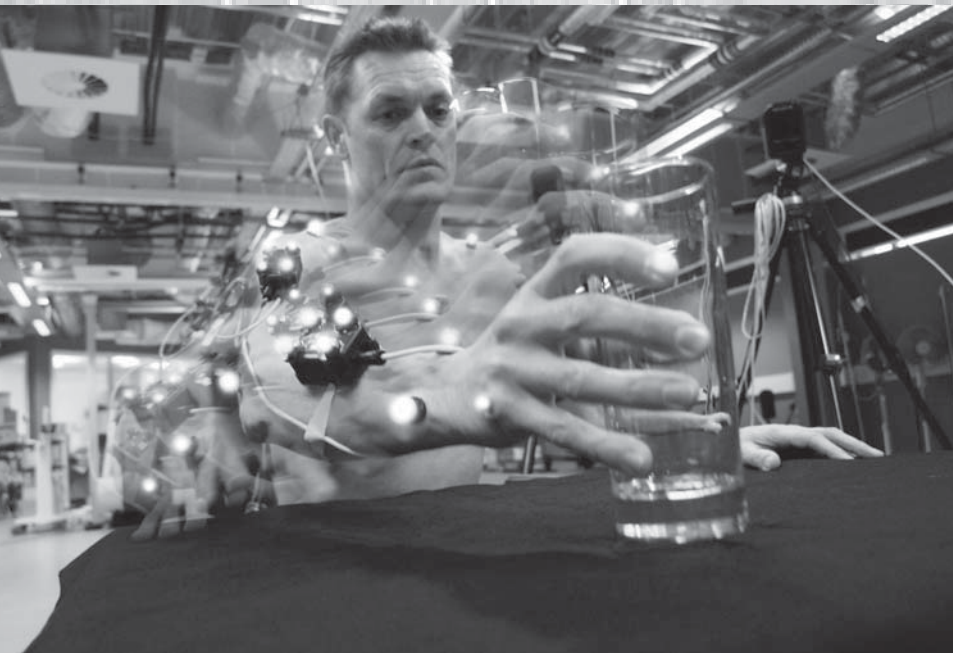


ifes The International Functional
Electrical Stimulation Society

1st Annual Conference of the UK and Republic
of Ireland Chapter of the International Functional
Electrical Stimulation Society

University of Salford, UK,
April 15th-16th, 2010

Proceedings



Welcome to the

**First Annual Conference of the United Kingdom and
Republic of Ireland Chapter of the International
Functional Electrical Stimulation Society**

April 2010
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Foreword

Welcome to the UK and Republic of Ireland Chapter of the International FES Society's first annual scientific meeting.

The aim of UKRI-IFESS is to provide a forum for interchange of ideas and opinions for all who have an interest in use of electrical stimulation in the rehabilitation of people who have medical conditions. UKRI-IFESS is multi-disciplinary and brings together clinical practitioners using FES in the clinic, engineers developing and testing new applications and basic scientists progressing our understanding. We also welcome those who have a commercial interest in bringing FES to a wider health care community and thank them for the support of the meeting.

While this is the first meeting of UKRI-IFESS, it builds on a strong history of interest in the field of FES, following the Special Interest Group meetings on FES by the BES in the 90's and the FESNET meetings in the 00's. I hope that that the society can take up the torch from these groups and continue their work of promoting the field of FES.

Please let us know if you have ideas for how UKRI-IFESS can better achieve its aims. We need your support. I also urge you to become members of IFESS. Membership will enable you to keep up to date with IFESS news and will also give a discount for future UKRI-IFESS meetings. You can find out more about membership at www.ifess.org.

Finally, I would like to thank Laurence Kenney and his team at the University of Salford for putting together such a high quality meeting. I hope you enjoy the meeting and that through shared learning and new contacts we may further the field of FES.



Paul Taylor
President of UKRI-IFESS

Program Overview

Thursday 15th April		Friday 16th April	
08:30	Registration opens	08:30	Registration opens
09:30	Welcome address	09:30	O6: Optimization of Functional Magnetic Stimulation (J Szecsi, University of Munich)
09:45	Workshops	09:50	O7: Human cortical control of a virtual, upper limb, FES system. (E K Chadwick, Case Western Reserve University)
	Workshop 1: Upper limb FES – what degree of functional restoration is possible using surface stimulation? (G Mann, Salisbury NHS Foundation Trust)	10:10	O8: A brain computer interface to improve respiratory function in tetraplegia (A J McLachlan, University of Glasgow)
	Workshop 2: The Benefits of FES in the Treatment of Spinal Cord Injury (J Holmes, North West Spinal Injuries Centre)	10:30	Coffee break
	Workshop 3: FES for Multiple Sclerosis (C Singleton, South Birmingham Community Health Trust)	11:00	Keynote Lecture: The role of neurostimulation and neuroplasticity in the rehabilitation of motor dysfunction after stroke (Dr Shaheen Hamdy, University of Manchester)
11:00	Coffee break	12:00	Poster teaser session (posters 15-29)
11:20	Panel discussion: New clinical applications for FES	12:15	Lunch and poster session
12:00	Poster teaser session 1 (posters 1-14)	13:30	O9: The Metabolic Efficiency of FES Exercise (N Donaldson, University College London)
12:15	Lunch and poster session	13:50	O10: An investigation into the acute effects of electrical muscle stimulation on cardiopulmonary function in a chronic obstructive pulmonary disease patient – a pilot case study. (E A Hennessy, University College Dublin)
13:30	Keynote lecture: Invention without adoption – just an academic exercise? (Margaret Parton, NHS Technology Adoption Hub)	14:10	O11: Effects of Functional Electrical Stimulation (FES) on post-stroke gait under dual task conditions – a pilot study (J McAdam, University of Salford)
14:30	O1: A pilot investigation into the effects of electrical muscle stimulation training on physical fitness in an adult cystic fibrosis population. (L B Holcroft, University College Dublin)	14:30	O12: Electrotactile feedback for trans-femoral amputee gait re-education (G D Webb, University of Surrey)
14:50	O2: The effect of neuromuscular electrical stimulation on congenital talipes equinovarus following correction with the Ponseti method: A pilot study (Y Gelfer, University of Surrey)	14:50	Coffee break
15:10	Coffee break	15:10	O13: Catch-like Stimulation – its Effect on Spinal Reflexes and Muscle Activation (D Hart, Salisbury NHS Foundation Trust)
15:30	O3: SHEFSTIM: A clinical trial of self-tuning array stimulation for foot-drop (M Reeves, Sheffield Teaching Hospitals NHS Foundation Trust)	15:30	O14: A Statistical Approach to Myoelectric Control of FES Cycling. (R Luo, University College London)
15:50	O4: An investigation into the effects of electrical muscle stimulation training in type 2 diabetes mellitus: a case study. (O M Giggins, University College Dublin)	15:50	O15: Higher-Order Sliding Mode Control of FES-Cycling: A Simulation Study (A Farhoud, Iran University of Science and Technology)
16:10	O5: Abdominal FES to support respiration in acute tetraplegia (H Gollee, University of Glasgow)	16:10	O16: The therapeutic benefits of electrically stimulating denervated muscle (S Salmons, University of Liverpool)
16:30	Close	16:30	Close
18:30	Reception at Museum of Science and Industry		
20:15	Evening meal at Akbar's		

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Workshops

Workshop 1: Upper limb FES – What degree of functional restoration is possible using surface stimulation?

Mann GE, Salisbury NHS Foundation Trust

Research over the past 30 years into the use of electrical stimulation for the upper limb following stroke has resulted in a considerable body of evidence supporting its use in reducing impairment such as shoulder subluxation, pain and spasticity and increasing joint range of movement, muscle strength and limb awareness. More recently the focus of both clinical applications and research has been on restoration of function and control mechanisms to facilitate this. There is also currently an emphasis on therapy that will promote neuroplasticity and motor relearning following central nervous system damage.

In this workshop we will look briefly at some of the evidence for recovery of function using both cyclical and 'triggered' stimulation and also for which patients are most likely to benefit. Protocols and guidelines for application of treatment will be presented and discussed. Participants will have the opportunity to work in small groups to set up stimulation to facilitate a functional task on each other. It is hoped that this exercise will generate further discussion concerning the feasibility and potential effectiveness of this treatment as part of a rehabilitation programme.

Workshop 2: The benefits of FES in the treatment of spinal cord injury

Holmes J, North West Spinal Injuries Centre

This workshop is intended to give an overall view of the North West Regional Spinal Injuries Centre at Southport and the work carried out there. How we assess for and use FES in the Occupational Therapy department to treat cervical injuries with limited and reduced function in their upper limbs. Also the benefits and limitations we have found when using FES with our patients.

Initially implemented when the patient presents with a flicker of movement, FES has become an increasingly important part of treatment and later combined with active exercises and practicing functional tasks we find we have good results in improving and increasing patients strength, range of movement and ultimately their functional ability.

Workshop 3: FES for multiple sclerosis

Singleton C, South Birmingham Community Health Trust

The workshop will demonstrate the applications of FES for people with Multiple Sclerosis (PwMS) highlighting its benefits and limitations and the ability to combine FES with other treatment modalities. The views of PwMS on their experience of using FES, particularly the dropped foot stimulators, will be shared. Difficulties in obtaining FES as a treatment modality through the NHS will be explained.

Keynote Lecture: Invention without adoption – Just an academic exercise?

Parton M, NHS Technology Adoption Centre

The UK government and the charities invests over £2bn each year on world leading healthcare research enabling us to develop a much wider understanding on the development of diseases and to develop better solutions and procedures to combat these. This high level of investment will lead to many new and improved drugs, devices and diagnostics being developed. However, only a very small percentage of these innovative solutions will eventually reach a UK patient as the NHS is such a late and slow adopter of innovation(Wanless 2002 and 2007). David Cooksey in his Review of UK health research funding in 2006 calls for a more systematic approach to the adoption of innovation and this was further emphasised by Lord Darzi in the NHS Next Stage Review High Quality Care for all in 2008.

The NHS Technology Adoption Centre (NTAC) was launched in 2007 to work with the NHS in understanding and overcoming the barriers to adoption. It works with a wide range of Trusts across England embedding innovative technologies which have a strong evidence base but limited uptake in the NHS as standard of care. The Guides produced from this work provide a road map for Trusts to follow to de-risk and accelerate the process. NTAC works with national and regional organisations to effect policy changes where there are clear barriers to uptake. Trusts working with NTAC agree to both procure the technology and to make the changes to the patient pathways which will enable the benefits to be realised.

This collaborative working has enabled NTAC to understand more fully the key evidence and information that NHS organisations need in order to make decisions to adopt and implement new technology into the healthcare system.



Margaret Parton
CEO NHS Technology Adoption Centre

Margaret Parton was appointed as Chief Executive Officer of the NHS Technology Adoption Centre in July 2007. This is the first Technology Adoption Centre for the NHS in England and its role is:

- To assist organisations to navigate the complexities of the 'NHS adoption landscape'
- To work with partners to identify those technologies which will provide cost effective improved patient outcomes in the NHS
- To work with NHS Trusts to support the sustainable implementation of new technology as an integral part of service and system solutions, identifying where changes to the pathway or service may be needed to unlock the full benefits of the technology
- To produce detailed NHS focused Guides detailing how the technology can be successfully implemented and the benefits to both patients and organisations that can be achieved

Formally the UKTI Life Science Sector Champion & Programme Manager for the DTI UK/US Bioscience Collaboration, A cardiovascular pharmacologist by background Margaret is an experienced business developer with an excellent track record in defining technology strategy, establishing partnerships & developing international project proposals.

Poster Session 1

Thursday 15th April 2010

12.15 – 13.30

An exploration of patients' beliefs about functional electrical stimulation: an interpretive phenomenological analysis

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1. Introduction

Previous research has focussed mainly on the efficacy of FES in terms of its impact on such factors as: walking speed, gait and physical effort [1,2]. There are only two previous studies of the social/psychological impact of lower limb FES and these were questionnaire based postal surveys [3,4]. While such research is valuable, the questions are set by the clinician and do not invoke the richness and depth of information that can be obtained from qualitative interviews.

2. Aims

In the present study we explore patients' beliefs about functional electrical stimulation (FES), including how and why they perceive it to work and the impact it has on their lives. By obtaining a fuller understanding of patients' beliefs we hope ultimately to help clinicians address issues of poor adherence.

3. Methods

Five participants were interviewed, four had multiple sclerosis and one had spastic paraparesis. All were interviewed after their first six weeks of using the Odstock Dropped Foot Stimulator. Interviews were tape recorded and transcribed. Transcripts were then analysed using interpretative phenomenological analysis (IPA).

4. Results

The main themes that emerged from the data included: the impact of the stimulator on the rest of the person's body and the strategies employed to cope with this; a sense of time being restored; feelings of liberation (including a reduction in physical *and mental* effort); the personal relationship with the stimulator including feelings of reliance on it and the ascribing of human characteristics to it; the societal reaction to the stimulator and concerns about its physical appearance.

5. Discussion and Conclusions

These themes provide clinicians with areas they could consider in future when preparing patients to use the stimulator. Themes also highlight areas for further research and other important areas for outcome measurement such as the reduction in mental/emotional effort afforded by

the stimulator (rather than just the reduction in physical effort).

6. Acknowledgements

The authors wish to thank the patients from the West Midlands Rehabilitation Centre who took part in the study.

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The use of combined muscle stimulation and functional electrical stimulation combined with dynamic elastomeric fabric orthoses in a child with hemiplegic cerebral palsy

Matthews MJA.

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1. Introduction

Most of the evidence and clinical relevance dynamic elastomeric fabric orthoses (DEFO) use in treatment of neurological dysfunction has been restricted to children[1]. DEFO socks have been used in milder presentations of hemiplegia due to the lack of an active dorsiflexion force within the orthosis.

2. Aims

The aim of this single case paper is to identify proof of concept, combining a combination of DEFO and functional electrical stimulation (FES) to provide a dorsiflex assisted change in gait.

3. Methods

The subject (9 year old male) undertook a 3 month period of daily, 30 minute muscle stimulation to tibialis anterior using the Odstock Microstim stimulator (set @20hz alternate format), whilst playing a favourite computer game the child repeatedly walked in a gait laboratory using Quintex video sampling in both coronal and sagittal planes to identify change in gait using five orthotic options. Namely 1) barefoot; 2) with 20° dorsiflex DEFO socks; 3) a combination of DEFO socks, functional foot orthoses (FFO) and footwear; 4) a combination of FES and footwear and 5) a combination of DEFO, footwear, FFO and FES.

4. Results

The paper will present the results in video format explaining the differences between the five walks. The barefoot video shows an atypical diplegic toe walking gait pattern, which is reduced to a hemiplegic toe walking pattern when the dorsiflex DEFO sock is applied to the right foot. A slight change is noted when the combination of FFO and footwear is applied. The application of the FES without the DEFO sock shows a clear heel contact gait although hip retraction is clearly evident. The addition of the DEFO sock initiates a reduced hip retraction and increased step length.

5. Discussion and Conclusions

The use of DEFO socks combined with FES in children with cerebral palsy suggests that there may be another option prior to more invasive techniques in the treatment of dynamic toe walkers. The sock appears to reduce the robotic elements seen when the power and ramping occurs at heel lift. The sock provides continual

pressure to the muscles of the lower limb and could be providing a neurophysiological response and increased proprioceptive feedback. The video appears to show some increased acceleration at swing through which could explain the increased step length. Previous papers using FES in children have discussed positive outcomes[2,3]. This orthotic intervention combined with both muscle strengthening and stimulation would appear to provide an innovative option for retraining of gait in children with cerebral palsy.

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Influence of selective stimulation of quadriceps on joint moments

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1. Introduction

FES cycling for Spinal Cord Injured (SCI) people has been studied for many years [1, 2]. However, the power output and metabolic efficiency of SCI cyclists remains considerably lower than that of able bodied (AB) cyclists [3], even after a long period of muscle training [4]. Three hypotheses for the low efficiency have been suggested [3]:

- 1) Inefficiency of electrical muscle stimulation.
- 2) Inherent SCI factors, e.g. atrophied muscles.
- 3) Biomechanics of FES cycling.

The influence of the first two hypotheses on metabolic efficiency were investigated by performing electrical stimulation (ES) on AB subjects [3, 5, 6]. These studies showed that, although the efficiency of muscle activation during ES is less than during voluntary contractions, AB cyclists have poorer performance than expected during FES cycling. This implies that cycling efficiency is being limited by the biomechanics of FES cycling. Currently all four component muscles of the quadriceps are stimulated, although this causes activation of rectus femoris to produce an unwanted hip flexion when leg extension is required and reduces the net power generated [1].

2. Method

Three positions of surface electrode over the quadriceps were used in an attempt to maximise knee extension while minimising hip flexion. These were:

- 1) *Standard* (current practice) - One pair of electrodes placed diagonally over the thigh and designed to stimulate all component muscles.
- 2) *Rectus* - One pair of electrodes placed centrally over the thigh.

- 3) *Vastii* (medialis and lateralis) - A pair of electrodes placed along both the medial and lateral thigh.

A dynamometer was constructed to measure the hip and knee moments simultaneously. Initial studies are being performed on AB subjects and the most promising electrode positions will be tested on SCI subjects.

3. Results

The Figure shows preliminary results for one subject. Stimulation over rectus clearly shows greater hip flexion than the other two, which, disappointingly, yielded very similar results.

4. Discussion and Conclusions

Current work is further investigating different electrode positions and sizes. MRI T2 scans are being used in an attempt to identify which muscles are being activated with different electrode positions, particularly those that flex the hip (rectus femoris and sartorius) and whether the stimulation also spreads to activate the hamstrings as they oppose knee extension.

