Tele-Supervised FES-Assisted Exercise for Hemiplegic Upper Limb

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***Abstract*—Stroke survivors often have upper limb (UL) hemiparesis, limiting their ability to perform activities of daily life (ADLs). Intensive, task-oriented exercise therapy (ET) can improve UL function, but motivation to perform sufficient ET is difficult to maintain. Here, we report on a trial in which a workstation was deployed in the homes of chronic stroke survivors to enable tele-coaching of ET in the guise of computer games. Participants performed six weeks of 1 h/day, five days/week ET. Hand opening and grasp were assisted with functional electrical stimulation (FES). The primary outcome measure was the Action Research Arm Test (ARAT). Secondary outcome measures included a quantitative test of UL function performed on the workstation, grasp force measurements and transcranial magnetic stimulation (TMS). Improvements were seen in the functional tests, but surprisingly, not in the TMS responses. An important finding was that participants commencing with intermediate functional scores improved the most. Conclusions: 1) Daily, tele-supervised FES-ET in chronic stroke survivors is feasible with commercially-available technology. 2) The intervention can significantly improve UL function, particularly in people who start with an intermediate level of function. 3) Significant improvements in UL function can occur in the absence of changes in TMS responses.**

***Index Terms*— Brain stimulation, electrophysiology, neuromuscular stimulation, patient rehabilitation.**

I. Introduction

STROKE is recognized as a leading cause of adult acquired disability [1], [2]. Although some recovery of UL motor function generally occurs in the first few months, debilitating hemiparesis often persists [3]. Previous research has shown that exercise therapy can improve function if it is repetitive [4], intensive [5] and task oriented [6]. It is a challenge to make such therapy motivating and engaging. Computer-based passive gaming devices offer advantages over conventional exercises in this regard. Participants are diversely challenged, motivated and cognitively engaged in goal-directed exercises performed in the guise of computer games [7]–[9]. Tele-supervision of exercises performed in the participants' homes is more likely to ensure adherence than simply providing lists of exercises to be performed on a voluntary basis [6], [10].

Many stroke survivors are unable to generate enough voluntary activation of UL muscles to perform ADLs [11]. FES can be used to augment voluntary hand opening and grasp formation in such cases. In previous studies we found that three weeks of daily FES-ET produced significant improvements in UL function in sub-acute and chronic stroke participants [12], [13]. As the improvements had not reached a plateau in these studies, in the current trial with chronic stroke survivors, we extended the treatment to six weeks. The aims of the present study were 1) to explore the feasibility of providing daily tele-coaching of FES-ET with devices that are available commercially; 2) to collect preliminary data on the efficacy of this intervention; 3) to study the correlation between functional improvements in UL function and corticospinal excitability assessed with TMS.

II. Methods

A. Participants

11 participants with chronic stroke were included in the final study analyses (ten male, aged 54–86, mean time post-stroke 52 months), see Fig. 1 for details. None were engaged in any other rehabilitation therapy programs during the experimental trial. All gave informed consent to the procedures, which were approved by the human research ethics committees at the University of Alberta, Edmonton and Queen's University, Belfast and were conducted in accordance with the Declaration of Helsinki.

Recruitment of chronic stroke survivors was by referral from physiotherapists or through community advertising. Inclusion criteria were (1) >1 year post-stroke; (2) Mini Mental State Test score >26; (3) no contraindications to TMS; (4) FES elicited comfortable hand opening and grasp; (5) some voluntary control of shoulder/elbow movement; (6) no botulinum toxin injections in the affected arm within the previous 6 months; (7) room for improvement (maximum score of 40/57) on the Action Research Arm Test (ARAT) [14]–[16].

B. Workstation: The Rehabilitation Joystick for Arm and Hand Exercise (ReJoyce: Fig. 2)

Participants were provided with a ReJoyce workstation that enabled computer gaming and allowed audio-visual communication with a remote tele-coach. The ReJoyce is a passive workstation comprising a segmented arm that presents the user with a variety of spring-loaded attachments. Each segment and attachment is instrumented with sensors detecting displacement

