limits many activities of daily living, such as eating and dressing. As such, it is important that rehabilitation technologies and therapies are developed to help recovery of upper limb motor function post-stroke.

Research has shown that intensive, goal-orientated practice of movement is vital for recovery of upper limb function post-stroke [2, 3]. Technologies such as robotic therapy and functional electrical stimulation (FES) have proved effective techniques in reducing upper limb impairment, enabling people with limited physical upper limb ability to practice repeated movements [3, 4, 5, 6, 7]. Furthermore, effectiveness of therapy is suggested to improve when associated with the patient's voluntary intention to move (i.e., voluntary effort) [6, 7], and it is important that voluntary effort is maximised in therapeutic interventions [7].

To achieve this, we have developed a system that uses robotic support and FES that is mediated by iterative learning control (ILC). Through use of performance data from previous trials, ILC algorithms control the applied FES in order to correct performance error in the next attempt. In this way, ILC encourages and supports voluntary effort by the participant, providing just enough FES to assist the participant in performing the movement [8, 9].

A recent study using ILC and FES applied to the triceps during planar reaching tasks demonstrated the clinical feasibility of using this technology. The participants' arm was supported by a custom built robot and FES was applied to the triceps brachii muscle to facilitate elbow extension during tracking tasks. Results from the study showed that impairment reduced and performance accuracy improved over the course of 18 to 25, 1 hour sessions [10]. To increase the potential of the approach for stroke rehabilitation, a new system has been developed to assist participants in performing more functional, 3D tasks with FES applied to a greater number of muscles [11, 12]. This technology has been termed Stimulation Assistance through Iterative Learning (SAIL).

Material and Methods

Following University of Southampton, Faculty of Health Sciences ethical approval a total of five participants were recruited to the study [12].

Clinical Assessment Sessions

Participants attended two assessments (set four weeks apart) prior to the intervention sessions to establish baseline performance on the Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT). Performance on these measures was then assessed a maximum of two days following the completion of 18, 1 hour training sessions [12].

Intervention Sessions

Participants were seated at the workstation with their hemiplegic arm loosely strapped into the arm holders on the robotic support. The robotic support was adjusted to provide just enough support so that the participant's arm was fully supported off the knee (see Fig. 1). Electrodes were located over the muscle body of participants' triceps and anterior deltoid. Parameters that were required for the model of the arm in the SAIL system were then established [9, 10]. These included maximum FES levels and a workspace corresponding to the full range of movement of a participants' upper limb, with assistance from FES [8, 9].

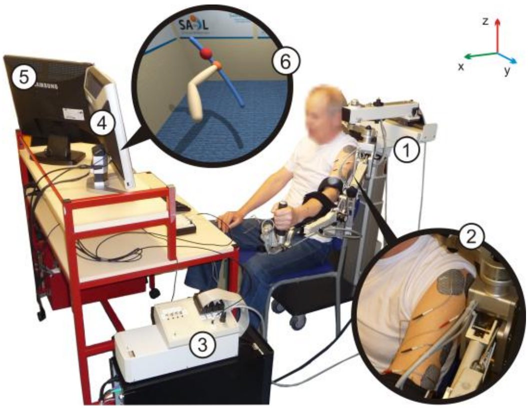

Fig.1: SAIL system components: 1) Hocoma ArmeoSpring® support, 2) surface electrodes on triceps brachii and anterior deltoid muscles, 3) realtime processor and interface module, 4) monitor displaying task, 5) monitor displaying therapist user interface, and 6) example of a reaching task displayed to a stroke participant with left hemipshere damage. An image of their own arm is shown and they are encouraged to follow a sphere which moves along a trajectory; in this case from bottom right to top left.

During the training sessions, participants practiced 3D reaching movements. To do this, they moved their impaired arm to track a slowly moving ball along a specified trajectory displayed on a computer screen in front of them. FES was applied to the triceps and anterior deltoid muscles in order to assist elbow extension and shoulder flexion and abduction respectively. The FES was mediated by advanced ILC algorithms, which use biomechanical models of the human arm in combination with performance data recorded over previous attempts of the task to adjust the amount of FES applied from trial to trial. Specifically, ILC adjusted the amplitude and timing of the FES applied to each muscle on each trial to provide precise movement. In this way, ILC provided just the right amount of FES to maximise performance and encourage maximal voluntary contribution.