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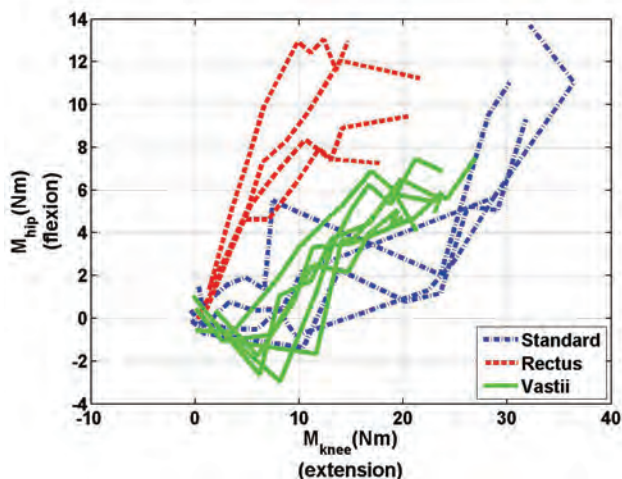


Figure 1: Moment curves measured for a subject

An evaluation of the impact of an Odstock Dropped Foot Stimulator (ODFS) on locomotion and activity patterns in people with MS

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1. Introduction

The Odstock Dropped Foot Stimulator (ODFS) is a single channel, foot switch triggered stimulator designed to elicit dorsiflexion and eversion of the foot[1]. A study[2] was conducted on 139 Multiple Sclerosis (MS) patients using an ODFS for foot drop. The results showed an improvement in walking speed and walking efficiency was noted up to 5 months after provision. In selected patients with MS presenting with footdrop ODFS can assist in improving posture and gait, thus increasing their confidence in participating in activities. To assess the benefits of an ODFS on activity levels for patients and the impact on their perceived health status the MS Team at the Walton Centre conducted the following pilot study. The primary measure was the Stepwatch Activity Monitor[3] (SAM) which is a highly accurate, unobtrusive instrument worn on the ankle which detects and counts steps for a wide variety of gait cycles. It has been shown to have high accuracy, reliability and easy use.

2. Aims

To evaluate the effectiveness of provision of an ODFS to people with MS, in terms of alteration to physical activity; the impact of the ODFS device on overall physical and psychological well-being and whether there is any correlation between the measures.

3. Methods

This longitudinal, waiting list controlled study recruited patients with MS and foot-drop that were referred to the MS FES clinic for assessment. At time of referral, if they consented, they wore the SAM for a continuous 2-week period. Baseline disability level and disability over time were established by EDSS score. Six weeks later, ODFS assessment occurred and if suitable for supply, the SAM was worn for a further 2 week period. After this period they were supplied with their ODFS device in accordance with the normal clinical routine. Patients were then invited to wear the SAM again for 2 week periods at their routine 6 week, and 18 week ODFS follow-up. To evaluate locomotion pre and post supply of the ODFS patients also completed the MSWS-12[4,5] and MSIS-29[6] on 4 occasions, at the same attendance visit as the SAM was fitted.

4. Results

9 completed data sets have been obtained. Analysis will be conducted using the software from the SAM system and the Statistical Package for Social Sciences (SPSS). Statistical advice has been sought regarding appropriate analysis. Analysis of this pilot data will inform power for a full study.

5. Discussion and Conclusions

Results and conclusions will be discussed appropriately.

6. Acknowledgements

Thanks to the Walton Centre and the patients with MS for supporting the study and Cymatech, Seattle, USA for advice on the use of the Stepwatch monitor and data analysis.

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Gathering therapists' views for the design of an advanced FES rehabilitation tool for upper limb therapy after stroke

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1. Introduction

Stroke affects approximately 130,000 people in the UK each year (www.stroke.org.uk/). Of all stroke patients starting rehabilitation with marked impairment of arm function, only around 50% regain useful function [1].

FES to support the user in performing voluntary-controlled, varied and task-focused upper limb exercise is a therapy approach supported by a growing body of evidence [2]. An FES controller to support such an approach would require both task-specific and subject-specific setup. Previous research by our group [3] demonstrated the potential for automating part of the controller setup process, but the resulting software was not appropriate for clinical use and hence further work was required

2. Aims

The aim of the study was to gather information from users that would inform the design of a tool for setting up upper limb FES controllers (FES Rehab Tool).

3. Methods

In order to gain a range of views from potential users of the software tool, invitations to join the advisory group were sent to a number of clinicians from both community and acute stroke settings. The advisory group comprised 11 senior clinicians, 6 physiotherapists & 5 occupational therapists who worked across a range of acute and community settings.

A total of 3 user groups were planned for the first stage of the design. Each user group was facilitated by an experienced academic physiotherapist. Each meeting was videoed and 2 researchers also took field notes during the meetings. These two researchers and the academic facilitating the meetings each separately analysed the data from each meeting.

4. Results

The first user group was aimed at exploring current rehabilitation practice for the upper limb and using this to identify patients who might benefit from the FES Rehab Tool. The second user group aimed to identify relevant FES tasks, FES parameters and practice schedules for patients who might use the system. A range of real life case studies were used to facilitate this process. At the third user group the attendees

were presented with a mock up of the first prototype of the software user interface and invited to comment.

4. Results

Three user groups have been held, but the analysis has yet to be fully completed. However certain themes are emerging.

- An acknowledgement from therapists that patients with more severe deficits might benefit from FES, especially earlier in the rehabilitation process.
- Due to the fast turn over from acute to rehabilitation, or community settings, there was a need for the system to be able to move with the patient.
- The potential for an FES system to provide feedback to patients and clinicians was a recurring theme across all meetings.
- Software that intuitively followed the therapists approach to treatment was essential.
- Adoption of an advanced FES rehab tool would be influenced by numerous factors, however ease of set up, and funding were two of the main drivers.

5. Discussion and Conclusions

Involving clinicians in the design process from the very start has proven to be invaluable during the early stages of the design process. The next series of advisory group meetings will involve patients and will take place in early 2010.

6. Acknowledgements

The authors acknowledge the support of the UK Department of Health NEAT programme (L030) and of the clinicians who generously gave their time to the advisory group meetings.

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Functional Electrical Stimulation in Hereditary Spastic Paraparesis

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1. Introduction

Hereditary spastic paraparesis (SP) is caused by a dying back axonal degeneration affecting the corticospinal tracts and dorsal columns. It leads to weakness, spasticity and stiffness that is greater in the lower limbs. People with SP have difficulties with balance and walking especially over uneven territory and often trip due in part to poor clearance of the foot in swing phase. In recent years functional electrical stimulation (FES), usually of the common peroneal nerve, has been used clinically to mainly improve foot clearance and aid walking ability.

2. Aims

This study measured the change in ankle stiffness and strength and their effects on foot clearance in people with SP. The effect of FES on walking speed; efficiency and kinematics and its' perceived effectiveness was explored

3. Methods

A convenience sample of long term users of FES (>0.5 yrs) was sampled. Isometric ankle dorsiflexion strength and stiffness was measured using a dynamometer (Biodex, USA). Ankle stiffness was measured following slow (5°/s) and fast (60°/s) 5° dorsiflexion ramp and hold stretches when the participant was at rest. Stiffness was defined as:
 $\Delta \text{Torque} / \Delta \text{Position}$

Ankle kinematics while walking was measured using a 3D motion analysis system (CODAmotion); three walking trials were recorded per subject. Results were compared to age, gender and weight matched controls walking at a matched walking speed.

Participants with SP were tested either without any FES (NONE), with bilateral FES to the common peroneal nerve (BIDF) or with their prescribed pattern of stimulation (PRES). The order of testing was randomised between participants. In each condition the walking speed, kinematics and physiological cost index was assessed over 10m (x3 per condition). Additionally, participants were asked to rate the perceived effectiveness of the usual stimulation and degree of discomfort on a visual analogue scale (VAS).

4. Results

Eleven people with SP were assessed (57 ±14.2 yrs mean ±SD; 9 male) and compared to 11 matched controls (56.4 ±8.0 yrs).

Comparison with controls

People with SP had an increase in ankle stiffness when measured at both slow (SP=74.3 ± 8.9 Control 57.4 ± 13.9 Nm/rad) and fast speeds (SP= 120.4 ±16.0 Control= 67.5 ± 19.6Nm/rad). There was a significant reduction in isometric dorsiflexion strength (SP= 0.13 ±0.02 control= 0.58 ±0.5Nm/Kg).

In people with SP the range of ankle dorsiflexion in midswing was more reduced in people with higher passive stiffness in the ankle plantarflexors ($R^2=0.19$) as measured during a slow stretch.

Effect of FES

People with SP had used FES for 2.6 yrs (±1.6). On a 10 point visual analogue scale they rated its' effectiveness as 7.5 (±3 median ± interquartile range) and discomfort as 0 (±1). This indicated a high perception of effectiveness (10 = most effective) and low degree of discomfort (0= no discomfort).

Eight people used BIDF routinely; other stimulation configurations targeted the hip abductor and lumbar extensors and the flexor withdrawal reflex. As a group BIDF resulted in a 7.0° ± 2.1 increase in the range of dorsiflexion in midswing ($P<0.01$). Walking speed increased compared to NONE (23.7 m/min) (ANOVA $P<0.05$) and this was slightly larger with PRES (25.8 m/min) compared to BIDF (25.3 m/min). There was no significant change in the PCI.

5. Discussion and Conclusions

FES may be a useful intervention for people with SP, it is generally well tolerated, can improve foot clearance and lead to a change in walking speed. Future work should explore the effects on community ambulation and utilise a control group of people with SP.

6. Acknowledgements

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Accelerometer Triggered Electrical Stimulation for Recovery of Upper Limb Function in Sub-acute Stroke Patients: A Feasibility Study

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1. Introduction

Electrical stimulation exercise for the upper limb has been shown to reduce impairment in patients following stroke[1,2]. It has been suggested that stimulation triggered on 'demand' combined with relevant task practice may be more effective in promoting recovery of useful everyday function[3]. A pilot study of 15 participants with chronic stroke demonstrated significant training benefits after 12 weeks use of the Odstock 2 channel Programmable Stimulator (O2PS), an accelerometer triggered stimulator used to stimulate forward reach and hand opening[4]. Benefits were maintained 12 weeks after treatment was stopped. Feedback from all participants in this study stated that they would have liked to have been able to use the device much earlier in their rehabilitation. It is also well documented that it is easier to influence motor recovery early in rehabilitation before both 'learned non use' and biomechanical changes occur [5].

2. Aims

This feasibility study aims to investigate whether it is practical to use the O2PS with sub-acute stroke patients prior to devising a randomised controlled pilot study to examine treatment effect.

2.1 Questions to be answered

- How easy is it to recruit patients?
- Are participants able to don and doff the equipment and set up the treatment?
- Are participants able to perform the exercise programme?
- Are the outcome measures appropriate?

3. Methods

The study is a longitudinal case study design with a 6 week treatment period.

6 patients who have had a first stroke between 1 and 6 months prior to the study and who fit the selection criteria are to be recruited. Surface stimulation will be applied to the shoulder flexors, and elbow, wrist and finger extensors to assist reaching and hand opening. Participants will also be given a functional task exercise programme to follow with and without stimulation.

Participants will use exercise stimulation only for the first 2 weeks. The trigger will then be set up enabling them to use stimulation to assist in activities of daily living (ADL).

Outcome measures include the Action Research Arm Test (ARAT), visual analogue scale (VAS) for pain and the Modified Ashworth Scale (MAS) for spasticity. An activity logger will monitor compliance and a Use of Device Questionnaire (UDQ), administered to gain participant feedback.

4. Results

Three patients have so far been recruited and have completed 5 weeks of the 6 week treatment period. It is hoped that a further 3 will be recruited and full results presented.

5. Discussion and Conclusions

6. Acknowledgements

The authors wish to acknowledge a grant from the Wessex Rehabilitation Foundation which has supported this work.

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The effects of electrical muscle stimulation training in a chronic obstructive pulmonary disease population – a pilot study.

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1. Introduction

Exercise training is currently advocated as a therapeutic modality for improving the systemic manifestations of chronic obstructive pulmonary disease (COPD) -including peripheral muscle dysfunction, decreased exercise tolerance, weight loss, depletion of muscle mass and muscle strength and poor health status. Owing to a limited cardiopulmonary reserve, COPD patients are frequently physically unable to tolerate sufficient training intensities which would afford them with the benefits associated with conventional exercise training interventions [1]. Electrical muscle stimulation (EMS) appears to have a limited demand on ventilatory requirements and dyspnoea, and may be a promising exercise training alternative for patients with COPD [1, 2].

2. Aims

To evaluate the effects of a 6 week EMS training intervention on peripheral muscle strength, exercise capacity, pulmonary function and health status in a COPD population.

3. Methods

5 participants (2 males, 3 females, Age: 56.40 ± 4.62 years, Height: 1.61 ± 0.06 metres (m), Weight: 65.80 ± 11.05 kilograms (kg), Body Mass Index: 25.43 ± 3.43 kg/m²), with a clinical diagnosis of mild-moderate COPD were recruited from a local hospital outpatient database. Exercise Capacity was assessed using a 6-minute walk distance test. Maximal isokinetic strength of the dominant lower limb was assessed using a dynamometer (Biodex, New York, USA). A subjective feedback questionnaire was completed post intervention. A specially designed hand-held muscle stimulator (NT2010, BioMedical Research Research Ltd, Galway, Ireland) was used to administer the EMS intervention. Participants were required to train 5 days per week for 6 weeks using a 30 minute aerobic parameter (stimulation frequency 3 Hertz (Hz)) and a 30 minute strength parameter (19 Hz), with voluntary leg extension for 50% of the strength protocol. Electrodes were placed bilaterally over the proximal and distal hamstring and quadriceps muscles.

4. Results

4 participants' completed the study, with 1 withdrawal owing to an unrelated injury. Subjectively, all 4 participants reported that they "felt fitter" post training, found "daily tasks easier to perform", with "decreased dyspnoea" during same and found the EMS modality to be a "highly acceptable" training method. Participants' quadriceps and hamstrings peak torque improved an average of 4.30 % and 13.71 % respectively. 6 minute walk distance tests increased on average 13.65 %.

5. Discussion and Conclusions.

Initial studies of EMS and COPD have suggested that this intervention may be most effective in those severely affected by the disease [1, 2]. This pilot study indicates that our EMS modality may also elicit benefits among a broader spectrum of the populations, including those with mild-moderate symptoms. Improvements were observed in peripheral muscle strength, exercise tolerance and health related quality of life. Future studies investigating the effects of our EMS modality on more severe COPD cases as an alternative or adjunct to traditional pulmonary rehabilitation techniques are required.

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The physiological effects of low-level electrical muscle stimulation on short-term recovery from supra-maximal exercise bouts – A case study.

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1. Introduction

Inadequate recovery from short-term, high-intensity bouts of exercise can be a limiting factor to optimal sporting performance [1]. Previous research investigating recovery from intense exercise using various intervention protocols (e.g., active recovery, massage, cold and contrast water therapy, compression suits etc.) have generally found positive results when compared to passive recovery [2,3]. A recent study utilised electrical muscle stimulation (EMS) as an intervention for short-term recovery (< 1 hr) between bouts of intense exercise [4]. They concluded that EMS shows promise as an alternate recovery treatment for lowering blood lactate when compared to passive recovery.

2. Aims

To determine the acute effects of EMS on lactate clearance and performance parameters during supramaximal cycle exercise.

3. Methods

A 33 year old healthy trained male (Height: 1.93 metres; Weight: 102.5 kilograms) volunteered to participate in this case study, which consisted of Wingate exercise sessions (6 bouts) on a cycle ergometer (Lode Sport Excalibur: Netherlands) undertaken on three separate days. Each session consisted of 3 x 15 seconds(s) Wingates (bouts 1-3) interspersed by 2 minutes (min) active cycling recovery at 80 revolutions per min ($\text{rev}\cdot\text{min}^{-1}$). This was immediately followed by 30 min recovery which included a 20 min randomly assigned intervention of either: 1) passive (seated), 2) active (cycling: 80W @ $80\text{ rev}\cdot\text{min}^{-1}$) or 3) EMS (low intensity) intervention. The 3 x 15s bouts were then repeated (bouts 4-6) and compared to bouts 1-3 for peak power output (PPO), mean power output (MP) and fatigue index (FI). Blood lactate (BLa) was taken at various time points throughout the recovery (0, 5, 10, 15, 20, and 30 min post exercise). Heart rate (HR) was recorded continuously at 5s intervals.

4. Results

BLa decreased at a faster rate for the active recovery intervention compared to the EMS and passive interventions (Fig. 1). MP increased for all the post exercise bouts (4-6) compared to the pre (1-3) for the EMS intervention, which was not the case for both the passive and active recovery interventions which in most cases were decreased (Fig. 2). PPO increased for both the

EMS and active interventions across all 3 bouts but decreased for the passive intervention across all three bouts. FI tended to be similar across all three interventions (data not shown).

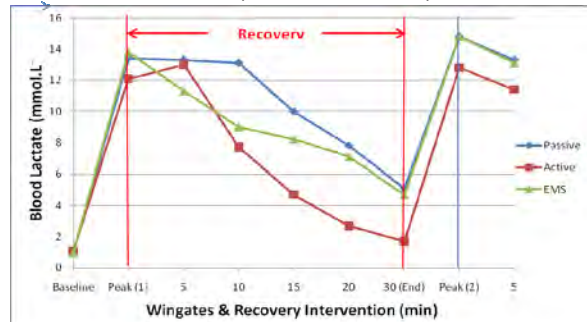


Figure 1: Blood lactate profiles during the three recovery interventions.

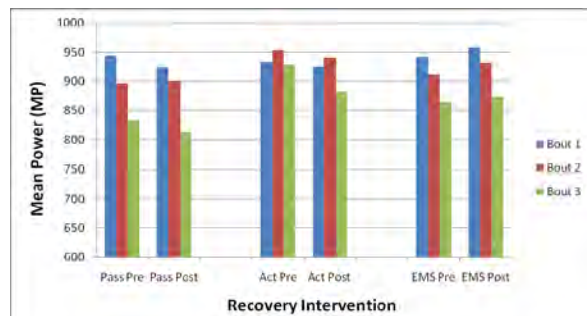


Figure 2: Mean power output comparisons between bouts across the three recovery interventions.

5. Discussion and Conclusions

This case study showed that EMS was more effective as a recovery intervention for maintaining MP between bouts of supra maximal cycle exercise than for both active and passive recovery. This is despite the fact that BLa was cleared at a faster rate during the active recovery intervention. This is an interesting finding which also lends support to the recent shift in scientific attitudes regarding lactate and its role as a major cause of muscle fatigue [1].

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Acute physiological responses to electrical muscle stimulation of a spinal cord injured man – a case study.