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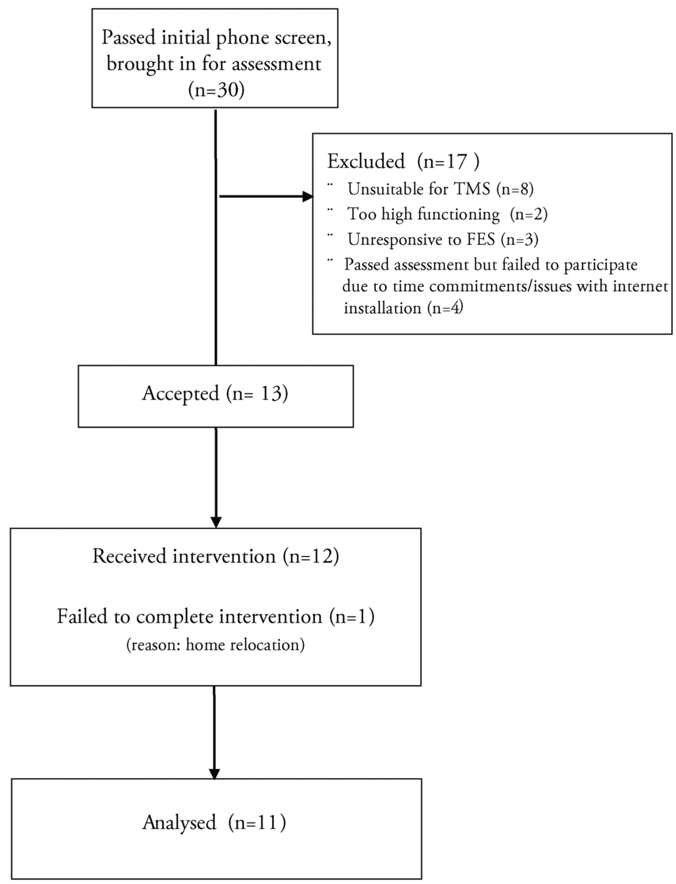
A.



B.

Participant	Age (years)	Home distance from lab (km)	Time post stroke (months)	Male / Female	Stroke type? (H=haemorrhagic, I=Ischemic)	Affected side	Handedness
Sub1	56	42	66	F	I	R	R
Sub2	54	22	21	M	I	R	R
Sub3	57	30	16	M	I	R	R
Sub4	58	205	53	M	H	R	R
Sub5	68	39	20	M	I	L	R
Sub6	59	60	46	M	I	L	R
Sub7	67	42	75	M	I	L	L
Sub8	73	5	54	M	I	R	R
Sub9	56	378	26	M	H	R	R
Sub10	86	52	178	M	I	L	R
Sub11	72	193	13	M	I	R	R
Mean	**64.18**	**97.09**	**51.64**				
St.Dev	**9.96**	**114.55**	**47.03**				

Fig. 1. (A) CONSORT chart of participants; (B) participant demographics and clinical details.

or force. Signals from these sensors enabled participants to play a suite of 9 virtual reality computer games, varying widely in subject matter and in each case with adjustable levels of difficulty. Games ranged from those designed to exercise basic range of motion (ROM) of the UL (by grasping one of the handles of the device and moving it within the 3-D space covering the full physiological range of an able-bodied person), to those involving coordinated movements of multiple joints and fine motor control of the hand and digits (grasp and squeeze, pinch grip, extension, flexion, pronation, and supination). All games involved cognitive effort and included virtual reality activities such as car racing, boxing, pouring drinks, target shooting, and weeding in the garden. Tasks carried out on the device were specifically designed to replicate activities of daily living (i.e., twisting a door knob, gripping a glass/soda can, turning a key, or unscrewing a jar lid) thereby encouraging repetition and practice of functionally relevant movements under the guise of gaming.

All exercise therapy sessions were carried out by participants in their homes, tele-supervised remotely via the internet. The participants were provided with a ReJoyce workstation, laptop and webcam in their own homes. The tele-supervisor also had a laptop and a webcam set up in the laboratory. Both parties could then log on at a pre-arranged time to undertake the exer-

Fig. 2. FES-assisted exercise therapy on the Rejoyce workstation. Top: Tele-coaching and exercise training; Middle: Dexterous tasks performed on the device. Bottom: Screen-shots of hand function test (far left) and examples of computer games available.

cise therapy, 1 h per day, five days per week for six weeks. For these remotely monitored sessions, the tele-supervisor's computer monitor showed a webcam image of the participant as well as the content displayed on the participant's monitor. The tele-supervisor was able to converse with the participant, view their posture and activity (thus ensuring that movements were performed correctly), remotely control the content experienced by the participant and direct the progress of treatment according to ability—by selecting the games, their initial level of difficulty and the combination of tasks required to play them. One example is the task of driving a car by grasping the hand grip attachment and moving it left and right to steer the car. The range of movement of the hand grip required to steer the car on-screen was altered by changing the initial difficulty level, e.g. at a low level of difficulty, moving the hand grip 10 cm resulted in the car turning 45°, whereas at a higher level of difficulty the same movement resulted in only a 20° turn. Similarly for the boxing game, participants moved the hand grip to aim an on-screen fist at an opponent, squeezing and releasing the grip to deliver a punch. Other games required participants to intercept on-screen moving objects such as a tennis ball with an on-screen racket, or adjusting the height of a plane to avoid obstacles. In each case, the speed required at the onset of the game was set by the remote therapist. The difficulty level was then automatically increased in steps by the software upon successful completion of each stage of the game (behavioral shaping) [14].

