Efficacy of iterative learning control for stroke rehabilitation

In the April 2008 issue of Progress, we featured an article describing a new technique for improving arm movement following stroke developed at the University of Southampton. The technique involves the use of a robotic workstation delivering precisely controlled electrical stimulation mediated by iterative learning control to improve task performance. Here, the scientists who developed the system discuss the promising results of their pilot clinical study using this technique.

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Strokes affect between 174 and 216 people per 100 000 population in the UK each year.[1] Approximately two-thirds of patients in England will survive their stroke; of the 900 000 stroke survivors, 50 per cent are disabled and dependent.[2] Although a high number of patients have upper limb impairments initially post-stroke,[3] despite therapy, very few regain useful arm movement[4] regarded as being an important factor affecting independence.[5] Upper limb function is clearly a major problem, which current treatment approaches are not solving. If the capacity of health and social services is to meet future demand, new approaches to rehabilitation are required.

Evidence supports the use of electrical stimulation (ES) to reduce arm impairments following stroke, but until now, techniques have not allowed performance-related feedback – as has been demonstrated with robotic devices. To promote voluntary activity using ES, the stimulation must be adjusted in response to the users' performance; providing only the minimum level of stimulation needed to assist the patient in performing the task to a high level of accuracy.

Robotic workstation for improving arm function

A system has been developed at the University of Southampton, which is believed to be the first to combine a purpose designed robotic workstation with precisely controlled ES that can deliver the high level of tracking performance needed to complete the task accurately. Iterative learning control (ILC) is the approach used to achieve this, and is a technique that has its origins in the control of industrial processes that repetitively perform the same task. The controller learns from experience by using all inputs and associated errors from previous trials in the calculation of the next stimulation input in order to sequentially improve accuracy. The development of this system has been possible through a multidisciplinary collaboration between therapists, engineers and users. Full details of the design and operation of this system have been previously reported.[6]

Study design

A clinical study has recently been conducted in which the system was used with five stroke patients, and stimulation was applied to their triceps brachii in order to extend their ability to perform two-dimensional tracking tasks (for demographic characteristics, see Table 1). Patient inclusion criteria consisted of a hemiplegia following stroke (at least six months previously), but with some residual voluntary control of finger flexors, upper arm and shoulder muscles. Patients also needed to respond to surface stimulation when in the robotic workstation. The exclusion criteria were: uncontrolled epilepsy, any active device implant, skin sensitivities to sticking plaster/tape or alcohol wipes, any serious medical, psychological or cognitive impairment that, in the opinion of the investigators, would compromise the patient's safety or ability to comply with the study, and any orthopaedic or neurological lesions that might have affected arm movement.

During the intervention, patients performed a range of tracking tasks in which their remaining voluntary activity was augmented by ES. The patients' forearm was supported using a hinged arm-holder, which constrained their hand to move in a two-dimensional horizontal plane (Figures 1 and 2 show the robotic workstation and a patient using it).

The ILC control scheme used a biomechanical model of the patient's arm to adjust the applied ES and so reduce the error between the actual and desired trajectory during repeated performances of a reaching task. Six repetitions of each task were performed, and the level of ES applied was reduced following accurate tracking of the task. In this way, the patient was encouraged to provide their maximum voluntary contribution to the task completion, ensuring they always worked at the limit of their ability. Sessions of one hour duration were conducted three times a week for a period of six

ID	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Age (years)	38	77	41	55	51
Gender	Male	Female	Male	Female	Male
Time from stroke (years)	2.8	8.4	4.8	3.6	0.7
Stroke type	Infarction	Haemorrhage	Infarction	Haemorrhage	Unknown
Side of hemiparesis	L	L	R	R	R
Previous dominant side	L	R	R	R	L
Baseline* FMA score	13.5	16.5	8.5	15.5	10.5

Table 1. Demographic characteristics of the five stroke patients in the study with Fugl-Meyer Assessment (FMA) score giving an indication of level of impairment. *Mean of the two pretreatment evaluations

weeks. After this time, two patients still showed improvement and were therefore offered an additional seven sessions.