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1. Introduction

Cardiovascular (CV) disease is a leading cause of death in populations with Spinal Cord Injury (SCI) and is contributed to by a lack of opportunities to engage in physical activity as well as limited motor function [1]. Functional Electrical Stimulation (FES) has been suggested as a novel CV training tool to alleviate this problem associated with SCI by increasing peak oxygen consumption (VO_2) and heart rate (HR) [2]. However the use of FES is limited by its effect on muscle fatigue as well as the need for specialist equipment and training. Our research group have devised an electrical muscle stimulation (EMS) training device which has improved CV health in obese and chronic heart failure populations [3], whose symptoms are akin to those of SCI patients with CV symptoms. These results warrant further investigation into this system's effects on the CV health of people with SCI.

2. Aims

To determine the acute effect EMS has on VO_2 and HR in a study participant with SCI.

3. Methods

A 36 year old male (Height: 1.95 metres (m), Weight: 95.6 kilograms (kg), Body Mass Index: 20.50 kg/m^2) who had sustained an incomplete T12-L2 SCI two years previous volunteered to participate in this study. Resting HR (RHR) was initially recorded. A specially designed hand held muscle stimulator (NT2010, BioMedical Research Ltd, Galway, Ireland) was used to produce rapid rhythmical contractions bilaterally in the quadriceps and hamstrings muscles. A familiarisation session was undertaken to ascertain the participant's maximal tolerable intensity at a frequency of 5 Hertz (Hz). Following a rest period to return to RHR levels, VO_2 (Quark, Cosmed, Italy) and HR were measured under two consecutive conditions:

(1) Sitting quietly with EMS at intensity 0 milliamperes (mA) for 5 minutes to establish steady state resting values (stage 1).

(2) Sitting for 7 stages lasting 3 minutes each with EMS applied incrementally per stage. The second stage began with an EMS intensity at 40% of the subject's maximum tolerable intensity (20 mA) and was increased equally over the

following 6 stages to 100% of maximal tolerable intensity (162 mA) (stages 2-8).

4. Results

Comparing the average results from the last minute of stage 1 with the last minute of stage 8, EMS elicited increases in VO_2 and HR (Figure 1 and 2).

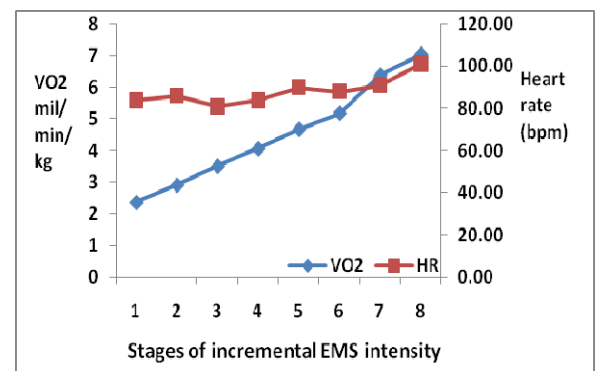


Figure 1: VO_2 and HR during incremental intensity levels of EMS.

5. Discussion and Conclusions

This case study demonstrates that using low frequency EMS is comparable with moderate intensity aerobic exercise activity. A metabolic equivalent (MET) increase of 2.95 of resting VO_2 was observed at maximal tolerable intensity. Increases in HR were also observed. These results present preliminary evidence for the potential use of this type of EMS as a CV training tool for individuals with SCI. Studies with larger participant numbers and intervention periods are required to investigate this further.

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The effects of an electrical muscle stimulation training intervention on physiological measures in a spinal cord injury male.

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1. Introduction

Participation in aerobic exercise activity is considered necessary for individuals with spinal cord injury (SCI) to reduce the potential development of common co-morbidities associated with SCI such as cardiovascular (CV) disease, reduced bone mineral density (BMD), increases in body fat and decreases in lean body mass [1]. Functional Electrical Stimulation (FES) has been advocated as offering a feasible exercise regime to SCI individuals. FES studies have reported improvements in BMD, CV fitness, body composition (BC) and quality of life (QOL) [1], however its application is limited by its effect on muscle fatigue, as well as the need for specialist equipment and training. Recently, researchers have developed a new type of electrical muscle stimulation (EMS) system, which appears to overcome the above issues. This system has improved heart rate (HR) and peak muscle oxygen consumption (VO₂) within Chronic Heart Failure (CHF) patients [2], obese and sedentary adults [3,4]. An SCI population may benefit from a similar intervention and justifies further research into the effects this EMS system may have on SCI.

2. Aims

To assess the effects a 6-week EMS training intervention has on VO₂, HR, BMD and BC in a male with an SCI.

3. Methods

One 40 year old male, (height: 179.8 centimetres, weight: 83.3 kilograms, SCI level: T6 incomplete, 5 years post injury), volunteered to participate in the study. The participant undertook a familiarisation session whereby he learnt how to apply the system. Electrodes were applied bilaterally to the proximal and distal quadriceps and hamstrings. A specially designed hand held EMS stimulator (NT2010, BioMedical Research Ltd, Galway, Ireland) producing rapid rhythmical contractions frequency of 5 Hertz was used to deliver EMS. The participant underwent pre and post intervention testing of peak oxygen consumption (VO₂), (Quark, Cosmed, Italy) and HR (Polar, Finland) whilst propelling his wheelchair on a treadmill at incremental speeds. BC and BMD were also evaluated by dual energy X-ray absorptiometry (DEXA). The participant trained at home with the EMS system for one hour 5 times a

week for 6 weeks at his maximum tolerable EMS intensity (130 mA) in his position of choice (long sitting).

4. Results

	Pre	Post
Peak VO₂ (ml/min/kg)	16.88	27.94
Peak HR (bpm)	161	173
Max propulsion speed (km/hr)	7.3	7.8
Duration of exercise (min:sec)	15:08	16:30

Figure 1: Differences in peak VO₂, HR, maximum propulsion speed and duration of exercise pre and post intervention.

	BMD	BMI	Total Body Fat%	Total Body Fat (kg)	Total lean tissue (kg)
Pre	1.20	24.7	28.6	23.96	56.83
Post	1.28	24.7	27.7	23.07	57.26

Figure 2: Differences in BMD, BMI, total % body fat and total lean body tissue pre and post.

5. Discussion and Conclusions

These results illustrate that training with EMS can lead to gains in peak VO₂ and ability to exercise at higher intensities for longer durations suggesting that it can improve the physical fitness of an individual with SCI. Additionally, the increase of total lean tissue and decrease in total body fat further emphasise the positive effects this type of EMS can have for people with SCI. Collectively, our results provide us with evidence that EMS could provide people with SCI a valuable exercise regime which could reduce the risk of developing secondary health complications.

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Electrical stimulation-Induced Gluteal and Hamstring Muscle Activation Can Reduce Sitting Pressure In individuals With Spinal Cord Injury.

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1. Introduction

Pressure ulcers (PU's) are a common problem for individuals with spinal cord injury (SCI), resulting in great discomfort and significant medical care costs. They are at increased risk for pressure sores due to factors such as reduced mobility, reduced microcirculation, impaired sympathetic function, muscle atrophy, and impaired sensation. Although special cushioning systems can better disperse seating pressures and thus reduce the risk of pressure sores, not all sores are prevented.

2. Aims

To evaluate the effect of ES-induced activation of the gluteal and hamstring muscles on the sitting pressure in individuals with SCI.

3. Methods

Pressure under the buttocks was measured in ten men with SCI (41 ±13 yrs; lesion C5-T11), who received ES (50Hz, 70mA) in their own daily-use wheelchair while sitting. They wore custom-made lycra shorts with electrodes over the gluteal and hamstring muscles. Two protocols were randomly applied consisting of 3 min of stimulation followed by a 17 min rest. Protocol A 1s:1s and protocol B a 1s:4s on-off duty cycle. Peak pressure under the buttocks and pressure gradient were calculated during rest and every hour while stimulating.

Figure 1: *Electrical Stimulation using Lycra Bioshort with embedded electrodes on hamstring and gluteal muscles.*



4. Results

For both protocols peak pressure decreased significantly during the 3-hr stimulation periods. The pressure gradient tended to decrease indicating an improved pressure distribution. Protocol B showed superior effects in general. For both protocols, the pressure reductions did not change significantly, indicating there was no considerable muscle fatigue.



Figure 2: *Interface pressure of sitting SCI individuals without and with ES of the hamstring and gluteal muscles.*

5. Discussion and Conclusions

ES-induced activation of the gluteal and hamstring muscles in SCI decreases peak and mean interface pressure and improves pressure distribution. Because stimulation did not result in muscle fatigue, this method may be used during daily life. The reduced sitting pressure during ES may reduce risk of pressure ulcers in SCI-individuals. Further studies have to eliminate which pressure reduction decreases the incidence of PU's in SCI.

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Cardiovascular Effects of FES Assisted Leg Cycling versus Passive Leg Cycling in Sub-Acute Spinal Cord Injury

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1. Introduction

FES cycling has been investigated in people with chronic SCI and has shown to be a modality to increase cardiovascular training [1&2]. This had not been investigated in people in the earlier stages of deconditioning post SCI. This study is a preliminary investigation in the cardiovascular responses of a sub acute, untrained, SCI population to FES cycling compared to passive leg cycling.

2. Aims

To investigate the changes in heart rate (HR) and oxygen consumption (VO₂) during FES assisted cycling on a leg cycle ergometer (FES-LCE) and passive cycling on a leg cycle ergometer (P-LCE) A secondary aim was to investigate the relationship between HR and VO₂ changes during FES-LCE

3. Methods

6 subjects with complete motor Spinal Cord Injury (C7-T8, ASIA A-B) injured less than 6 months, completed 10 minute exercise interventions under 2 conditions: passive cycling and FES assisted leg cycling. Breath by breath analysis and HR monitoring was carried out 5 minutes before, and throughout the exercise period.

A mean of the last 3 minutes of the rest period under both conditions was used for analysis of resting values. The last 8 minutes of the exercise period were used to analyse exercising values. HR, VO₂, respiratory rate (RR) and tidal volume (TV) were analysed.

4. Results

VO₂ was significantly higher with FES cycling than rest or passive cycling. There was no significant difference in HR and no correlation between HR and VO₂.

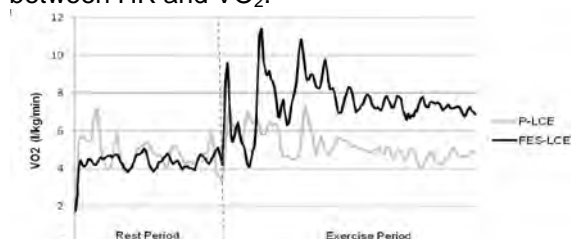


Figure 1: An example of VO₂ for one subject across P-LCE and FES-LCE conditions

Table 1: Cardiorespiratory Responses

	Rest	P-LCE	FES-LCE
HR (bpm)	80.1 ± 10.6	79.9 ± 14.2	78.0 ± 13.1
VO ₂ (l/min)	0.320 ± 0.036	0.360 ± 0.048*	0.424 ± 0.031*†
VO ₂ (ml/kg/min)	4.506 ± 0.590	5.105 ± 1.146	6.048 ± 1.219*†
RR (bpm)	17.0 ± 2.3	19.4 ± 2.4	19.6 ± 2.3
TV (l)	0.575 ± 0.040	0.595 ± 0.083	0.704 ± 0.079

* Denotes a significant difference from rest $p \leq 0.05$

† Denotes a significant difference from P-LCE $p \leq 0.05$

5. Discussion and Conclusions

FES cycling increases VO₂ in sub-acute SCI subjects over an acute exercise intervention, without any pre-training, but chronic training effects are yet to be investigated.

6. Acknowledgements

The staff at the Physiotherapy Department at QENSUI, Glasgow, and Lindsay P Jack, from the department of Medical Engineering at Glasgow University.

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Adaptation to the FES in healthy subject during treadmill walking: foot pressure distribution

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1. Introduction

It is well known that locomotion adapts well to the sensory environment. For instance, changing body weight support resulted in significant changes of kinetic parameters (contact forces and EMG), but in limited changes of global kinematic coordination [1]. Motor relearning during FES-assisted gait is not clear yet. Here we address the issue of the changes of load-related contact forces at the ground in the process of FES-assisted treadmill walking.

2. Aims

Purpose of this study was to identify the influence of FES on plantar pressure variables in healthy adults and the time course of plantar pressure adaptation to 30 minutes of FES.

3. Methods

8 normal subjects between 25 and 49 years of age participated in the experiment. They walked on the treadmill with 3,7 km/h speed. FES was applied to tibialis anterior, medial gastrocnemius, quadriceps and biceps femoris muscles of both legs. Every 10 minutes the intensity of stimulation was increased. Tekscan software was used to quantify regional difference in pressure experienced across the sole of the foot during 3 min of walking before FES started (BEFORE), 3 times during 30 min walking with FES (STIM1, STIM2, STIM3) and 3 minutes afterwards (AFTER). The foot print was divided into five sub-sections: medial heel, lateral heel, midfoot, medial forefoot and lateral forefoot [2]. Mean peak forces and center of pressure (COP) trajectory were identified as the average of maximum force and COP calculated over the series of about 140 steps during 3 minutes of data collection and this value was obtained for each gait cycle using Matlab custom design software.

4. Results

Along the foot regions FES resulted in a significant decrease of mean peak force in medial forefoot ($p < 0.05$) from $0.51 \pm 0.21\%$ of body weight (BW) (BEFORE) to 0.42 ± 0.21 (STIM3) and to 0.41 ± 0.22 (AFTER) and the tendency to decrease of the mean peak force in lateral heel from 0.38 ± 0.13 BEFORE to 0.34 ± 0.16 AFTER. At the end of 30 min of FES assisted walking the trajectory of COP along foot decreased its length

(up to $93.2 \pm 7.7\%$) and width (up to 87 % of this value BEFORE). 3 minutes after the end of FES the trajectory of COP remained decrease up to $92.6 \pm 8.1\%$ of its value BEFORE. The normalized stance and double stance phases of gait increased during FES and come to the norm afterwards.

5. Discussion and Conclusions

During FES the natural foot roll is disturbed. One of the reasons for this could be the excessive stimulation of tibialis anterior muscle at the beginning and the end of stance phase. COP trajectory change accompanied by stance support time increase. This global gait parameter returned to the norm after the end of FES, but pressure distribution along the foot did not. It could be supposed that ground contact forces during FES were changed in order to prevent the deviation of lower limb kinematics [3].

6. Acknowledgements

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Presentation Session 1

Thursday 15th April 2010

14.30 – 16.30

A pilot investigation into the effects of electrical muscle stimulation training on physical fitness in an adult cystic fibrosis population.

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1. Introduction

Cystic Fibrosis (CF) is the most common life-limiting genetic disease in Caucasians. [1] Progressive respiratory and gastro intestinal disease are the predominant clinical manifestations of the disease. As a consequence of general de-conditioning, skeletal muscle weakness and exercise intolerance is prevalent among patients with CF. [2] Although higher levels of fitness have been associated with better quality of wellbeing and eight-year survival, training among individuals with CF is limited due to fatigue, hypoxemia and dyspnoea. [3] Electrical muscle stimulation (EMS) has demonstrated improvements in muscle strength, exercise tolerance and aerobic capacity in chronic cardio respiratory disease populations, while having minimal impact on heart rate (HR) and oxygen saturation levels. [4,5]

2. Aims

To investigate the effects of a 6-week EMS training program on physical fitness in a CF population.

3. Methods

12 participants (10 males (M) and 2 females (F)), undertook a 6 week EMS training program using a specially designed stimulator (NT2010, Biomedical Research Ltd, Galway, Ireland). Training consisted of EMS of the major leg muscles for a minimum of 1 hour per day at home five days a week. The training parameters used were designed to deliver 30 minutes of aerobic training and 30 minutes of strength training. The training effect was evaluated by means of a modified shuttle walk test (MST), body mass index (BMI), spirometry and isokinetic measurement of concentric quadriceps (Q) and hamstring (H) strength. Assessment was carried out at baseline, midway (3 weeks) and on completion of the training program (6 weeks). Descriptive statistics were used to analyse data.

4. Results

6 (Age: 28.83 ± 5.12, BMI: 21.68 ± 2.49 M/F: 5/1) participants completed the study with 6 participants withdrawing owing to pulmonary exacerbation unrelated to the training. Full results are detailed below (Table 1).

Table 1: Mean Values

	Baseline	3 Weeks	6 Weeks
MST (m)	968.33 ± 265.7	1015.0 ± 267.5	1015.0 ± 299.78
Q Peak Torque (Nm iso)	142.62 ± 64.69	152.42 ± 67.05	148.03 ± 51.96
H Peak Torque (Nm iso)	64.45 ± 30.52	72.37 ± 29.25	74.83 ± 32.14
FEV₁ (%)	46.00 ± 29.13	No data	46.67 ± 28.42

M – metres, Nm iso – Newton metres isokinetic
% - percent predicted

5. Discussion and Conclusions

This is the first study to investigate the effects of EMS training in a CF population. Our results demonstrate an improvement in MST and lower limb strength measures following a 6 week intervention and suggest that EMS may be used as a method to improve physical fitness and function in this patient group. The lack of significant increases following the midway test session suggests that participants may have adapted to the training program and indicates that parameters may need to be altered at this stage to produce a further training response.

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The effect of neuromuscular electrical stimulation on congenital talipes equinovarus following correction with the Ponseti method: A pilot study

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1. Introduction

Congenital Talipes Equino Varus (CTEV) is the commonest congenital orthopaedic condition with an incidence of 1.5 per 1000. The current approach to treatment is non operative. Two main methods are utilised; the Ponseti [1] and the French functional method [2]. Satisfactory initial correction is reported following both, however maintenance of correction is noted to be challenging. The Ponseti approach employs use of a foot abduction brace for several years after initial correction. Maintenance of correction is directly correlated with compliance with the brace. Compliance is variable, with reports ranging from 50 to 100%. The French functional method aims to maintain the foot position by attempting to strengthen the foot evertors through manual stimulation

Clubfoot is a complex condition with the deforming forces continuing their action after passive correction is achieved. The current method of treating relapse or residual CTEV due to muscle imbalance is tibialis anterior muscle transfer after walking age.

Neuromuscular stimulation (NMES) has been used therapeutically to improve muscle strength and improve range of motion (ROM) [3]. It is possible that this dynamic intervention, which can be given at an early stage, may be an effective addition to the current treatments addressing muscle imbalance associated with clubfoot.