C. *Functional Electrical Stimulation*

Participants wore a custom-built FES wristlet that delivered trains of electrical stimuli to the extensor and flexor muscles to open and close the hand, used to assist with grasping different attachments on the ReJoyce during exercise training. Stroke subjects were able to easily don the glove themselves and controlled FES with voluntary toothclicks that were detected by a wireless earpiece [15], [16]. This proved unreliable in participant #2, who had dentures and participant #6, whose spectacles caused faulty triggers. These participants controlled FES by tapping the wristlet with their less-affected hand. A 3-axis accelerometer in the device detected these taps.

D. Experimental Schedule

1) Baseline assessments. Participants were assessed pretreatment on tests of motor function and responses to TMS. The baseline data were collected in the laboratory on two occasions (each lasting $\sim$2.5 h), between three and 10 days apart. Means of the two sets of values were calculated.
2) Treatment. All participants performed tele-supervised FES-ET in their homes for 1 h/day, five days/week, for six weeks. Further assessment sessions (lasting $\sim$2.5 h) occurred mid-treatment (after three weeks) and post-treatment (immediately following the six weeks of training).

E. Assessments

Three tests of UL motor function were performed in each assessment session. These were undertaken both with and without the use of the participant's FES device. Motor evoked potentials (MEPs) recorded in the muscles of the affected limb, in response to TMS of the contralateral primary motor cortex provided measures of corticospinal excitability. The participant's subjective assessment of the FES device was also monitored.

1) The Action Research Arm Test (ARAT) [17]–[19]. This clinical test has been shown to have construct validity for ADLs in stroke survivors [20] and is correlated with other UL function tests commonly used in clinical assessments [18], [21], [22].
2) The ReJoyce Arm and Hand Function Test (RAHFT). This is an automated, quantitative test of function that does not require human intervention or judgement. It incorporates a variety of tasks requiring whole-arm ROM in addition to wrist and hand dexterity. It takes about 4 minutes to perform. In a recent study on tetraplegic people, concurrent validity of the RAHFT was demonstrated by virtue of a high degree of correlation with ARAT scores [21]. The RAHFT thus offers a standardized, quantitative outcome evaluation of UL function, comparable to accepted and widely used qualitative tests.
3) Pinch force was measured using a calibrated pinch gauge (0–30lbs, B&L Engineering, Tustin, CA).
4) TMS was carried out pre-, mid-, and post-intervention. Participants were seated in a comfortable chair that provided support for the head, neck, and torso. Forearms were supported and stabilized in a neutral (semi-prone) position with the elbows semi-flexed (100° to 120°). The electromyographic (EMG) activity of 6 UL muscles was recorded from the affected arm using bipolar surface electrodes: abductor pollicis brevis (APB), first dorsal interosseus (FDI), flexor carpi radialis (FCR), extensor carpi radialis longus (ECR), biceps and triceps brachii. EMG signals were amplified, band-pass filtered (30 Hz–1 kHz) and digitized with a 16 bit analogue-to-digital interface at a sampling rate of 4000 Hz.

Magnetic stimuli were delivered by a Magstim 200 stimulator (Magstim, Carmarthenshire), using a 90-mm round coil (maximum field strength 2.0 Tesla) centred at the vertex, inducing posterior-to-anterior current flow across the motor cortex to evoke a short-latency MEP in the muscles of the stroke-affected arm. The coil location over the vertex was used over the motor "hotspot" in order to promote reliability of placement across sessions, compatibility across research sites, and also to reduce the time required to conduct the assessments. Ten magnetic stimuli were delivered in a random order at each of 7 intensities between 30% and 90% of the maximum output of the device. MEP recruitment curves were constructed and compared pre- and post-treatment.

5) The Psychosocial Impact of Assistive Devices (PIADS) [23] was administered mid- and post-intervention to assess usage and acceptance of the FES wristlet. This is a 26-item self-report questionnaire with responses ranging from -3 to $+3$ representing negative/positive impact on measures of participant competence, adaptability and self-esteem.

F. Analyses

One-way repeated measures ANOVA with Bonferroni-corrected pairwise comparisons were used to assess changes in hand function (as measured by the ARAT, RAHFT and pinch force) across the course of the treatment. A p-value below 0.05 was taken to indicate a statistically significant difference between the separate time-points (pre-to-mid and pre-post intervention). Effect sizes (Cohen's f) were calculated.

MEP's elicited when the background EMG exceeded 15 μV in an interval 93 ms to 3 ms prior to the stimulus were excluded. An exception was made in relation to the data derived from participant #7. In this case, as there was a persistently high level of background EMG in the finger muscles, the exclusion threshold was set to 25 μV. For assessment sessions, the area under the recruitment curve (AURC) of each muscle, bounded by magnetic stimulation intensity and MEP amplitude (in units of mV*Tesla), was obtained using the trapezoidal rule. The AURC has construct, face, and concurrent validity and provides a measure of the state of corticospinal projections to hand and forearm muscles [24]. The mean onset latencies of MEPs elicited in each muscle were also calculated.