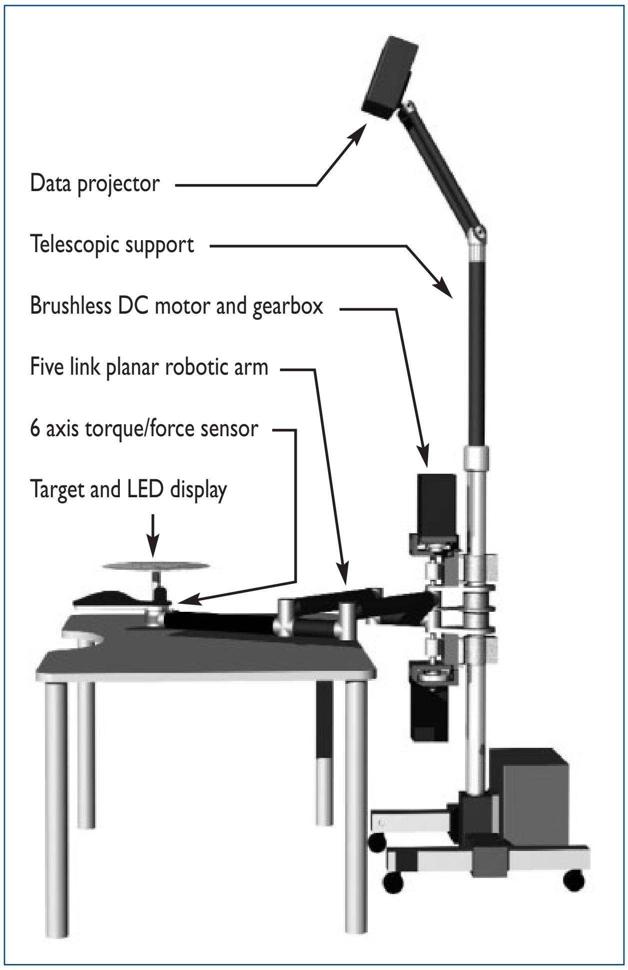

Figure 1. The robotic workstation delivering precisely controlled electrical stimulation mediated by iterative learning control

The level of unassisted error tracking of a set of four trajectories conducted at the beginning and end of each session were used as an outcome measure for the intervention. Additional outcome measures taken prior to and after the intervention included the Fugl-Meyer Assessment (FMA), the Action Research Arm Test (ARAT), and the ability to apply isometric force in six directions.

In order to identify underlying changes in muscle activation patterns, sessions were also conducted before and after the intervention in which the patients undertook nine tracking tasks while surface electromyography (EMG) was recorded from seven muscles in their impaired shoulder and arm. These were compared with activation patterns identified from neurologically intact participants in preliminary work.[7] As a final outcome measure, a question set was developed in order to understand patients' perceptions of the system.

Results

The results demonstrated statistically significant ($p \leq 0.05$) improvements in: FMA motor score, unassisted tracking ability over the course of the intervention (see Figure 3), and in the ability to generate isometric force (see reference 8 for full details of these results) Statistically significant differences in muscle activation patterns were observed between stroke and neurologically intact participants for timing, amplitude and co-activation patterns between triceps and biceps. After the intervention, significant changes were observed in many of these towards neurologically intact ranges. The question set showed that the robot-assisted therapy was well accepted and tolerated by the stroke patients.

The greatest improvements in unassisted tracking were seen in patients with the lowest initial FMA score. The study results also demonstrated that the level of ES used by each patient when performing the assisted tracking tasks decreased over time, while similar levels of tracking accuracy were maintained, indicating that the patients were increasing their voluntary input over the intervention.[8] Although the impairment measures showed a significant change, neither clinical outcome measure (FMA and ARAT), however, showed a clinically relevant change. Despite this, patients' comments both during intervention sessions and in the semi-structured interview subsequent to the study revealed that they had experienced some functional benefits from participating. This may reflect a lack of sensitivity in the clinical outcome measures used.

Figure 2. Stroke patient using the robotic workstation

Conclusion

This study has demonstrated the feasibility of using ILC mediated by ES for upper limb stroke rehabilitation in the treatment of stroke patients with upper limb hemiplegia. Future plans are to replace the tasks performed with unconstrained three-dimensional functional movements across the shoulder, elbow, wrist and hand, which will include reaching and grasping objects. Stimulation will be applied to a greater number of muscles, and the biomechanical models and ILC schemes that have been developed will be extended to assist patients in performing these movements with the same high level of accuracy.

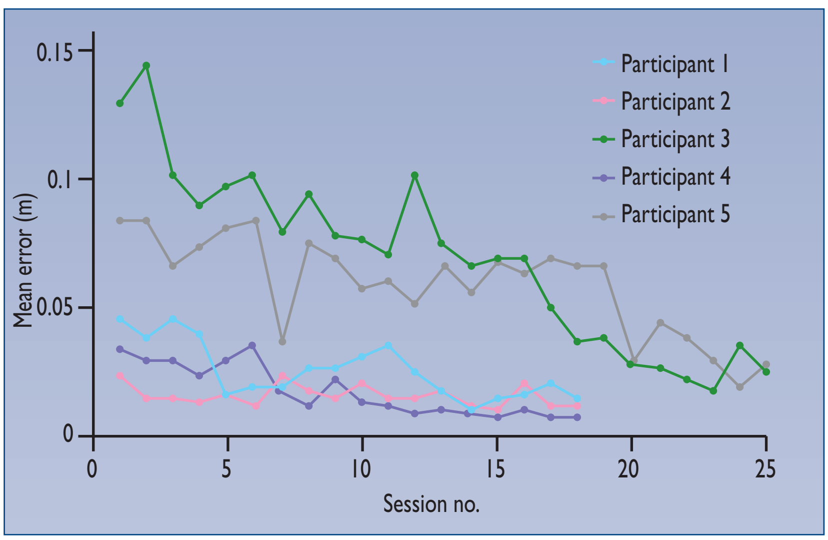

Figure 3. Changes in mean tracking error for each of the five patients in the study over the four unassisted tasks performed at the beginning of each intervention session

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