2. Aims

The aim of this study was to investigate the feasibility of using NMES in infants with club foot, and to give preliminary data on its potential to increase or maintain ROM and facilitate evertor muscle activity.

3. Methods

An ABA study design was used, with six week phases, (A-stimulation, B-no stimulation, A-stimulation). Data was collected from a study group of eight feet and matched controls. Evertor muscle activity, Pirani score and ankle ROM were assessed at the beginning and end of each phase. Usage and parents perspective were assessed using a questionnaire.

4. Results

There was a significant improvement in range of passive ankle dorsiflexion knee flexed and

extended, and a non significant trend towards increase in calf muscle bulk in the study group only, associated with the stimulation phases. Qualitative grading of evertor muscle activity following stimulation showed an improvement in the one foot in the study group where activity was absent and no deterioration of activity in the others. There was no improvement in the initial absent activity in the one foot in the control group and deterioration in activity was noted in a second foot in this group. Two feet were non compliant with the foot abduction brace (one in each group); the non stimulated foot relapsed with a 2 point increase in the Pirani score, the stimulated foot did not relapse. Parents were positive about the NMES intervention and there were no compliance issues.

5. Discussion and Conclusions

This pilot study suggests that it is feasible to use electrical stimulation in infants with club foot, and has given preliminary data on its potential to increase or maintain ROM and facilitate evertor muscle activity. Although further work is required, results indicate that NMES could be a useful adjunct to treatment in preventing recurrence of deformity in CTEV.

6. Acknowledgements

This study was funded by Cerebra - Foundation for Brain Injured Children and Young People.

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SHEFSTIM: A clinical trial of self-tuning array stimulation for foot-drop

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1. Introduction

Difficulty in locating the correct electrode site is the principal reason (after improvement in mobility) for discontinuing FES use [1]. Array stimulators have been proposed as a solution to this problem by several groups [2,3,4]. The principle of operation is that the electrode array is sufficiently large to guarantee coverage of the target neural tissue; one or more electrodes are energised while the response of the limb is monitored and the optimal electrodes are found through an appropriate search strategy.

2. Aims

Such systems have previously been demonstrated using manual electrode searching; but, to the authors' knowledge, have not used a fully-automated electrode search strategy nor subsequently evaluated patients' walking with an autonomous (standalone) FES system.

3. Methods

A self-contained 64 channel programmable stimulator was developed (see Heller *et al.* elsewhere in these proceedings); 4x4 groups of 8 mm square electrodes were combined to form each 'virtual electrode'. The 3-stage search algorithm consisted of a rapid motor threshold search, followed by a thorough search for suitable candidate electrodes based on twitch response, followed by selection of the optimal electrode with a cost function based on the results of ramped stimulation. Foot and shank movement were monitored by a two channel Polhemus 6 d.o.f. magnetic tracker. The entire process lasted approximately 5 minutes, depending on the number of sites found, and was fully automated with minimal manual intervention.

24 FES users with foot-drop were recruited to the study (12 stroke, 12 MS), with 11 tested to date. Each subject is tested for speed, effort and foot kinematics over a 10m walkway. Two walks are completed for each condition in a randomised order: no stimulator; patient set-up; clinician set-up; automated set-up (ShefStim stimulator).

4. Results

Full analysis will await completion of the trial and will be presented at the conference. However, data from one individual trial subject is presented here. For this subject ShefStim showed correction of inversion over the subject's set-up,

while demonstrating a similar improvement in dorsiflexion to both the clinician's and subject's set-ups. Walking speed increased by 36% relative to no stimulation, compared to a 21% increase with both other set-ups.

Table 1: Speed and physical exertion results

Stimulator setup	Mean walking speed (m/s)	Improvement cf. no stim. %	Perceived exertion (Borg Scale)
None	0.17	0	17
Subject	0.20	+21	13
Clinician	0.20	+21	11
ShefStim	0.23	+36	9

The subject commented that he had to put less effort into walking while using the ShefStim than during the other walks, and this was reflected in the lowest Borg scale score of 9.

5. Discussion and Conclusions

An automated electrode search algorithm was developed for FES users with stroke and MS. We await the results of the complete study to assess whether the result given above is typical.

6. Acknowledgements

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An investigation into the effects of electrical muscle stimulation training in type 2 diabetes mellitus: a case study.

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1. Introduction

Exercise is a vital component in the management and prevention of type 2 diabetes mellitus (T2DM). Both the American College of Sports Medicine (ACSM) and the American Diabetes Association (ADA) advocate exercise as a treatment method for T2DM [1, 2]. However, given the benefits of engaging in physical activity, many T2DM patients are often unable to partake in physical activity secondary to complications of their diabetes or other musculoskeletal problems. Electrical muscle stimulation (EMS) exercise is a likely alternative for diabetic individuals who face barriers to physical activity. EMS has received much attention in recent years as a new form of inducing exercise. Banerjee and colleagues showed that prolonged EMS exercise in sedentary adults resulted in significant improvements in maximal aerobic capacity, muscle strength and capacity for physical activity [3].

2. Aims

To investigate the effects of EMS training in an individual with T2DM.

3. Methods

A 44 year old male with T2DM (Height 1.82 metres (m), Weight 116 kilograms (kg), Body Mass Index: 35 kg/m²) was recruited for this study.

3.1 Screening tests

Baseline tests (Week 0) included an Oral Glucose Tolerance Test (OGTT), a DEXA scan and an isokinetic dynamometry test to assess knee extensor and flexor strength. Venous blood samples were taken both before and 2 hours after the subject consumed a 35g solution of glucose. The baseline tests were repeated at the 8 week follow-up.

3.2 Training protocol

A specially designed hand held muscle stimulator (NT2010, BioMedical Research Ltd, Galway, Ireland) was used to deliver impulses through 8 silicon-rubber electrodes (17cm x 10.3cm) applied bilaterally to the proximal and distal quadriceps and hamstring muscles via custom made neoprene garments. The stimulation consisted of 6 phases at a frequency of 19 Hertz (Hz) and one final phase combining 2 group frequencies at 90 Hz and 3 Hz. The participant completed six 45 minute training sessions per week after his evening meal for 8

weeks. Fasting glucose and 2-hour postprandial glucose levels were recorded each day by the subject using his own personal glucose analyser.

4. Results

EMS training resulted in a reduced body fat from 35.7% to 34.3% and an increased lean muscle mass from 75.54 kg to 77.92 kg. However, a reduction was found with isokinetic and isometric extensor torque (Table 1). Venous blood markers at week 8 showed improved glucose control both pre and post glucose load (Table 2). Fructosamine, a short term indicator of glycemic control reduced from a reading of 312 umol/L at week 0 to 240 umol/L at week 8 (Table 2).

Table 1: Peak knee flexion and extension torque (Nm)

	Week 0	Week 8
Isokinetic extension	194	179
Isokinetic flexion	111	122
Isometric extension	275	256

Table 2: Venous blood markers

	Week 0	Week 8
Preload glucose(mmol/L)	9.8	8.2
Insulin	8.71	8.83
Fructosamine(umol/L)	312	240
Postload glucose(mmol/L)	11.6	10.5

5. Discussion and Conclusions

This case study demonstrates that an 8 week EMS training programme resulted in improved glucose control and body composition. These results present preliminary evidence for the potential use of this type of EMS training in T2DM. Studies with larger participant numbers and intervention periods are required to investigate this further.

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Abdominal FES to support respiration in acute tetraplegia

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1. Introduction

A spinal cord injury at the cervical level, leading to tetraplegia, affects primary and secondary respiratory muscles and often results in a period of mechanical ventilation [1]. While most patients with at least partial diaphragm function can be weaned from mechanical ventilation, this usually leads to a delay in their rehabilitation. Patients with a high-level cervical injury will remain at lifelong risk of requiring intermittent ventilation during respiratory illness. Most breathing muscles cannot be accessed easily using transcutaneous FES, however, this technique can be applied in abdominal muscles during the expiratory breathing phase to support respiration and coughing [2]. This approach has mainly been used in the chronic phase of injury, but it may also be feasible as a tool to assist weaning from mechanical ventilation in acute tetraplegia

2. Aims

The aim of this study is to evaluate the use of abdominal stimulation during the weaning phase from mechanical ventilation in acute tetraplegia.

3. Methods

A neuromuscular stimulator (Rehastim, Hasomed, Germany) with customised application software was used which allowed periodic abdominal muscle stimulation according to the required breathing rate, with stimulation applied for a variable portion of the breathing cycle. Stimulation intensity could be adjusted manually. The beginning of the stimulation cycle could be synchronised with the expiratory phase of mechanical ventilation, using an external trigger input. Four sets of stimulation electrodes were applied: Two sets were placed over the rectus abdominus muscles, while the other two sets were placed over the lateral abdominal muscle groups on either side. Stimulation current was adjusted individually for each channel, with a stimulation frequency of 30Hz and a pulsewidth between 50 and 500µs.

The system was evaluated in a single subject case study, involving a 24 year old male, with a functionally complete tetraplegia following a fracture at C4-5 level. At the time of intervention (2 months post injury) he was able to breathe independently for up to 3 min before desaturating, but was otherwise fully ventilator dependent.

Tidal volume, derived from expiratory flow measurements (Microloop, Micromedical, UK) at the tracheostomy tube, were compared during

ventilator free breathing with abdominal stimulation and without any support. Oxygen saturation levels were monitored throughout, and mechanical ventilation was resumed if levels decreased to less than 92% SpO₂.

4. Results

Initially, exhaled tidal volume could be increased from 130ml to 390ml with stimulation. This allowed the subject to remain off the ventilator for 10 minutes, which increased to 20 minutes after one week of regular abdominal stimulation sessions. After 2 weeks of regular abdominal stimulator session, the subject's unassisted tidal volume had increased to 380ml while stimulator assistance led to 700ml exhaled tidal volume, Following the 7 week weaning program, the subject was able to breathe without ventilator assistance for up to 12 hours.

5. Discussion and Conclusions

The results show that the application of abdominal muscle stimulation can augment ventilation to allow adequate levels of respiration without additional mechanical ventilation. We suggest this approach can be used to assist ventilator weaning by allowing the patient to spend longer periods of time without mechanical positive pressure ventilation.

Stimulation of the abdominal muscles leads to movement of the diaphragm. It is therefore possible, that the technique suggested leads to faster functional recovery of a partially innervated diaphragm by assisting its movement. Another result of abdominal stimulation may be an improved fulcrum effect were diaphragm movement becomes more effective as the abdomen provides better resistance to the diaphragm movement.

6. Acknowledgements

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Presentation Session 2

Friday 16th April 2010

9.30 – 10.30

Optimization of Functional Magnetic Stimulation

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1. Introduction

Using magnetic stimulation (FMS) for supporting cycling of complete parietic patients[1] (Fig. 1) is possible and it is a potentially superior alternative to surface electrical stimulation (FES) in persons with partially or completely preserved sensibility because FMS is supposed to be "painless".

2. Aims

We determined and compared the torque-pain relationships in paralyzed persons with preserved sensibility during magnetic (FMS) and electrical stimulation (FES), in order to optimize stimulation parameters and conditions.



Fig 1. Principle of FMS propelled cycling: complete paraplegic subject

3. Methods

Torque and pain induced by quadriceps stimulation in 13 subjects with preserved sensibility (with chronic progressive multiple sclerosis, MS) were investigated under the following conditions: 1. small vs. large stimulated surfaces of the thigh, 2. varying contraction velocities of the muscle (isometric vs. 15 and 30 rpm isokinetic conditions), and 3. different stimulation modalities: FMS vs. FES. In addition, the role of the placement of the round coil during magnetic stimulation was investigated in 29 subjects with MS.

4. Results

In persons with preserved sensibility, torque and pain significantly depended on the amount of stimulated surface during FMS, on the muscle contraction velocity during FES and FMS, on the stimulation location during FMS, and on the stimulation modality (FMS vs. FES). In particular, FMS with a saddle-shaped coil produced more torque ($p < 0.05$) than any other FES or FMS stimulation modality and less pain than standard FES ($p < 0.05$).[2]

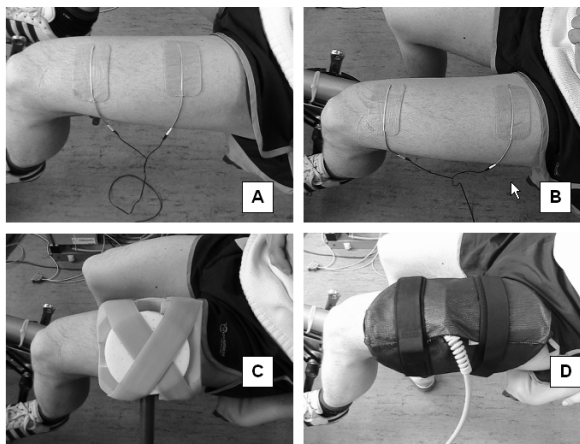


Fig 2: Setups: short(A), normal(B) electrode-distance FES, round-(C) and saddle(D)-coil FMS

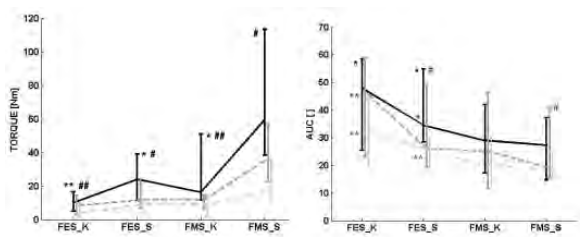


Fig. 3. Dependency of evoked torque(left) and pain(right) in subjects with partially pre-served sensibility on stimulation modality (FMS vs. FES), the amount of stimulated surface (small vs. large), and the kinematics of movement (isometric-black vs. isokinetic-gray). Setups: FES_K, FES_S short and normal distance FES; FMS_K and FMS_S round- and saddle-coil.

5. Discussion and Conclusions

To support mechanically constrained motion of the legs by muscle stimulation in subjects with paresis and partially preserved sensibility, we recommend applying magnetic stimulation with a large-surface saddle-shaped coil and focusing maximal stimulation on the proximal fronto-lateral surface of the thigh.

6. Acknowledgements

The conference organisers acknowledge the authors' cooperation in keeping to the template.

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Human cortical control of a virtual, upper limb, FES system

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1. Introduction

Functional electrical stimulation (FES) has been used to restore functional arm and hand movements in people with paralysis [1]. Neural interface systems may offer a natural source of commands for restoring dexterous movements via FES. In fact, such systems based on signals recorded from the motor cortex in human subjects with paralysis [2], have shown the ability to control computer cursors and robotic arms. However, the ability to use neural signals to control the complex dynamics of a reanimated limb, rather than the kinematics of a cursor, has not been demonstrated.

2. Aims

The aim of this study was to show the ability of an individual with complete arm paralysis to use cortical signals to command the real-time movements of a simulated, dynamic arm.

3. Methods

Our subject is a participant in an ongoing pilot clinical trial of neural interface technology [2], and has a multi-electrode array implanted in the arm area of the primary motor cortex (Caution: Investigational Device. Limited by Federal (USA) Law to Investigational Use).

The participant has long-standing incomplete arm paralysis, and to simulate a potential FES system, a "dynamic arm simulator" (DAS) has been developed. This includes a 6-muscle musculoskeletal model of the human arm that executes in real time, and replicates the dynamics associated with arm mass and muscle contractile properties. It also includes an FES controller that converts user-commanded movements into the required patterns of muscle activation [3].

The participant was seated in front of a monitor on which the virtual arm was displayed. She was asked to command the virtual arm to move to and acquire a series of targets presented randomly on the screen. Movement velocity commands were calculated based on neural spike data, the DAS and controller calculated the required muscle activations and their effect on the virtual arm, and the resulting movement was displayed to the user via the computer monitor.

4. Results

The participant was able to reach various targets on the screen and select them by generating a separate "click" (a decoded state change related to imagined hand grasp). In order to compare our results with previously demonstrated non-dynamic cursor control tasks, the subject also controlled a virtual arm with no dynamics ("no DAS"). A summary of the results is shown in Table 1.

Table 1: Successful acquisition rates in target reaching tasks.

	No DAS	DAS
# targets presented	69	110
# targets reached	66 (96%)	89 (81%)
# targets clicked	60 (87%)	84 (76%)

5. Discussion and Conclusions

The participant was able to use the DAS to control the complex dynamics of the virtual arm in a manner comparable to non-dynamic cursor control tasks. These results suggest that combining a neural interface with existing FES systems could provide a high-performance, natural system for restoring arm and hand function in individuals with extensive paralysis.

6. Acknowledgements

The authors would like to acknowledge the contributions of the Braingate research team to this work (<http://www.braingate2.org/>). Funding was provided by the NIH grants NICHD-NCMRR N01-HD-5-3403 and NINDS N01-NS-5-2365.

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A brain computer interface to improve respiratory function in tetraplegia

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1. Introduction

Respiratory complications resulting from reduced respiratory function, are one of the dominant causes of death and one of the leading sources of rehospitalisation in tetraplegia [1]. Surface FES applied to the abdominal muscles has been shown to improve respiratory function [2]. Previous work has designed automatic control for the timing of stimulation [2] but the issue of an adequate user interface suitable for tetraplegics still needs to be addressed. Brain computer interface (BCI) technology creates a non neuromuscular communication pathway [3], allowing people with physical impairment to control their environment directly. Steady state visual evoked potential (SSVEP) type BCIs infer a user's intent by detecting their visual attention to one of a panel of rapidly oscillating light sources. In this study, the combination of FES and BCI is investigated.

2. Aims

The aim of the project is to develop a SSVEP type BCI as a novel user interface for an abdominal FES system. The system is tested on able bodied volunteers, its performance evaluated and possible interference of the FES with the BCI signal investigated.

3. Methods

Subjects were presented with a panel of 4 LEDs, each relating to a control command for the FES system and each flickering at a different frequency. When a subject looked at an LED, a response at the corresponding frequency was elicited in their visual cortex. The BCI could detect this frequency by decoding the EEG of the visual cortex in real time. From this the user intent was inferred and the FES system responded accordingly, allowing the user to change between different modes of stimulation (quiet breathing and cough) and to adjust stimulation intensity. 12 able bodied volunteers were recruited for the project. Each subject took part in one assessment session in which they were asked to complete a task three times. The task was designed to imitate envisaged use of the system and required a minimum of 15 correct classifications to be completed.