III. Results

A. Motor Function Tests

Fig. 3 shows that there was a reliable effect of the intervention on the mean ARAT scores; $F_{1.34,13.35} = 5.13$, $p = 0.03$ with FES and $F_{2,20} = 11.96$, $p < 0.01$ without FES. The mean ARAT score after six weeks of FES-ET increased by 8.8% from baseline when the test was performed with FES assistance (p = 0.05, f = 0.36) and by 9.5% when the test was performed without FES ($p = 0.01$, $f = 1.0$).

A similar pattern of outcomes was obtained for RAHFT scores obtained with FES ($F(2,20) = 5.994$, $p = 0.009$) and without ($F(2,20) = 7.26$, $p = 0.004$). Fig. 4 shows that the mean RAHFT score after six weeks of FES-ET increased by 12.1% from baseline when the test was performed with FES ($p = 0.01$, $f = 0.74$) and by 10.5% when the test was performed without FES ($p = 0.04$, $f = 0.8$).

Increases in pinch force were also observed, both when assessed with ($F(2,20) = 8.053$, $p = 0.003$) and without ($F(2,20) = 3.678$, $p = 0.04$) FES. Fig. 5 shows that there was an increase of 9.5N in mean pinch force ($p = 0.01$, $f = 0.86$) with FES and 7.7N ($p = 0.07$, $f = 0.55$) without FES. As with the ARAT and RAHFT scores, the changes in pinch strength