There were 18 different trajectories that spanned the whole workspace and could be tracked at different speeds. Participants completed 6 trials of the same tracking movement, and there was a 15 second rest period between iterations to reduce fatigue. Participants started each movement from the same initial position, which was determined at the start of the first trial. Participants completed between 4-6 tasks in each session depending on fatigue. Participants were instructed to move their arm so that their hand kept pace with the sphere. For feedback on performance, the sphere changed colour : green indicated tracking error of less than 5cm and red indicated tracking error that was greater than 5cm.

At the start and end of each session participants also completed four unassisted tracking tasks in which they received no assistance from FES. These tasks spanned a diverse range of movements within the workspace. Participants attempted each unassisted tracking trajectory once.

Results

Tracking Performance Measures

Fig. 2 illustrates ILC correcting the applied FES to bring about accurate tracking over a course of 6 trials. As shown in Table 1, regression slopes showed that all assisted and unassisted performance measures significantly changed over the intervention for both the shoulder and the elbow [14]. Specifically, over the 18 sessions, assisted tracking performance was found to improve, the amount of FES required for accurate tracking reduced and unassisted tracking performance improved for all four tasks.

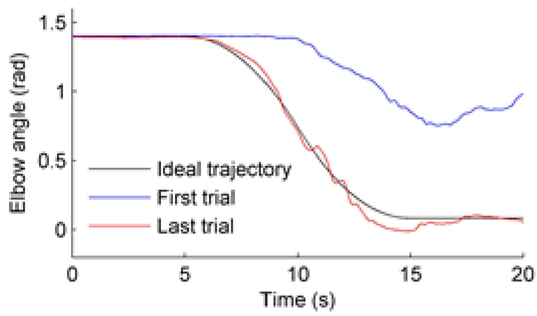

Fig. 2: Example of ILC correcting tracking at elbow

Clinical Outcome Measures

The results of the FMA and ARAT assessments are shown in Table 2 [14]. FMA scores were shown to increase pre- to post-intervention, indicating that impairment in the upper limb reduced. No changes were found for the ARAT. Thus, SAIL effectively reduced upper limb motor impairment but not functional improvements assessed by the ARAT.

Table 1: Regression slopes for performance measures

	Elbow		Shoulder	
	Slope	p-value	Slope	p-value
Trajectory	Unassisted Performance measures			
Centre distal	0.05	.01	0.06	.05
Off-centre middle	0.04	.03	0.03	.02
Far middle	0.03	.03	0.03	.01
Far distal	0.03	.03	0.03	.01
	Assisted Performance measures			
Assisted tracking	.01	.03	.01	.01
% of FES applied	-1.31	.02	-1.37	.02

Table 2: Average clinical outcome measures

	ARAT		FMA	
	Pre	Post	Pre	Post
Mean (SD)	6.4 (4.62)	6.8 (5.89)	23.5 (12.95)	32.8 (12.28)
z-test	z(5) = -.69, p= .49		z(5) = -2.02, p = .04	

Discussion

A platform for stroke rehabilitation has been developed and tested, comprising a 3D rehabilitation mechanical support and FES system mediated by ILC to precisely assist arm movement. The technology employed by SAIL was designed to help stroke patients train their upper limb muscles to improve motor control. The ILC component of SAIL was employed to optimise the potential benefit of combining FES with a persons' own voluntary intention to move.

The results demonstrate the feasibility of SAIL and confirm that SAIL can accurately assist upper limb movement in stroke participants. In addition, SAIL was shown to be effective in reducing upper limb impairments following chronic stroke, as demonstrated by improvements on the FMA and in unassisted tracking performance. However, the observed motor improvement did not transfer to functional improvements, as measured by the ARAT. This is consistent with previous work [4, 10], and suggests that to obtain functional improvements on the ARAT, future work should extend SAIL to incorporate training of the hand and wrist. Work by the authors is currently underway to address this.

Conclusions

In conclusion, SAIL assisted upper limb motor training in chronic stroke participants, minimizing FES support whilst maintaining accurate movements. The positive results indicate that the application of SAIL technology may be clinically relevant for chronic stroke rehabilitation and are promising with respect to reducing upper limb impairment.

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