4. Results

The times taken to classify which LED a subject was looking at and the accuracies were analysed. Three groups can be distinguished

according to the classification time: 8 users were able to use the system fast (5.1 ± 2.8 sec [mean \pm SD]) and accurately (97%), while in two subjects, the classification time was longer and less consistent (11.1 ± 13.1 sec, 98% accuracy). Two further subjects required longer times (15.6 ± 17.1 sec) with reduced accuracy (90%). Some interference from the FES in the EEG signal was observed, but this had little effect on the classification performance of the BCI system.

5. Discussion and Conclusions

The system developed was effective in allowing users to control an abdominal FES system by merely focussing their visual attention at different visual stimuli, demonstrating that the combination of FES with BCI is feasible. Importantly this was achieved with no user or system training. This is an important complement to previous work as it allowed, for the first time, users complete control over the type and intensity of stimulation. System parameters were chosen in this project to strike a balance between speed and accuracy for the whole group. By judicious choice of these parameters for individual subjects it may be possible to improve the results achieved. However, it is known that the strength of the SSVEP response can vary between people and so differences may remain in spite of parameter optimisation. Future work needs to corroborate the results presented with a tetraplegic population and to verify that the higher stimulation intensities used in those subjects do not exacerbate the mean time and accuracy achieved.

6. Acknowledgements

This research was supported by the European Community projects *BrainRobot* (MTKD-CT-2004-014211) and *RehaBCI* (PERG02-GA-2007-224753).

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Keynote Lecture: The role of neurostimulation and neuroplasticity in the rehabilitation of motor dysfunction after stroke

Hamdy S, University of Manchester

Motor dysfunction after stroke is common, and post the acute phase, can be difficult to treat. One important example of motor dysfunction is swallowing problems or dysphagia after stroke. Dysphagia can affect as many as 50% of patients in the period immediately after a stroke. In some cases this can lead to serious morbidity, in particular malnutrition and pulmonary aspiration. Despite this, swallowing therapies remain controversial, with limited evidence base and little in the way of objective scientific criteria. Moreover, swallowing can sometimes recover in certain patients to a safe level within weeks making it an interesting model for understanding brain recovery, neurostimulation and cortical plasticity. A better understanding of these adaptive processes as seen in spontaneous recovery may therefore help in developing therapeutic stimulation based interventions that can drive plasticity and so encourage the recovery process. In this lecture, I will examine present knowledge about the cortical control of the swallowing motor system, in man particularly from investigations with Transcranial Magnetic Stimulation (TMS), and explore what aspects of its organisation are important for compensating for recovery after damage. I will then describe current approaches to swallowing therapies and review the evidence base for such interventions. Finally, I will discuss new approaches for the rehabilitation of swallowing, including TMS, peripheral stimulation, paired associative stimulation and Transcranial direct current stimulation, which have been recently applied in the setting of acute and chronic stroke. These neurostimulation based treatment may be useful in speeding up the process of recovery and form the basis for future clinical trials of dysphagia after brain injury.”



Dr Shaheen Hamdy
Clinical Senior Lecturer, University of Manchester

Dr Shaheen Hamdy is currently a clinical Senior Lecturer based in the School of Translational Medicine, Faculty of Medical and Human Sciences, University of Manchester. His research interests include neural mechanisms within the gastrointestinal system, with a particular focus on neuroplasticity and functional recovery following brain injury using human swallowing as an experimental model.

This work, in collaboration with Prof. John Rothwell (Institute of Neurology, Queen Square) has provided new knowledge about the cortical control of swallowing in man, and defined which aspects of its organisation are important for recovery after stroke. Dr Hamdy has prominence in most aspects of TMS, and has utilised a number of complimentary imaging modalities including PET and fMRI. His most recent work has begun characterising the role of therapeutic interventions in driving cortical plasticity and recovery after cerebral injury in association with the NW stroke research network, with a particular interest in medical device based neurostimulation. His research has attracted over £2 million in external grant income including current WT and RfPB NIHR grants to assess treatments for dysphagia after stroke. He has published over 50 peer-reviewed research papers and has contributed to 8 books.

Poster Session 2

Friday 16th April 2010

12.15 – 13.30

Evaluation of new silicone rubbers for implant encapsulation

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1. Introduction

In the 1970s, implants designed and produced in small groups such as the MRCU in London and elsewhere used silicone rubbers for encapsulation of their electronics [1]. The most commonly used rubbers was DC3140, a single-part alkoxy-terminated PDMS sold by Dow Corning, US. It had been selected after years of practice and extensive tests amongst other on the quality of the adhesion they offered to 96% alumina [2]. Due in part to advances in medical devices regulations it became increasingly difficult to obtain material for human implants. New suppliers were sought in the 1990s and we have since tested and used a selection of silicone rubbers manufactured by Nusil, an ISO-9001 certified company producing a large range of silicones. These underwater ageing tests are justified by the importance of the silicone rubber encapsulation for the long-term function of electrical stimulation implants.

2. Methods

Rubbers are selected for their adhesive properties, un-cured viscosity, electrical properties, hardness, cure time and temperature, curing chemistry, ease of handling (cure inhibition) and optical properties. They then undergo long-term tests to assess how these properties evolve under water at elevated temperature as the implant must operate for 30 years or more in the body, thus in a warm and moist environment. The selection is often the result of a compromise and will be different for each new project so it is important to maintain a set of rubbers of known characteristics. For a full range of Nusil products, including primers and adhesion promoters, see <http://www.nusil.com/products/index.aspx>.

3. Results

The table summarises the rubbers currently under test and the main reason why they were chosen. The underwater tests that will be discussed at the conference will give specific information on the adhesion to 96% alumina, the insulation, the diffusion of selected compounds present inside the implant and the sensibility to cure inhibitors.

4. Discussion and Conclusions

The role of silicone rubber encapsulation in the long life of electrical stimulation implants is often misunderstood by the engineering community, hence it is grossly underestimated [3]. Yet new manufacturers are now offering a variety of products covering a wide range of characteristics. If we

Table 1: Summary of rubbers currently under test at the IDG

Rubber code	Comments
DC3140	single-part, de facto standard
MED-1000	single-part, non thixotropic
MED-6208	developed for adhesion to plastic
CV14-2500	developed for adhesion to metal
MED1-4013	developed to stick to many materials without primer
MED-6015	no filler, very good adhesion to alumina, equivalent to DC184
MED-4210	equivalent to DC4-4210 used at the MRCU because it was an RTV
EPM-2420	very fluid, includes an adhesion promoter in the 2-part version
CF1-6755	2-part, needs adhesion promoter R2-2655 to be an adhesive

are to make the most of these opportunities and reap the benefits from these new developments we must continuously update our knowledge by undertaking long-term underwater tests. These tests are time and resource-consuming but their importance should not be overlooked if we are to establish and maintain a set of silicone rubbers suitable for all our implanted devices projects.

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Bilateral Pudendal Afferent Stimulation Improves Bladder Emptying in an Animal Model of Urinary Retention

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1. Introduction

Chronic urinary retention can lead to reflux, upper urinary tract damage, urinary tract infection, and overflow incontinence, and traditional treatments are inadequate. Currently, sacral nerve root neuromodulation has been applied in patients with urinary retention who initially failed standard treatment [1]. While effective in some patients, many patients do not respond to sacral nerve neuromodulation. Thus, there is a need for a more effective prosthesis to restore the bladder voiding function. Our recent studies demonstrated that unilateral electrical stimulation (UES) of the pudendal sensory nerve improves bladder emptying efficiency in an animal model of urinary retention, established by acute transection of the pudendal sensory nerves in rat [2].

2. Aims

In the present study, we sought to determine whether bilateral electrical stimulation (BES) of the pudendal sensory further enhanced bladder emptying efficiency, as compared to UES.

3. Methods

Female Sprague-Dawley rats (n=6) were anesthetized with urethane (1.2 g/kg, s.c.). All rats underwent bilateral transection of the pudendal sensory nerves (BST), and the proximal ends of the transected sensory nerves were mounted in bipolar cuff electrodes for electrical stimulation. Continuous transvesical infusion cystometrogram (CMG) measurements were conducted to quantify the effect of UES and BES on voiding.

4. Results

Contraction duration (CD), inter-contraction interval (ICI), bladder contraction area, and voiding efficiency (VE) were significantly reduced following BST (Fig. 1). The average CDs and ICIs were prolonged by both UES and BES across all tested amplitudes and frequencies, and no significant differences were found between the effects of UES and BES. Further, both bladder contraction area and voiding efficiency (VE) were significantly increased by UES and BES across all tested stimulation parameters. Although BES consistently generated a 4-5% larger increase in VE than UES, this improvement did not reach statistical significance.

5. Discussion and Conclusions

Disruption of sensory feedback carried by the pudendal sensory nerves dramatically reduced voiding efficiency and created an effective animal model of urinary retention. Artificial replacement of sensory activity by either unilateral or bilateral electrical stimulation prolonged the duration of voiding bladder contractions and enhanced bladder emptying efficiency. Therefore, either unilateral or bilateral electrical activation of pudendal nerve afferents may be a new direction for the design of alternative neuroprostheses for patients with urinary retention as well as other voiding dysfunctions.

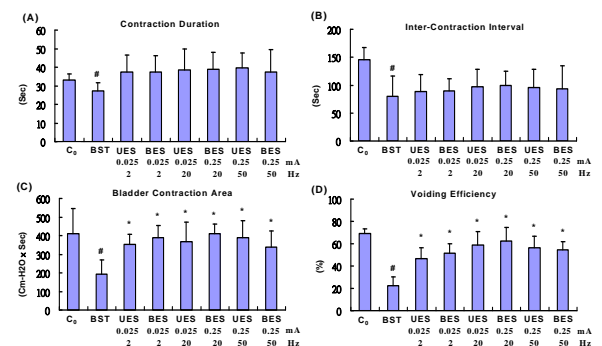


Figure 1: The changes in CMG parameters following bilateral (BST) transection of the sensory branch of the pudendal nerve and application of unilateral (UES) or bilateral (BES) electrical stimulation of the pudendal nerve with different amplitudes and frequencies. Each bar represents the mean \pm SD. # indicates a significant difference ($p < 0.05$) between before (C_0) and after BST, and * indicates a significant difference ($p < 0.05$) between after BST and in trials on which stimulation was applied.

6. Acknowledgements

This work was supported by the National Science Council, under grants NSC97-2314-B-038-047-MY2, and Taipei Medical University (TMU97-AE1-B09), Taiwan, ROC.

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FES leg and arm cycle ergometry

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1. Introduction

FES cycling has been commercially available in the United States since 1984. The original systems (e.g. Ergys and StimMaster) had limited deployment due to their large physical size. They also offered limited functionality for example only providing stimulation bilaterally to a fixed set of muscle groups (quadriceps, hamstrings and gluteals). Since 2005 a second-generation system has been available which addresses the limitations of the original systems and is proving to be another example of widespread adoption of FES technology.

2. Aims

The aim of this paper is to provide an overview of the 2nd generation FES cycling system (RT300 by Restorative Therapies, Baltimore MD); discuss some outcomes from the widespread deployment of the technology.

3. Methods

The RT300 system was originally cleared by the FDA in the USA in June 2005. The original system provided functionality similar to first generation systems but provided a motor the control of which was software integrated with the FES system. Since that time FDA has re-cleared the RT300 system on several occasions enhancing the available functionality.

Table 1: FDA clearances have allowed enhanced functionality

	Date	Reference #
Original functionality	27JUN05	K050036
Added internet connection	10MAR06	K060032
Added pulse oximetry	5JUL07	K07113
Added unilateral functions	10SEP07	K071486
Added FES for upper extremities	21NOV07	K072398
Added extra wireless FES channels and trunk stimulation	5AUG09	K090750

4. Results

The RT300 system is now available to patients with a wide range of neurological conditions including CVA, multiple sclerosis, cerebral palsy and SCI.

The system is in widespread clinical use in the USA, Australia and the UK. Home use systems dominate, representing 80% of the total.

The system's Internet connection facilitates data collection from each use. Figure 1 shows how mean distance cycled (endurance) from a sample of 600 riders with a SCI. An initial rapid increase is evident over the first 20 sessions which continues until around session 120.

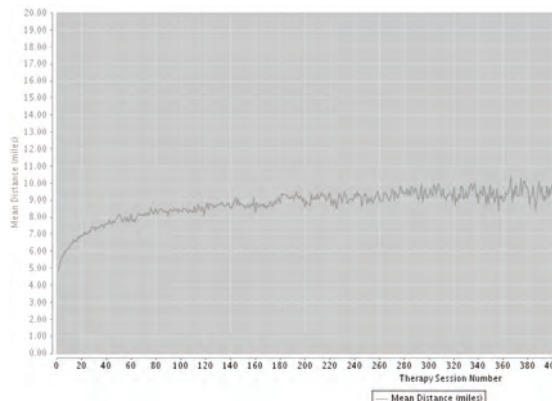


Figure 1: Mean distance cycled for n=600 SCI

Figure 2 shows how mean kcal/hr also rapidly builds over the first 20 sessions but continues to build beyond 400 sessions.

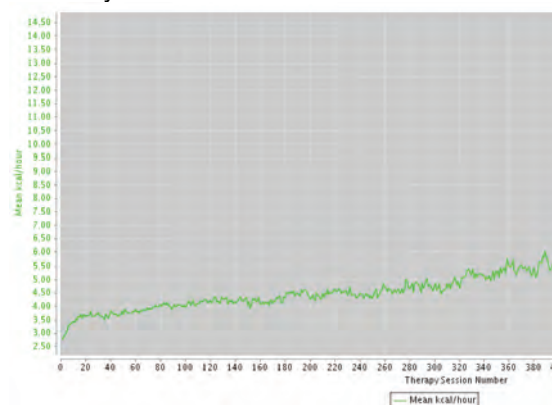


Figure 2: Mean kcal/hr expended for n=600 SCI

5. Discussion and Conclusions

FES cycling ergometry is experiencing significant renewed clinician and patient interest. This has been facilitated by technological advances as evidenced by the RT300 system, however the primary driver is patient demand driven by expectations of better outcomes; a commitment to maintain health as new treatments for neurological injuries are developed.

A novel, portable 64 channel surface array stimulator

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1. Introduction

Array stimulators have been proposed as a solution to the difficulty reported by patients in finding the correct stimulation site¹. Array stimulators for transcutaneous use have typically been restricted to a few channels switched to individual array elements via multiplexing circuits^{2,3}; their use outside the laboratory has not been reported. In order to investigate the clinical utility of array stimulation a device is required that may be used at home. The current device is currently being used with stroke and MS patients in a gait lab based pilot study, and will later be used in patients' homes.

2. Hardware Design

The stimulator is designed to meet the EU Medical Devices Directive (93/42/EEC) and the relevant particular standard EN 60601-2-10:2001 (requirements for the safety of nerve and muscle stimulators). The stimulator has two identical 32 channel output boards, each channel being capable of delivering up to 10mA of individually programmable constant-current charge-balanced stimulation. Stimulation is delivered to the body via a flexible PCB with 8x8 electrodes. A third board generates the 200V high-voltage supply, and houses the 32-bit ARM microcontroller and safety limit circuitry. The system is powered by 4 AAA batteries, which provide more than 12 hours continuous use; it is light enough to be worn on the lower leg during gait. The bare boards are shown in Fig. 1, and within the enclosure in Fig. 2. The prototype stimulator has dimensions 130x65x25mm and weighs <200g.

3. Software Design

The stimulator is set-up in clinic using a PC via a USB interface. This allows 'virtual electrodes' to be defined as groups of individual electrodes, each with the same stimulation parameters. An automatic setup routine searches for the optimal stimulation site to achieve a defined movement, measured using a 6DOF measurement system. The corresponding stimulation parameters are downloaded to the stimulator which may then be disconnected from the PC and functions as a stand-alone foot-drop stimulator with timing of stimulation via a heel-switch.

4. Acknowledgements

This work has been funded by the NIHR through HTD funding and by Sheffield Charitable Research Trust.

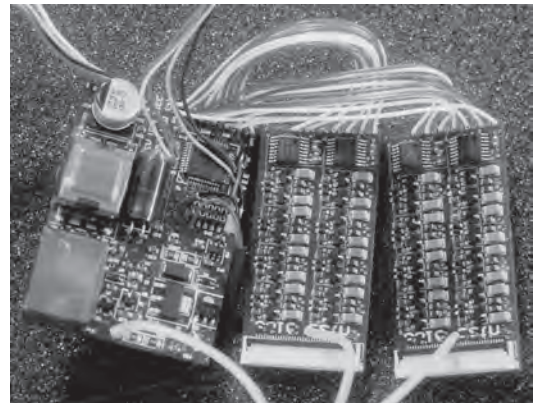


Figure 1 Two output boards and control board

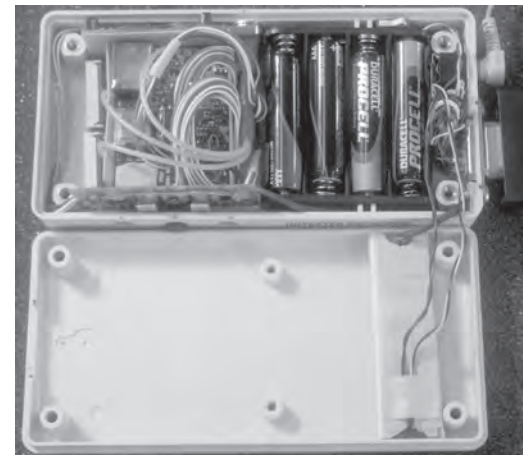


Figure 2: The prototype stimulator

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The effect of FES on knee and ankle kinematics and temporal spatial parameters of gait in patients with Multiple Sclerosis

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1. Introduction

Compared to able-bodied subjects, people with Multiple Sclerosis (MS) walk more slowly with reduced stride length, reduced ankle, knee and hip range of motion, and altered temporal spatial characteristics [1, 2]. Impaired foot clearance during swing phase of gait is a common problem in MS, impacting on gait performance. FES has been shown to be effective in increasing walking speed and reducing effort of walking [3], but there has been little quantitative investigation of changes in joint angles or temporal spatial parameters.