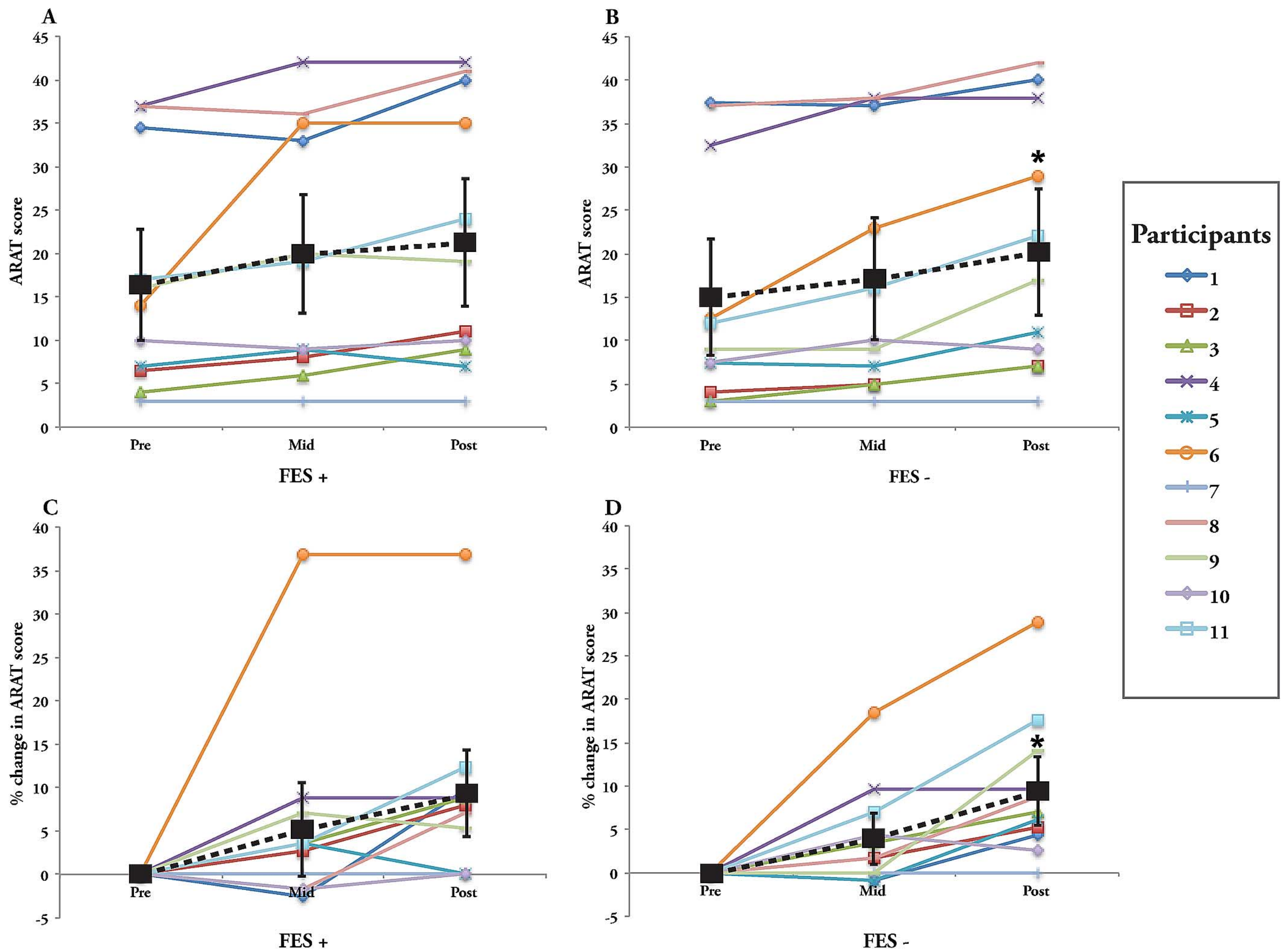


Fig. 3. UL function pre-, mid-, and post-intervention, as measured by the ARAT. Individual scores are plotted, with the group mean (error bars representing 1 S.D.) superimposed in black. Instances of a statistically reliable ($p < 0.05$) difference pre-post intervention are indicated by the symbol ($*$). (A) Mean ARAT scores, pre, mid-, and post-treatment, tested with FES assistance. (B) Mean ARAT scores, pre, mid-, and post-treatment, tested without FES assistance. (C) and (D) Mean percentage changes in ARAT scores in (A) and (B).

were not statistically significant when these were assessed at the mid-point of the intervention (i.e., after three weeks of FES-assisted ET).

B. TMS

Participants were categorized as MEP+ if MEPs with a peak-to-peak amplitude $\geq 50\ \mu$V were elicited from at least 3 of the 6 muscles at baseline. If this criterion was not met, participants were categorized as MEP-. Seven participants were classified as MEP+ (participants 4, 5, 6, 8, 9,10 and 11) and 4 were MEP- (participants 1, 2, 3 and 7). Further analysis was restricted to the data from the MEP+ participants.

Table I summarizes the TMS data. There was no statistically reliable effect of the intervention on the mean AURC recorded for any of the six muscles studied (APB ($F_{2,12} = 0.19$, $p = 0.83$), FDI ($F_{2,12} = 1.52$, $p = 0.26$), FCR ($F_{2,12} = 0.69$, $p = 0.52$), ECR ($F_{2,12} = 1.69$, $p = 0.23$), BB ($F_{2,12} = 0.118$, $p = 0.89$), TB ($F_{2,12} = 0.83$, $p = 0.46$).

MEP onset latencies were similarly unaffected by the intervention (APB ($F_{1.1,6.5} = 0.411$, $p = 0.67$), FDI ($F_{2,12} = 0.04$, $p = 0.97$), FCR ($F_{2,12} = 0.37$, $p = 0.70$), ECR ($F_{2,12} = 0.51$, $p = 0.62$), BB ($F_{2,12} = 2.58$, $p = 0.12$), TB ($F_{2,12} = 0.08$, $p = 0.92$).

C. PIADS

Responses to the PIADS questionnaire revealed that by week six, participants reported a moderate positive impact of the assistive device on measures of competence (+1.01) and adaptability (+1.1). Self-esteem was also reported to have increased slightly (+0.46).

IV. Discussion

In this study, we found that six weeks of daily, tele-supervised FES-ET improved UL function in a small cohort of chronic stroke survivors. This was in line with expectations based on previous studies utilizing FES-ET [12], [25], [26] and with evidence that motor practice that is intensive, repetitive, and which incorporates cognitive effort [27] and elements of skill acquisition [28], [29] can enhance motor function. Mean increases of 9.5% and 10.5% respectively were observed for the ARAT and RAHFT scores (when measured without FES). A change of 10% is often quoted as the minimal clinically important difference [30], but it has recently been argued that for improvements to

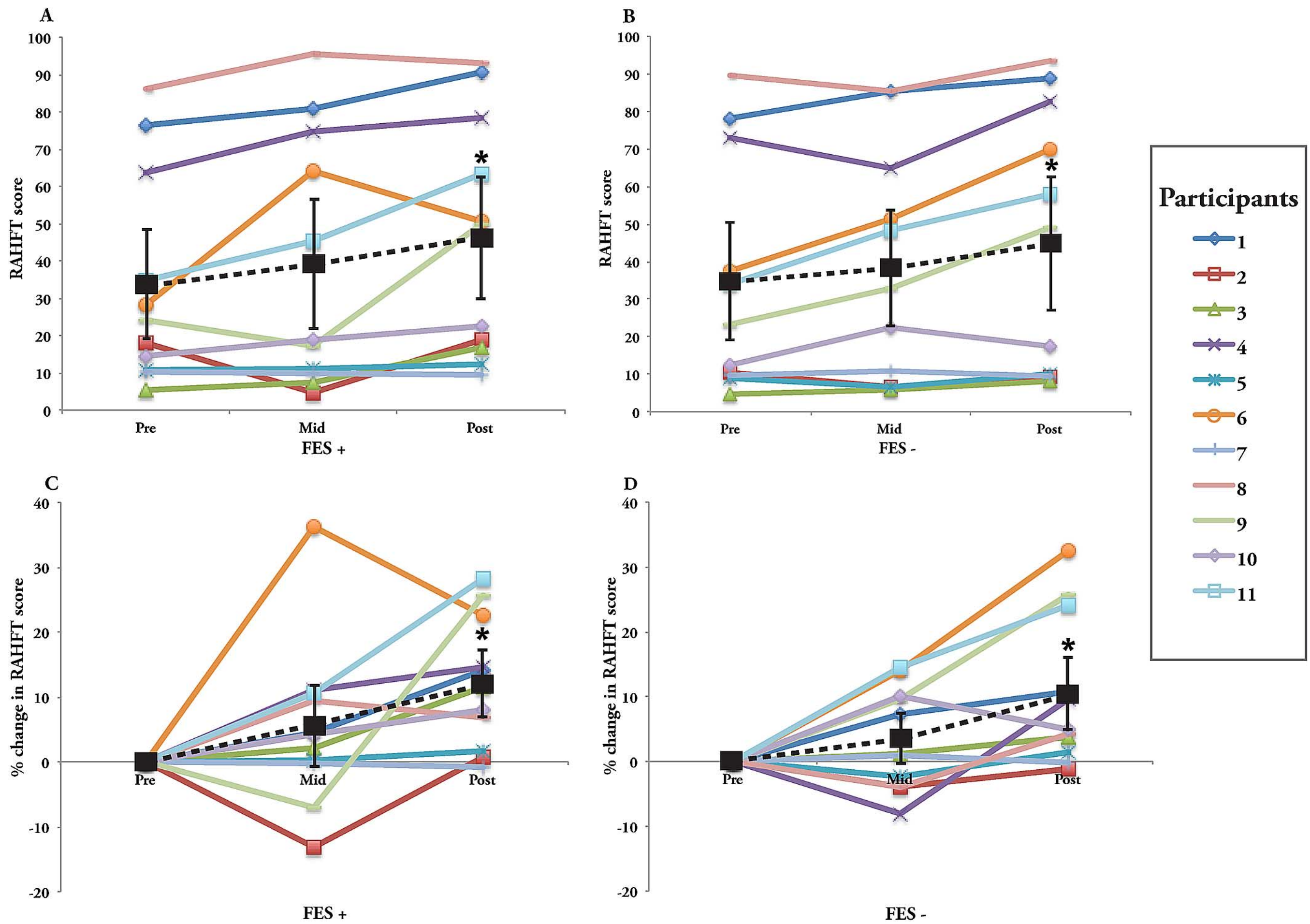


Fig. 4. UL function pre-, mid-, and post-intervention, as measured by the RAHFT. Same format as in Fig. 3.

be considered important to patients or clinicians, much larger changes in the ARAT are needed (21% in the affected dominant arm and 30% in the affected nondominant arm) [31]. Only 3 of our 11 participants came close to achieving such large improvements: participant #6 (29% change in ARAT, 33% in RAHFT, nondominant), participant #11 (18% change in ARAT, 24% in RAHFT, dominant), participant #9 (14% change in ARAT, 25% in RAHFT, dominant). Notably these three participants had ARAT and RAHFT scores between 15% and 40% of full range at baseline, measured in the absence of FES; thus, these individuals could be interpreted as having an intermediate level of hand and arm function at the beginning of the trial. It is reasonably well accepted that low-functioning chronic stroke survivors generally show less improvement than those starting at higher functional levels [31]–[33]. Also, those at the upper end of the ARAT scale have little room for improvement. In some cases, this may be because of a ceiling effect of the test itself: a perfect score can be achieved even when the participant still has a fairly obvious motor deficit compared to normal, age-matched people. In a previous study of FES-ET in chronic tetraplegia we found that participants with intermediate ARAT or RAHFT scores at baseline showed more improvement than those with either low or high baseline scores [34].

In the present study, improvements had not reached statistical significance when measured at three weeks. Six weeks of FES-ET was needed. It is possible that an optimal period, when cost is factored in, may be somewhere between three and six weeks. For example Barker and colleagues [26] found significant improvements in UL function after four weeks of ET in their study of chronic stroke survivors.