2. Aims

This study aims to evaluate the effect of Functional Electrical Stimulation (FES) applied to the ankle dorsiflexors on ankle and knee sagittal plane kinematics, and associated changes in temporal spatial characteristics of gait.

3. Methods

A retrospective analysis of kinematic data was carried out from 17 people with a confirmed diagnosis of MS, referred for provision of FES to correct drop foot. Patients completed two walks at a self selected speed along a 10m walkway, first with the stimulator OFF and then ON. Data was collected 6 weeks after set up and use of FES as part of routine clinic procedure.

Mean joint angle data of knee and ankle at initial contact, peak angles in swing, walking speed, step length, and single and double stance times were derived from the kinematic data and compared for walking without and with FES.

4. Results

Table 1 presents preliminary data for the group, with normal values for comparison where appropriate. Compared with able bodied subjects, peak swing knee flexion and ankle dorsiflexion, and ankle angle at initial contact were reduced and subjects walked slower, with a shorter step length, and reduced single stance and increased double stance times (as a % of cycle). Knee angle at initial contact was increased (more flexed). With FES, mean peak knee flexion in swing and knee angle at initial contact increased slightly. Peak swing dorsiflexion and ankle angle at initial contact showed a more notable increase. Temporal spatial parameters improved, with an increase in speed, step length, and an increase in single

support time and a reduction in preswing double support time, both expressed as a % of the gait cycle.

Table 1: Summary of kinematic and temporal spatial results, mean (standard deviation)

Stimulated Leg mean and (SD)	Angle Without FES	Absolute change with FES	Normal Database Angles*
peak swing knee flexion	42° (13°)	1° (5°)	59° (4°)
peak swing ankle flexion [#]		3° (3°)	
knee angle at IC	9° (6°)	1° (4°)	3° (5°)
ankle angle at IC [#]		5° (5°)	
		Change with FES	
speed (m/min)	42.1 (15.9)	14 % (25.4 %)	87 (7.6)
step length (m)	0.52 (0.08)	9 % (13.5 %)	0.72 (0.05)
single stance (% cycle)	30 (6.0)	7 % (14.4 %)	39 (2)
preswing double support (%cycle)	19 (8.9)	-11 % (10.7 %)	11 (2)

*Normal database of adults walking barefoot.

[#]Absolute values not reported due to changes in the foot model used within the 17 subjects.

5. Discussion and Conclusions

Results suggest a positive effect on ankle kinematics and spatial temporal characteristics. Benefits at the knee are less clear, but individual data was varied; for example peak swing flexion increased in 8 subjects, but was further reduced in 9. A reduction in swing knee flexion could be detrimental to foot clearance and highlights the need for a more robust (kinematic) measure of foot clearance.

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Fuzzy feedforward-feedback FES controller for elbow joint angle control

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1. Introduction

Electrical current has been used for various purposes in labs and clinics including functional and therapeutic applications. Using functional electrical stimulation for restoration of hand movement is a context that researchers have focused during last years. A FES controller have been proposed in this paper that employ adaptive fuzzy feedforward-feedback architecture for elbow joint angle control in high-level SCI patients.

2. Aims

Due to complex nature of reaching movement and musculoskeletal system, FES control of reaching movement is a challenging problem. The aim of this paper is to present a control strategy that satisfactorily control the joint angle, and to be robust against time-varying properties of muscles and external loads and disturbances.

3. Methods

Design and test of controller on paralysed human is time-consuming and risky, so we need a dynamic model of hand, for design and evaluate controller performance[1]. First, a model including biceps and triceps muscles was developed using excitable muscle model [2]. We have used simmechanics and simulink toolboxes in MATLAB software to implement the model. Next a close-loop controller consist of an inverse model of arm and a fuzzy-PID controller was designed. For implementation of inverse model, a fuzzy system was developed that is used in forward path. The feedback controller is a fuzzy controller that replace by a PID controller when absolute value of error decrease to 13 degree. Genetic algorithm have been used to determine PID controller parameters.

4. Results

The presented control plan was compared with some other plans like single fuzzy and single PID controller. Controller was evaluated in different hand movement like elbow flexion from 0 degree to 100 degree or tracking a sinusoidal trajectory. maximum error of joint angle for tracking the sinusoidal waveform is 0.4 degree, by comparison, the corresponding value for fuzzy controller is 8 degrees as shown in fig.1. Then we tested the controller stability in presence of external load. also controller's robustness against external disturbance and model variations like changing the hand weight or hand length, and muscle fatigue and recovery time-constants was

evaluated. External disturbance was modeled as torque applied to elbow joint in period of 0.2 sec. maximum error in tracking a sinusoidal trajectory in presence of external load and disturbance have shown in table.1.

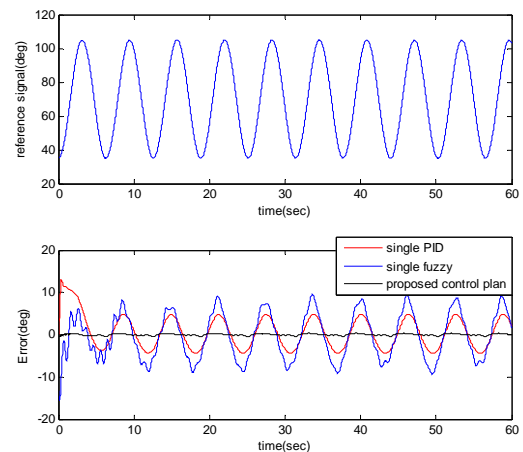


Figure 1: sinusoidal reference and Joint angle error in different controllers

Table 1: maximum Error and deviation in presence of external loads and disturbances

	Maximum error	Maximum deviation
Without load or disturbance	0.4deg	-
With 100gr load	0.4deg	-
With 300gr load	0.6deg	-
With 2N.m disturbance	-	3.5deg
With 4N.m disturbance	-	5deg

5. Discussion and Conclusions

The presented control plan Shows good performance compared with other controllers. it has less average error in sinusoidal tracking, and more speed in elbow flexion/extension while having less fluctuation. It is result of using advantage of forward control like speed, and feedback control such as precision. Also, change the strategy of control for coarse control and fine control enhanced the performance of controller.

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Sensors for triggering practical Functional Electrical Stimulation walking systems

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1. Introduction

Functional Electrical Stimulation (FES) techniques have shown significant improvement in mobility and functionality to many patients with pathological gait resulting from upper motor neurological injuries such as stroke, Multiple Sclerosis (MS), etc. Effective functioning of FES walking systems relies on accurate and reliable detection of gait events (i.e heel rise and heel strike) which depends on the type of sensors and the detection algorithm used.

2. Aims

The aim of this paper is to review the literature in the field of FES sensors to compare the performances, reliability, and practicality of the different sensing techniques and the detection algorithms associated with them in order to identify the best options available currently for next generation FES walking systems.

3. Methods

A literature search has been performed in the electronic data base PubMed. The review focused on papers reporting gait event detection techniques used for FES walking systems published over the last two decades up to December 2009.

4. Results

The literature search resulted in identifying six types of sensors used for FES walking systems found in 64 papers reviewed; Force Sensing Resistors (FSR), Accelerometers, Gyroscopes, Electromyography (EMG), and Tilt sensors, Electronystagmography (ENG). Kinematic sensors (Accelerometers and Gyroscopes) are found to be the most investigated types of sensors. Also, machine learning techniques were investigated to be combined with detection algorithms.

5. Discussion and Conclusions

FSRs (foot switches) are commonly used in commercial FES walking systems such as the Odstock Stimulator, NESS L300, and the Duo-STIM. FSRs are characterised by the simplicity of their output signal which is in an on/off format. For most patients, FSRs sensors provide reliable performance, however, reliability can be affected by the position of the FSR in the shoe [1] and some gait patterns (eg: shuffling or toe walkers). The alternative is using kinematic sensors which

can be placed on the shank or on the thigh of the subject, making the FES systems more cosmetic. The advantage of these sensors is that they can be used to measure joint angles making it possible to identify all gait phases. However, the output signal from this type of sensors is complex and depends on where they are worn, requiring advanced detection algorithms making them more liable to errors [2]. Moreover, reliability differs from one person to another depending on their gait pattern.

Combining different types of sensors might be a logical choice in order to compensate for the disadvantages of each sensor separately; for example, combining a FSR with a kinematic sensor as described in [2] will improve the reliability in different walking conditions and avoids detecting false events such as shifting weight from one side to another. Another approach to improve reliability in different circumstances is by integrating a machine learning technique to learn different gait patterns as suggested in [3] where a neural network was trained on gait data collected from 50 unimpaired subjects. The detection system was reported to be robust and accurate. Such system may require larger processing resources which might raise the cost and power consumption.

This comprehensive literature review has identified that some of the sensing techniques used in FES systems are reaching maturity and offer high levels of performance and reliability. Furthermore, it is apparent that future development of FES systems will benefit from exploiting the rapid advances in machine learning techniques currently being made in fields such as robotics. Our group is currently developing adaptive systems tailored specifically to address the requirements of the next generation of FES systems.

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A New Multiple Motor-Unit Muscle Model for FES Applications

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1. Introduction

Many FES controllers have been developed using a simulation approach and the performance of these controllers depends on the muscle model accuracy. During FES, the activation level can change in a continuous fashion such that different motor units are recruited at different muscle lengths. Furthermore, it is the length at initial activation that should be the input to the muscle force-length relationship [1]. Therefore, it seems reasonable to account for these facts in muscle models that are to be used in the development of FES controllers. However, in most previous work on FES control [2,3], the instantaneous muscle length is used rather than the length at initial activation.

Whilst not commonly used in FES control studies, the Hill-type model described by Epstein & Herzog [1] does use the length at initial activation of the muscle (i.e. when the first motor unit is recruited). However, this does not properly model the situation where the activation varies with time and muscle length (i.e. different motor units are recruited at different lengths).

We present a Hill-type muscle model which accounts for different motor units being recruited at different lengths. Hence the model can account for a continuously changing activation level whilst using the individual motor unit lengths at initial activation as input to the force-length relationship (i.e. modelling the history effect).

2. The Model

Referring to Figure 1, a Hill-type model is used in which each recruited motor unit is treated as a separate fully activated muscle for the purposes of calculating the isometric force. The number of recruited motor units depends on the activation level, $\beta(t)$. The isometric force ($f_{iso,i}$) produced by each motor unit depends on the length at which it was initially recruited. The effective isometric force for the entire muscle ($Eff.f_{iso}$) is the sum of the individual motor units' isometric forces.

$$Eff.f_{iso} = \sum_{i=1}^n f_{iso,i} \quad (1)$$

This effective isometric force is used as input to the force-velocity relationship of a Hill-type muscle model. Thus the total muscle force is determined by the number of recruited motor units, the length of each motor unit when initially recruited, and the instantaneous muscle velocity.

It should be noted that the virtual motor units in the model don't correspond to real motor units. Rather, the number of virtual motor units used in the model is chosen to give the required force resolution. For example if we want a resolution of 1%, then we would use a model based on 100 motor units.

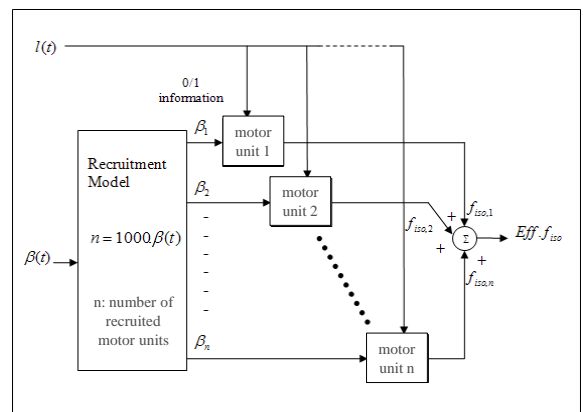


Figure 1: Calculating effective isometric force

3. Discussion

The new muscle model accounts for the activation history during FES control whilst allowing the activation to change continuously. As such, the model is suitable for the design, development and simulation of feedback control systems prior to clinical trials; with the proviso that other important features, such as a fatigue model, are included.

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Electrode arrays & hydrogel skin interface

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1. Introduction

Research is exploring the use of electrode arrays for functional electrical stimulation to enable software-steerable stimulation to remove the need for manual positioning of electrodes. Laboratory-based research has shown that an electrode-skin interface of high resistivity hydrogel shows promise, not only in maintaining focality of stimulation, but also as a means of reducing stimulation sensation [1-3]. Most, if not all of these studies have been conducted over short timescales (~up to 2 hours). We propose that changes to high-resistivity hydrogel, when in contact with the skin over longer timescales, may decrease the practicality of this approach.

2. Aims

This paper studies the effects of prolonged skin contact on the resistivity of hydrogel. The change in resistivity was measured experimentally. Also a computer model was used to predict the impact of the observed changes in electrical properties on the distribution of current in the tissue

3. Methods

3.1 Prolonged hydrogel skin contact

Four hydrogel samples, 0.3-0.6mm thick and of significantly differing initial resistivities were placed on the test subjects' leg, just below the head of fibula and worn for a 6 hour period over 7 consecutive days. The electrical resistivities of the samples were measured at a frequency of 1kHz at the start and end of each day.

3.2 Modelling of the hydrogel electrode array

The low frequency solver of SEMCAD was used to model a metal 8x8 electrode array, with one 8mm² electrode activated and an intra-electrode gap of 3mm. The array was interfaced, via a thin hydrogel layer, with the underlying tissue (skin, fat and muscle thickness 2, 3, 100mm & resistivity 909, 43, 3.3Ωm respectively).

4. Results

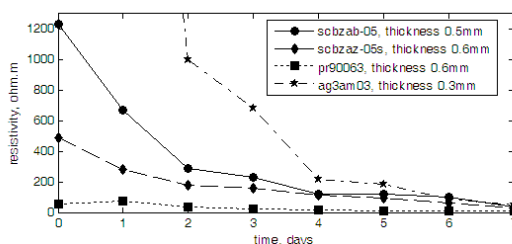


Figure 1: Change in resistivity of hydrogel with time when in contact with skin.

Figure 1 shows the resistivity of the 4 different hydrogel samples plotted against time. The electrical resistivity of all 4 hydrogel samples drop dramatically over a seven day period to reach low impedance levels of approximately 20Ωm. Figure 2 shows the current spread in the tissue for both high and low resistivity hydrogel respectively.

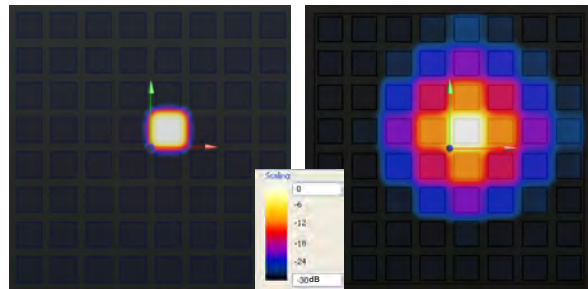


Figure 2: Calculated current distribution in the skin for high (1200Ωm, left) & low (20Ωm, right) hydrogel resistivity.

5. Discussion and Conclusions

It is thought that ions in sweat from the skin surface are passing into the hydrogel layer thus decreasing its electrical resistivity. From figure 2, it is seen that the current spread within the tissue and hence focality of stimulation decreases significantly for the lower resistivity hydrogel. This is caused by a combination of current flow horizontally in the hydrogel and by some current exiting the hydrogel to pass into adjacent un-driven electrodes because of their very low resistivity, and then returning into the hydrogel further away from the excited electrode. Hence using a continuous layer of high resistivity hydrogel as an interface between an electrode array and the skin is a good solution for short periods of time. However, our results suggest that it is not an ideal solution for long term use by a patient in the home.

6. Acknowledgements

The work was funded by the UK NIHR (HTD480).

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An On-Line EEG-based BCI System for Controlling Hand Movement with Self-initiation Capability

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1. Introduction

Brain-computer interface (BCI) technology has the potential to enable people who suffer from severe physical disabilities to communicate and control their environment directly by brain signals. However, there are still several issues that need to be addressed before BCI systems can be used for real-world tasks. One important issue in developing an on-line BCI for disable people is the ability to turn the communication device on and off without assistance from others.

2. Aims

This paper presents a new EEG-based Brain-Computer Interface (BCI) for on-line control of hand grasping and opening. The goal of this work is to develop a BCI system to be effective in real-world scenarios and can be turned on and off by subject intention without external assistance.

3. Method

In this work, we used a probabilistic neural network with a real-time recurrent learning algorithm for classification of EEG signals [1]. Two schemes of classification process were used here for virtual hand grasp control: adaptive and static classification. Adaptive scheme was used to train the classifier on-line during the first sessions.

The experiments were carried out with five able-bodied volunteer subjects. Fig. 1 shows a typical trial of experiment.

Three classifiers were designed. The first classifier which is based on the imagination of right-hand movement is for controlling the hand grasping and holding. The second classifier, which is based on the imagination of left-hand movement is designed for hand opening, and the third classifier for turning the system on and off. The third classifier is based on closing the eye and classification of EEG signal recorded from positions O1 and POz.

4. Results

The EEG data was continuously recorded and filtered and the eye blink artifacts were removed online using neural adaptive filter proposed in [2]. At each point of EEG data, the features were extracted from 1-s sliding window and classified. Fig. 2 shows the results during different runs of first session for subjects HK. Table 1 summarizes the results of online hand movement control during all sessions and all subjects.

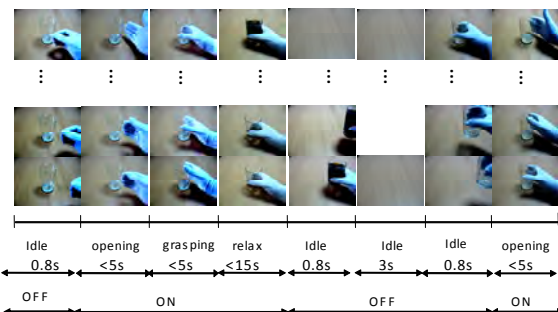


Figure 1: The structure of a typical trial of experiment.

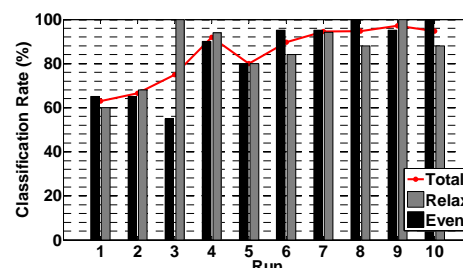


Figure 2: The classification accuracies obtained during different runs of the first session for the subject HK.