Interestingly, the functional improvements we observed were not accompanied by corresponding changes in the amplitude or latency of TMS responses. This is contrary to what we expected, based on previous studies [35]–[38] For example, in a recent report, decreases in MEP latencies were detected in association with improvements in UL range of motion after 12 h of FES-ET performed over a period of four weeks in a cohort of chronic stroke survivors [39]. The participants in that case had nonfunctional hemiplegic arms, with scores on the UL portion of the Motor Assessment Scale ranging from 1 to 3. This indicates that they were probably lower-functioning than all of our participants. Another difference was that TMS was delivered during voluntary contractions, which might have involved the activation of spinal motoneurons by descending pathways other than the corticospinal tract. While TMS is a useful investigative tool, we have found that MEP responses tend to vary from one day to the next, whether in able-bodied people or people with stroke or spinal cord injury. This variability significantly limits the resolution of TMS in detecting small but possibly significant training-related changes in corticospinal excitability.

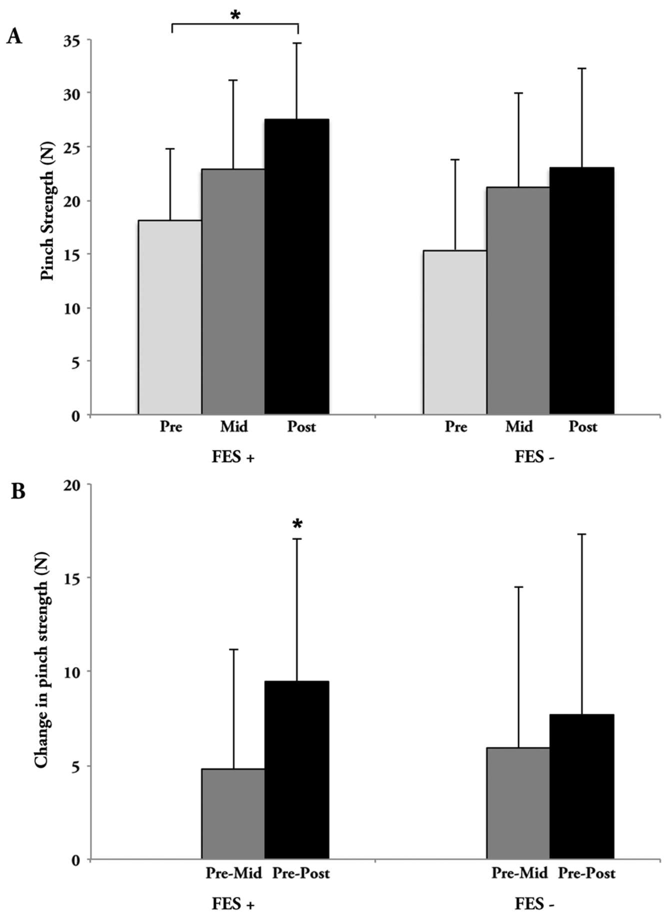


Fig. 5. Bar graphs illustrating pinch grip strength pre-, mid-, and post-intervention. Error bars represent 1 S.D. Statistically reliable $(p < 0.05)$ differences are indicated by the symbol $(*)$. A) mean pinch grip force $(n = 11)$ with (left) and without (right) FES assistance. B) corresponding percentage changes in pinch grip force.

In principle, chronic stroke survivors exhibiting a wide range of functional abilities can use FES-ET. All of the participants—who were of varying levels of functional ability, engaged in the intervention with enthusiasm and reported finding the ReJoyce exercises interesting and challenging to complete. Through online remote monitoring of task success and subsequent modification of the difficulty of the games, the tele-supervisor can continuously drive forward performance. In addition, their online presence gives participants a schedule to adhere to and provided support, direction and reassurance during therapy. Even within this small cohort, however, there were large variations in outcomes. Those who started the treatment with an intermediate level of UL function gained the most, but there may be other predictive factors including lesion size and location, integrity of the corticospinal tract, and genetic profile [40].

The intervention described herein involved several components, each of which might have contributed to the functional improvements that were observed: regular task-related exercise, tele-coaching, motivating computer games and FES. In our study the first three components were linked, in that tele-coaching and the use of computer games ensured that there was adherence to regular task-related exercise. Could electrical neuromuscular stimulation alone produce comparable results, whether used in the context of task-related exercise (functional electrical stimulation: FES) or otherwise (therapeutic electrical stimulation: TES)? This is a difficult question to address, as very few relevant studies are available for comparison. There is certainly some evidence that TES alone can improve hand function after stroke. In an RCT in which sub-acute stroke participants received 1.5 h/day cyclical TES of the wrist extensors over eight weeks—in addition to standard therapy, the TES group showed improvements in the ARAT of 21 points compared to 10 points in the control group, a 19% difference [41]. These outcomes are not, however, directly comparable to our findings, as the participants were at an early stage of recovery. In a more closely related study, chronic stroke participants who received 3–6 h/day of TES (50% cyclical, 50% EMG-triggered) showed a mean 12% improvement in the number of blocks moved in the Box and Block test, and in the time taken to perform some of the tasks in the Jebsen Taylor test [42]–[44]. In another investigation, 77 chronic stroke participants performed home-based FES training two–three times/day, seven days/week for five weeks [45]. The mean number of blocks moved in the Box and Block test increased by 26% post-exercise. This is an impressive increase, given that the exercise regime was self-motivated. These impressive results notwithstanding, they remain an insufficient basis upon which to conclude that cyclical or EMG-triggered TES or FES alone are as effective as the combination explored in the present study. In the aforementioned investigations of chronic stroke survivors, the participants exhibited some capacity for voluntary hand closing and opening at baseline, i.e., they were mildly to moderately impaired. Furthermore, the Box and Block test is more restricted than the ARAT, as it involves the repetition of a single task (grasping, moving and releasing blocks of a single size). The ARAT includes nine tasks ranging from fine manipulation of very small ball bearings to grasping and moving large, heavy objects over a large distance. The RAHFT also includes tasks ranging from small-scale (lifting and releasing a small peg) to large-scale (gripping, moving and releasing the hand-grasp attachment). The question, therefore, remains open as to whether the addition of a computer-gaming workstation and tele-coaching to FES-assisted exercise, results in a level of benefit sufficient to justify the extra expense. This is fertile ground for further investigation.

A. Limitations and Conclusions

Our study was not a randomized controlled clinical trial, so placebo effects occurring as a result of daily interaction with tele-coaches cannot be excluded. The number of participants $(n = 11)$ was too small to draw definitive conclusions; however, the results do support the idea that regular, prolonged FES-ET involving voluntary effort, skill acquisition and cognitive engagement, can significantly improve UL function in chronic stroke survivors, particularly those with intermediate levels of function. Compliance was high throughout, with the participants exhibiting commitment to the high intensity programme of rehabilitation conducted over the six weeks period. We would suggest that it is likely that both the use of daily, online supervision and also the motivating,

TABLE I
TMS RESULTS PRE-, MID-, AND POST-TREATMENT IN EACH OF SIX MUSCLES OF THE MORE AFFECTED UL [ABDUCTOR POLLICIS BREVIS (APB), FIRST DORSAL INTEROSSEUS (FDI), FLEXOR CARPI RADIALIS (FCR), EXTENSOR CARPI RADIALIS LONGUS (ECR), BICEPS AND TRICEPS BRACHII]. EACH CELL SHOWS MEAN + SD OF ONSET LATENCY OF MEP (MOTOR EVOKED POTENTIAL), AURC (AREA UNDER MEP RECRUITMENT CURVE), N (NUMBER OF PARTICIPANTS WITH MEASURABLE MEPS)

Muscle	Variable	Pre	Mid	Post
APB	MEP onset (ms) ± SD	22 ± 5.90	24 ± 2.32	23 ± 5.49
	AURC (mV-Tesla) ± SD	0.57 ± 0.83	0.70 ± 1.01	0.79 ± 1.39
	N participants with MEP's	7 (63.6%)	8 (72.7%)	9 (81.8%)
FDI	MEP onset (ms) ± SD	23 ± 7.55	22 ± 6.56	23 ± 9.40
	AURC (mV-Tesla) ± SD	1.17 ± 2.66	1.04 ± 2.06	1.01 ± 2.21
	N participants with MEP's	7 (63.6%)	7 (63.6%)	8 (72.7%)
FCR	MEP onset (ms) ± SD	17 ± 3.47	16 + 3.77	16 ± 5.28
	AURC (mV-Tesla) ± SD	0.32 ± 0.53	0.44 ± 0.72	0.33 ± 0.56
	N participants with MEP's	7 (63.6%)	8 (72.7%)	8 (72.7%)
ECR	MEP onset (ms) ± SD	17 ± 7.47	16 ± 4.72	18 ± 7.12
	AURC (mV-Tesla) ± SD	0.19 ± 0.34	0.19 ± 0.31	0.16 ± 0.30
	N participants with MEP's	8 (72.7%)	8 (72.7%)	8 (72.7%)
BB	MEP onset (ms) ± SD	16 ± 6.90	16 ± 10.50	21 ± 8.07
	AURC (mV-Tesla) ± SD	0.17 ± 0.38	0.16 ± 0.31	0.09 ± 0.09
	N participants with MEP's	7 (63.6%)	7 (63.6%)	8 (72.7%)
TB	MEP onset (ms) ± SD	13 ± 6.28	12 ± 5.75	12 ± 6.78
	AURC (mV-Tesla) ± SD	0.11 ± 0.15	0.17 ± 0.26	0.26 ± 0.44
	N participants with MEP's	7 (63.6%)	8 (72.7%)	8 (72.7%)

competitive nature of the games made available through this technology makes it possible to deliver intensive, task-oriented repetitive practice that is also enjoyable and encouraging for participants. The study demonstrates that tele-coaching of FES-ET by stroke survivors in their homes can be readily and successfully be performed by nonspecialists using existing, commercially-available devices.

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