Table 1: Classification accuracies obtained using probabilistic neural network.

Session	Subject				
	SP	HK	AF	MK	RF
1 (adaptive)	84.5	84.7	84.4	84.1	81.3
2 (adaptive)	89.6	86.9	89	91.9	90.8
7 (static)	92.7	95.3	85.1	84.7	90

5. Discussion and Conclusions

The results show that the subjects were able to achieve an accuracy more than 81% during the first session of experiment and 84%-95% during the last session using single-trial classification with no adaptation.

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Sliding-Mode Control of Walking Using Functional Electrical Stimulation: A Simulation Study

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1. Introduction

The lower extremities of human walking are a highly nonlinear, highly time-varying, multi-actuator, multi-segment with highly inter-segment coupling, and inherently unstable system. Moreover, there always exists uncertainties in system model. A useful and powerful control scheme to deal with the uncertainties, nonlinearities, and bounded external disturbances is the sliding mode control (SMC) [1]. In this paper we use a sliding-mode control for control of walking in paraplegic subjects.

2. Aims

The aim of this paper is to present a robust control system for online controlling of paraplegic walking.

3. Methods

A planar model of bipedal locomotion [2] is considered here as a virtual patient. The equation motion of the musculoskeletal system can be described as:

$$\ddot{\mathbf{x}} = \mathbf{F}(\mathbf{x}) + \mathbf{G}(\mathbf{x}) \cdot \mathbf{u} \quad (1)$$

where

$$\mathbf{u} = \hat{\mathbf{G}}^T(\mathbf{x}, \boldsymbol{\theta}_g) [\varepsilon_0 \mathbf{I}_m + \hat{\mathbf{G}}(\mathbf{x}, \boldsymbol{\theta}_g) \hat{\mathbf{G}}^T(\mathbf{x}, \boldsymbol{\theta}_g)]^{-1} (-\hat{\mathbf{F}}(\mathbf{x}, \boldsymbol{\theta}_f) + \mathbf{v} + \mathbf{K}_1 \text{sgn}(\mathbf{s})) \quad (2)$$

$\hat{\mathbf{F}}(\mathbf{x}, \boldsymbol{\theta}_f)$ and $\hat{\mathbf{G}}(\mathbf{x}, \boldsymbol{\theta}_f)$ are estimates of $\mathbf{F}(\mathbf{x})$ and $\mathbf{G}(\mathbf{x})$ functions, respectively. \mathbf{s} is a vector of sliding surface for every state space. ε_0 is a small positive constant and \mathbf{I}_m is $m \times m$ identity matrix. $\mathbf{K}_1 = \text{diag}(k_{11}, \dots, k_{1m}) > 0$. In this work, we use fuzzy systems to estimate the nonlinear functions $\mathbf{F}(\mathbf{x})$ and $\mathbf{G}(\mathbf{x})$. The identified system is used to design the sliding control law.

4. Results

The results indicate that the sliding mode control strategy provides accurate tracking control with fast convergence during different conditions of operation, and could generate control signals to compensate the effects of muscle fatigue and external disturbances. Interesting observation is that the controller generates muscle activations and net joint moments that accurately mimic those observed during normal walking. Figure 1 shows the results of the fuzzy-based sliding mode control of walking in the virtual subject. It is

observed that a good tracking performance can be achieved by using proposed control strategy. Interesting observation is the fast convergence of the proposed control strategy.

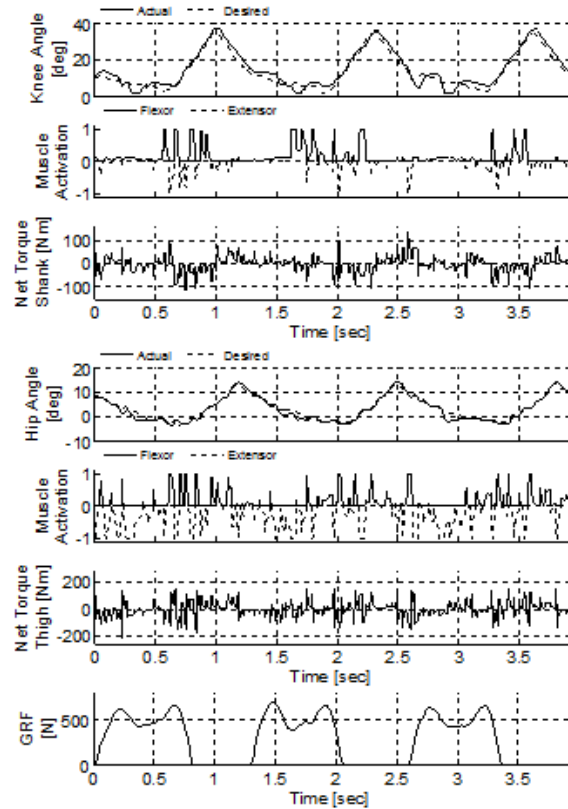


Figure 1: Walking control results over three gait cycles: Measured (desired) and actual joint angle of knee and hip, activation of flexor and extensor muscle groups, active torque acting at the joint, the net torque acting at the shank and thigh, and ground reaction force.

5. Discussion and Conclusions

The results of this work indicate that SMC is a promising approach to online control of walking.

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Decentralized Robust Control of Standing Up in Paraplegics Using Functional Electrical Stimulation: A Simulation Study

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1. Introduction

A major impediment to restore sit-to-stand transfer in paraplegia using functional electrical stimulation (FES) is the highly non-linearity and time-varying properties of electrically stimulated muscle which limit the utility of open-loop FES control systems. A useful and powerful control scheme to deal with the uncertainties, nonlinearities and bounded external disturbances is the sliding mode control (SMC). In this work, we used a control strategy which is based on SMC for control of standing up. Moreover, the *lower extremity* of human body is a complex inherently unstable system with multi-segment and multi-actuator with highly inter-segment coupling. Centralized controller design of such system requires a complex mathematical model of musculoskeletal dynamics in the control law formulation.

2. Aims

In this work, we present a decentralized robust control strategy which is based on neuro-sliding mode control (SMC) [1] for control of FES-assisted standing up.

3. Methods

3.1 Musculoskeletal model of standing up

A three-segmental planar model of the human body consisting of shank, thigh, and upper body in sagittal plane with nine mono- and biarticular muscle groups was considered as a virtual subject [2]. Feet are flat on the ground and two nonlinear spring-dashpot pairs were used to model the visco-elastic characteristics of body-chair contact. To account the patient's voluntary upper body effort, three independent Fuzzy controllers were used to adjust horizontal and vertical shoulder forces and the shoulder moment. The details were described in [2].

3.2 Decentralized Robust Control Strategy

The decentralized control problem is to design a set of independent controllers in which, each subsystem is controlled by a stand-alone controller. Each joint is considered as a subsystem and a neuro-SMC controller [1] is designed for each subsystem. Each controller operates solely on its associated subsystem. The interactions between the subsystems are taken as external disturbances for each isolated subsystem.

4. Results

Fig.1 shows the results of controlling the standing-up movement using proposed control strategy. It is observed that there is a perfect agreement between generated and measured sit-to stand movement trajectories.

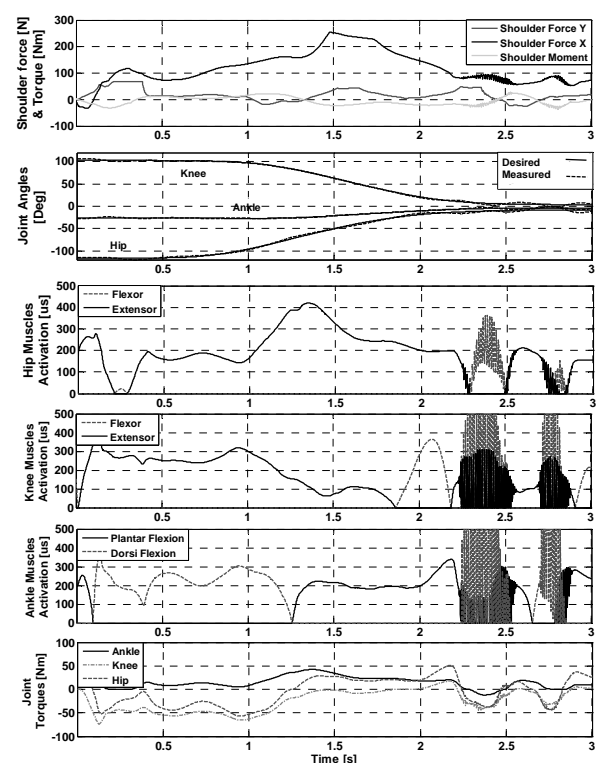


Figure 1: The performance of decentralized robust control of standing up movement.

5. Discussion and Conclusions

The results of this analysis show that the decentralized robust control strategy provides accurate tracking control with fast convergence.

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Optimal frequency and pulse width in the application of Electrical Stimulation for maximizing contractile output

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1. Introduction

Muscle weakness is a common clinical problem resulting from a variety of internal and external factors. The primary therapeutic treatment is muscle strengthening. However, many people are not able to comply with currently recommended protocols. Treatment with Electrical Stimulation (ES) can be used for muscle strengthening [1]. However, the literature is still not clear on whether there are optimal parameters that need to be set if ES is to be used for strength training purposes [2].

2. Aims

To investigate the muscle response to variations in frequencies or pulse widths, and see whether a maximal response exists.

3. Methods

Ten non-impaired male subjects, who gave written consent (aged 18-80 SD 7.9 yrs, no contraindications to ES and able to comply with protocols), were recruited. Participants had previous minimal exposure to ES, and refrained from strenuous activity 48 hours prior to testing. The faculty ethics committee approved the study. The lower limb was positioned within a specially built measuring system (60° knee flexion, neutral ankle). The maximum isometric moment of the gastrocnemius was measured for each stimulus. Frequency was set at 40 Hz when pulse width was varied between 100–450 microseconds (μ s). Pulse width was set at 450 μ s when frequency was varied from 20–100 Hz. Protocols were administered with a 2 second contraction time, followed by 30 seconds rest. Maximum tolerated current intensity was used. Four repeated measures were taken on day one and a fifth was taken after 24 hours.

4. Results

Joint moment increased as pulse width increased in a linear pattern [mean $R^2=0.89$ (range 0.72-0.99); mean slope= 0.01 Nm/ μ s(range 0.01-0.07)]. The relationship between muscle response and frequency was nonlinear with a plateau occurring between 50 - 70 Hz [mean $R^2=0.66$ (range 0.22-0.93); mean slope= 0.02 Nm/Hz(range 0.01-0.09)]. The absolute joint moment was variable in both protocols. However, when expressed as a percentage relative to the maximum moment, the relationship demonstrated less variability.

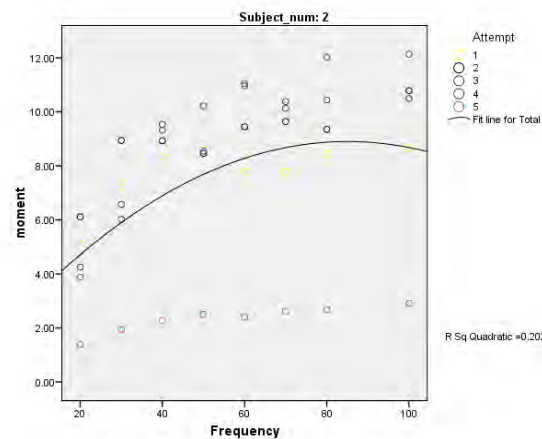


Figure 1: Variability of the force (Nm)-frequency (Hz) response of one subject

5. Discussion and Conclusions

In the present study the greatest joint moment was obtained with a pulse width of 450 μ s. It is not clear if the linear response would continue if pulse width increased further. However, the pulse width yielding the greatest response here is higher than the recommended value of 300 μ s [3]. Frequency response showed no clear optimum and absolute response varied between days. The factors contributing to these variations are unclear. These could include; variability in electrode positioning and impedance or voluntary contribution to stimulation. Fatigue (resulting from the short period between test stimuli) may have also contributed to this variability. Further investigation into these issues is currently underway.

6. Acknowledgements

Thanks to volunteers from Keele University, staff at ORLAU, and Action Medical Research for funding the project (Grant ref- AP1131)

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Control of swinging leg in cyclical motion using control techniques to reduce fatigue

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1. Introduction

Spinal Cord Injury (SCI) occurs as a result of an injury to the spinal cord, a part of the central nervous system, or as a result of trauma, infection, or disease. Individuals with SCIs have limited mobility because of the loss of voluntary muscle control and limitations in sensory, autonomic, reflexes, and visceral organ functions [1]. Functional Electrical Stimulation (FES) is a mean of producing contraction in muscles, paralysed due to central nervous system lesion by the utilising electrical stimulation [1]. Fatigue is always an issue restricting utilisation of FES in paralysed subjects. Choosing a suitable control strategy in a FES based activity appears to be an effective method to reduce fatigue in stimulated muscles.

2. Aims

The aim of this paper is to asses whether using a fuzzy controller would lead to less muscle fatigue in comparison to a PID controller in Paraplegics.

3. Methods

3.1 Leg Model

Based on each subject's leg complex's characteristics such as mass and dimension, sinusoidal reference trajectories have been obtained using a previously developed and tested leg model [2].

3.2 Controller

A fuzzy logic (FL) controller as well as a PID controller was developed to control the leg movement and the results from each controller have been compared.

3.3 Fatigue

Both controllers have been designed to follow the obtained sinusoidal reference trajectory with the same stimulation parameters in both techniques. The controller's performance would be assessed based on how the fatigue is reduced. The test has been performed on 3 paraplegics.

4. Results

Muscle fatigue is related to the energy consumption in the muscle, which in turn depends on the time integral of both the activation of a muscle (the stimulation input) and the actively generated muscle force (output of the

muscle). Under stimulation conditions the activation of the muscle is directly related to the number of stimulation pulses and the level of recruitment "u" of every pulse. This leads to the criterion presented in equation 1 for muscle fatigue [3].

$$Cu = \sum u_i \tag{1}$$

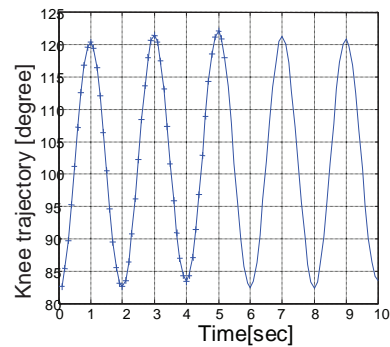


Figure 1: Reference knee trajectory

Table 1: The FL rule base

Δe c	NB	NS	Z	PS	PB
NB	NB	NB	NS	Z	Z
NS	NB	NS	NS	Z	Z
Z	NB	NS	Z	PS	PB
PS	Z	Z	PS	PS	PB
PB	Z	Z	PB	PB	PB

5. Discussion and Conclusions

The outcome of the study has proven that using a fuzzy controller would lead to less muscle fatigue due to fewer stimulation bursts.

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Presentation Session 3

Friday 16th April 2010

13.30 – 16.30

The Metabolic Efficiency of FES Exercise

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1. Introduction

Spinal cord injury (SCI) causes paralysis of the largest muscles in the body, preventing exercise and therefore increasing the risk of poor health. The likely benefits of using FES to exercise these muscles have been recognised for many years and stationary pedal ergometers have been available since the 1980s. The number of people with an SCI who use these machines remains small, probably because they have mostly been sited at clinics, which are not convenient for everyday use, and are boring. These shortcomings led to the development of FES rowing, still using stationary machines, but allowing additional voluntary upper-body effort to contribute in competitive time trials. They also led to FES-cycling on mobile tricycles which can be kept at home for frequent exercise, indoors (on rollers) or outdoors. We have showed at three 'FES Sports days' that paraplegics with well-trained leg muscles can enjoy races and games in sports halls.

However, even after training for one hour/day, five days/week, which probably takes 10-12 hours per week in total, paraplegics, still develop very low pedalling power output. In a three-centre trial involving Glasgow, the Swiss Paraplegic Centre (Nottwil) and London, we found that the peak power in Incremental Exercise Tests was only 18.8W [1]. Hunt *et al.* [2] pointed out that their metabolic efficiency (7.6%) remained very similar to untrained paraplegics doing FES cycling. In able bodied (AB) subjects doing FES cycling with epidural anaesthesia efficiency (9.9%) was about one third that during voluntary cycling [3]. This showed that low metabolic efficiency was not due to SCI but was related to FES cycling in some way.

We wished to further investigate the cause of low efficiency during FES exercise.

2. Methods

We performed two investigations. The first [4] was a comparison between the five London-based FES-cyclists and five AB subjects, matched for age and size. We measured quadriceps muscle thickness, isometric knee moment at maximal intensity stimulation or MVC, and maximal cycling power output (PO) in a maximal ('all-out') test.

In the second [5], we measured VO₂ consumption while AB subjects made isometric quadriceps contractions with FES, then voluntarily using the same force-time profile as a target, and lastly while they performed concentric contractions during imposed reciprocating movement of the knee.

3. Results

Quadriceps thickness, strength and peak PO of SCI subjects were 88, 34 and 13% of AB respectively.

Isometric contractions required 33% more metabolic power if produced by FES than voluntary activation. The efficiency of concentric contractions was 29.6%.

4. Conclusions

(i) Low efficiency is mainly not due to electrical stimulation but is probably due to the poor biomechanics of FES cycling. (ii) An improvement in efficiency by a factor of two might be possible but the short-fall in output power is about ten, therefore there is also a large physiological deficiency.

5. Acknowledgements

EPSRC, the INSPIRE Foundation.

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An investigation into the acute effects of electrical muscle stimulation on cardiopulmonary function in a chronic obstructive pulmonary disease patient – a pilot case study.

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1. Introduction

Chronic obstructive pulmonary disease (COPD) patients commonly find it difficult to participate in conventional aerobic exercise training owing to limited cardiopulmonary reserve, excessive dyspnoea and muscle fatigue. Recent studies have shown that significant improvements in oxygen consumption can be gained post 6-week electrical muscle stimulation (EMS) training [1]. Low frequency currents elicit a sustained and significant aerobic response and may be appropriate for COPD patients, who cannot exercise in a conventional manner [2]. A recent study compared the acute metabolic response among COPD patients during resistance training and EMS, using a tetanic frequency of 75 Hertz (Hz) [3], however no investigations have reported on the acute effects of EMS on cardiopulmonary function in a COPD population, using low frequency stimulation current.

2. Aims

To investigate the acute effects of EMS on VO_2 , heart rate (HR), percentage oxygen saturation ($\text{SaO}_2\%$) and perceived dyspnoea in a COPD patient.

3. Methods

A female participant (Age: 58 years, Weight: 58 kilograms (kg), Height: 1.54 metres (m), Body Mass Index: 24.46 kg/m^2), with a clinical diagnosis of COPD was recruited from a local hospital. An initial 30-minute EMS familiarisation session to ascertain the participant's maximal stimulation was performed. The participant had trained with the EMS system for 6 weeks prior to this acute measurement. A facemask and a gas analysis system (Quark b², Italy) was used to measure the expired oxygen as well as carbon dioxide concentration and volume. VO_2 was calculated from these measurements. Incremental stimulation intensity was recorded at 40, 50, 60, 70, 80, 90 and 100% of the maximal stimulation intensity tolerated in the familiarisation session. HR, $\text{SaO}_2\%$ and dyspnoea-level (BORG) were recorded at increments relating to the stimulation intensity above. A specially designed hand-held muscle stimulator (NT2010, BioMedical Research Research Ltd, Galway, Ireland) was used to administer the EMS intervention using a frequency of 3 Hz applied bilaterally to the

proximal and distal quadriceps and hamstring muscles.

4. Results

The maximum stimulation intensity reached was 101 mA. Maximal VO_2 for the stages increased from 5.51 $\text{ml}/\text{min}/\text{kg}$ at rest to 5.87 $\text{ml}/\text{min}/\text{kg}$ at 40% intensity to 17.41 $\text{ml}/\text{min}/\text{kg}$ at maximum intensity. Similarly, HR increased from 99 to 126 beats per minute. $\text{SaO}_2\%$ remained constant at 95% throughout. Perceived dyspnoea remained low at 6-7, only rising to 13 (somewhat hard) at 100% intensity.

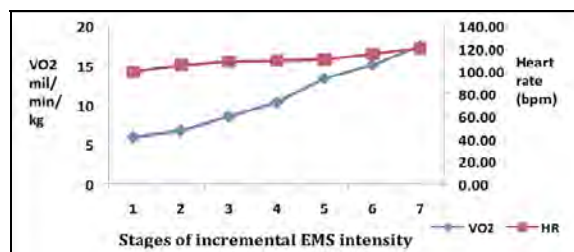


Figure 1: VO_2 and HR response to stimulation.

5. Discussion and Conclusions.

This case study demonstrates that using low frequency EMS is comparable with moderate to vigorous intensity aerobic exercise activity. Minimal ventilatory demands and dyspnoea were elicited despite significant VO_2 and HR increases. These results suggest that EMS may be a highly acceptable form of aerobic exercise training for COPD patients.

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Effects of Functional Electrical Stimulation (FES) on post-stroke gait under dual task conditions – a pilot study

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1. Introduction

A questionnaire study of drop foot FES users found that use of FES reduces the concentration required during walking and that users rate trip avoidance as one of the most important effects of FES [1]. More recent studies have shown that use of FES reduces gait timing variability, a factor associated with falls risk [2].

2. Aims

This paper reports on a preliminary study to investigate the feasibility of a gait laboratory based, dual-task study of the effects of FES on gait parameters associated with trips and falls. In order to evaluate the effects of FES on gait stability, the primary requirement is to be able to accurately detect key gait events from kinematic data.

3. Methods

Two subjects, both with right sided hemiparesis, walked at a comfortable pace along an 8 metre walkway under 3 task conditions - no task, verbal task and visual task – both with and without FES (a total of 6 conditions). Both secondary tasks tested short-term recognition memory, using a format based on the Camden Memory Tests [3]. A motion analysis system collected data from reflective markers placed on both shoes and at the waist.

4. Results

Heel and toe markers were used to calculate heel strike and toe off [4] [Fig 1] and subsequently to obtain step time, width and length [Fig 2]. Parameter variability was characterised by the standard deviation and coefficient of variance. Waist markers were used to obtain gait speed. Toe clearance and its variability (IQR) were derived using a simulated marker [5] [Fig 3].

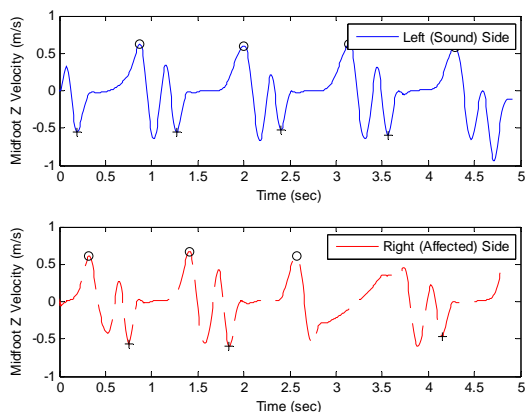


Fig 1: Derivation of heel strike(+) & toe-off(o).

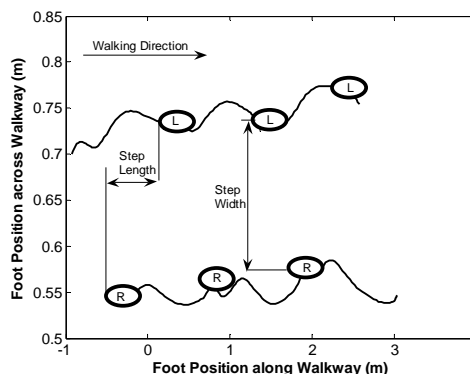


Fig 2: Derivation of step width and length.

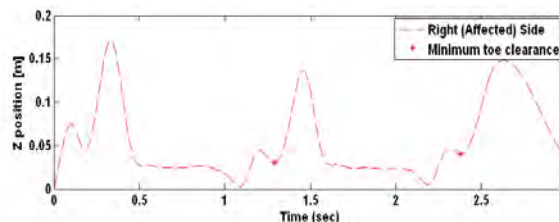


Fig 3: Derivation of toe clearance.

5. Discussion and Conclusions

It proved possible to collect gait event data associated with risk of falls and trips, under all conditions. Initial analysis of the pilot data indicates that speed increased with use of FES, as previously reported and that dual-task conditions reduced speed. Toe clearance on the affected side and step width appear to be altered by the addition of a memory task. These preliminary findings require further investigation. Recruitment of further subjects is planned.

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Electrotactile feedback for trans-femoral amputee gait re-education

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1. Introduction

There has been renewed interest in the application of biofeedback for gait and posture re-education. Electrical stimulation is one means of presenting feedback stimuli to patients and has been used with amputees to provide knowledge of gait event timing through implanted and surface stimulation of discrete anatomical regions [1, 2].

Electrotactile displays (ETD) use an array of electrodes to present information through transcutaneous electrical stimulation, thus providing spatial resolution for information coding. ETDs have found various uses. For example Vuillerme has developed a device to present information about ankle orientation to the tongue [3].

2. Aims

This paper briefly describes the development of a prototype stimulator and electrode array that will provide real-time electrotactile feedback to trans-femoral amputees undergoing gait re-education.

3. Method

During treadmill training, for example to minimise circumduction or abduction gait patterns, amputees will receive feedback about thigh orientation through an electrode array worn around the circumference of the residual stump. Thigh kinematics will be determined using a ProReflex motion capture system (Qualisys, Sweden). A programme has been written in LabVIEW to read marker coordinates from the Qualisys software in real-time via a TCP/IP connection. Joint angles are then calculated and will be used to drive a surface sensory stimulator. The flexible electrode array will consist of a ring of active electrodes surrounded by a single reference, to allow the sense of stimulation to move across the thigh surface. Sixteen channels are being considered. To account for variations in afferent sensitivity, patient feedback will be acquired during a static calibration process. During operation stimulation will occur if the patient's gait moves outside limits set according to individual clinical goals. Information will be conveyed through stimulus intensity and the spatial location of the active electrode. Figure 1 shows a graph of hip joint flexion / extension against abduction / adduction, at an instance in the gait cycle, with a transverse section of a patient within a standard deviation band for normal flexion, but with excessive abduction, as may be

seen in an amputee circumducting through swing. The active electrode is selected according to the angle of the vector connecting the two crosshairs. Stimulus intensity is proportional to the vector magnitude.

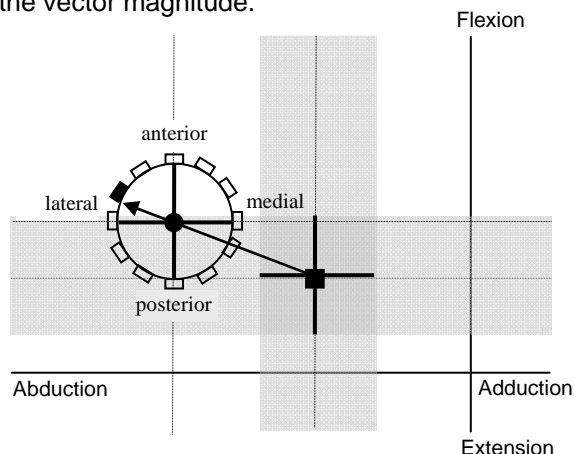


Figure 1: Scheme for electrode selection and stimulus intensity. The cross with the square represents the mean and standard deviation of normal sagittal and coronal hip angles at an instant in the gait cycle. The cross with the circle represents the patient undergoing training. For clarity a reduced number of electrodes are shown.

4. Discussion and Conclusions

Factors being considered before practical implementation include: the trade off between electrode resolution; pain threshold and the spatial information content; flexible array materials; and the overall stimulus presentation in accordance with theories of motor learning.

5. Acknowledgements

The authors would like to acknowledge the support from staff of the Douglas Bader Rehabilitation Centre, Queen Mary's Hospital.

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Catch-like Stimulation – its Effect on Spinal Reflexes and Muscle Activation

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1. Introduction

When discussing the effects of electrical stimulation there appears a tendency for only direct motor rather than afferent or antidromic motor effects to be considered in the literature. Excitation or inhibition of spinal reflexes due to such affects is not well understood and may partly account for observed enhanced torque when using catch-like stimulation with subjects. The catch-like effect is inherent to skeletal muscle and describes the torque augmentation seen when two or more high frequency pulses (e.g 5.0ms spaced doublet) are applied at the start of a low frequency train of electrical stimulation [1]. Doublet discharge patterns are also observed during sudden voluntary contractions and catch-like stimulation may liken this natural activation pattern more effectively than conventional constant frequency stimulation.

2. Aims

This study aims to improve understanding of conventional and catch-like stimulation on spinal reflexes such that both can be utilised more effectively in clinical Functional Electrical Stimulation (FES) systems. The focus will be whether catch-like stimulation has an increased excitatory or inhibitory effect on spinal reflexes thus partly explaining the increased torque and reduced rates of fatigue observed when adopting such stimulation with human subjects. Muscle fibre types activated through spinal reflex pathways are thought to differ from those of direct motor stimulation and may have associated beneficial muscle training or conditioning effects.

3. Methods

3.1 Developed Instrumentation

A modified design EMG amplifier [2] enables electrical muscle activity to be recorded a few milliseconds after stimuli. Comprehensive control over stimulation pulses and patterns is provided by a computer controlled stimulator (Figure 1).

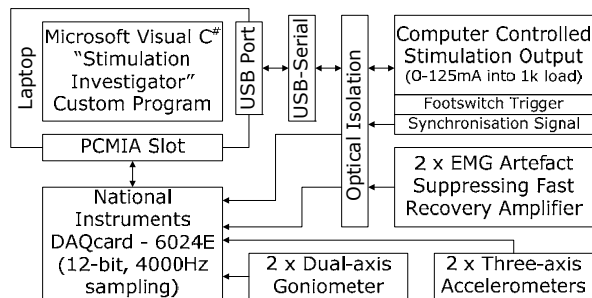


Figure 1: Instrumentation block diagram.

3.2 Protocol

Surface stimulation of the common peroneal nerve will test the research hypothesis. Data will be gained from unimpaired subjects and subsequently current drop foot stimulator users. A proposed protocol comprising 35 individual tests will assess the effects of:

- Single, doublet twitch and burst stimulation, with and without effort at different muscle lengths in sitting and walking.
- Single and doublet stimuli triggered from RMS EMG levels whilst under isometric load.
- Single and doublet stimuli triggered from joint angle whilst under isotonic load.

4. Results

Initial exploratory data from the author suggests:

- Substantial reflex mediated muscle activation due to single stimuli when applied during voluntary contractions (Figure 2).
- Variation in the compound muscle action potential amplitude over a burst of stimulation modulated by muscle length.

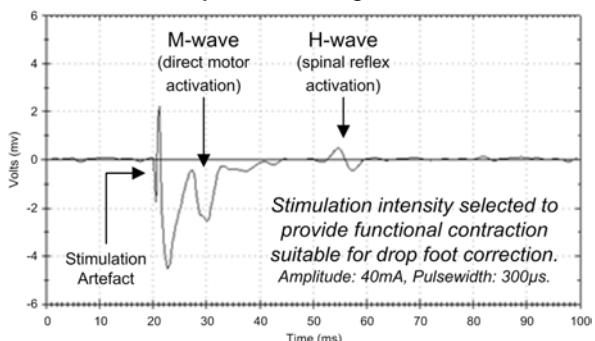


Figure 2: Mean tibialis anterior EMG response to single stimuli (n=10) applied during active dorsiflexion of foot without resistance.

5. Discussion and Conclusions

Due to mixed results and limited understanding the catch-like effect remains a largely experimental finding yet to be utilised clinically. Developed instrumentation enables further investigation of the effect whilst assessing the fundamental role of spinal reflexes during FES.

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A Statistical Approach to Myoelectric Control of FES Cycling

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1. Introduction

In a clinical study of foot-drop stimulator users [1], over 50% of patients with stroke and SCI achieved a 10% increase in without-stimulation walking speed. What causes this “carry-over” effect? The hypothesis is that FES combined with coincident voluntary effort causes motor relearning [2]. To test the hypothesis, an FES cycling system is being developed which stimulates with an intensity that is based on patients’ effort, assessed by muscle EMG. As part of the control system, a time series model is being constructed. It will be used to analyse the EMG signals statistically in order to determine the stimulation intensities applied.

2. Aims

To estimate the voluntary activity, the r.m.s. amplitude of the EMG signal is measured in a short time window after the stimulation pulse. Statistical analysis is used to find the appropriate time delay before the recording window from which the control signal to the stimulator should be extracted.

3. Methods

We recorded EMG from 4 able-bodied subjects who were asked to pedal with a fixed cadence for 10 revolutions. A cycling computer was used to control the resistance levels applied to the back wheel and hence the effort of the cyclist. For simplicity, one single stimulation pulse was applied to the Rectus Femoris (RF) per revolution with random change in 5 load resistances and 3 stimulation intensities. The EMG data was extracted in a 40ms window just before stimulation (pre-stimulus EMG signal) which represents the voluntary drive to the muscle without artefact and correlated to the signal extracted in 40ms windows starting T ms, from 30 to 110ms, after the stimulus (post-stimulus signal). The R square values of the post-stimulus EMG signals and the pre-stimulus EMG signals with different window delays were compared.

4. Results

The post-stimulus windows starting in the range of 65-80ms give best correlation to the pre-stimulus windows despite the fact that there are other effects or reflexes present. The same experiment was repeated on different days. Points in Figure 1 and 2 represent R square values of the post-stimulus and pre-stimulus EMG signals for 150 cycling revolutions (10 revs×3 intensities×5 loads) for the time windows.

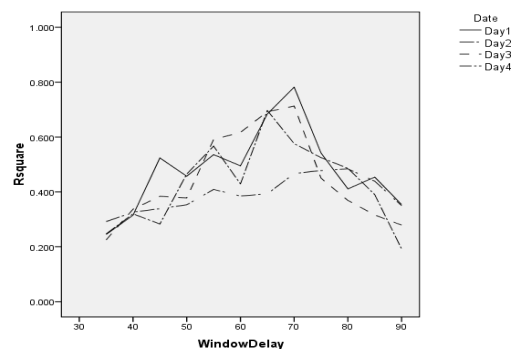


Figure 1: R square values vary with window delay for one subject on four different days

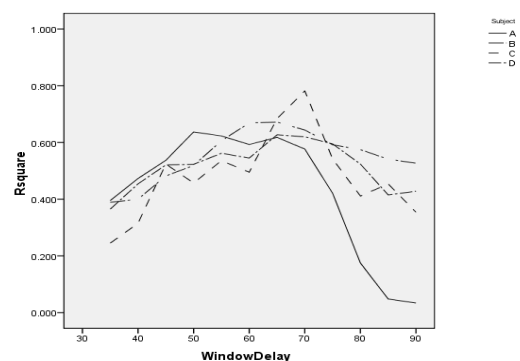


Figure 2: R square values vary with window delay for four subjects

5. Discussion and Conclusions

The statistical analysis of the experiment results has demonstrated that EMG measurement in an appropriate time window after the stimulation can provide a reasonable estimation of the true voluntary effort with an R square value peaks at 0.713 and a standard error of 0.028. However, in reality, multiple pulses must be sent to the muscle to produce enough force for the cycle movements. Stimulation patterns with irregular inter-pulse intervals will be used to allow enough time between consecutive stimulation pulses for the extraction of the voluntary drive signal.

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Higher-Order Sliding Mode Control of FES-Cycling: A Simulation Study

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1. Introduction

It has been demonstrated that FES cycling is beneficial in that it leads to improved fitness in peripheral muscular, elevated cardiorespiratory activity, and reduced atrophy of skeletal muscle. To evaluate the physiological effects of FES-cycling, it is crucial that both cadence cycling and workrate are well controlled. Daily changes in patients' physical condition, highly non-linearity and time-varying properties of stimulated muscle, and occasional occurrence of spasticity are major impediment to the development of FES-cycling control system. Moreover, the complexity of the interface between the ergometer and stimulated limb can make the design of a system controller even more complicated.

2. Aims

Sliding mode control (SMC) is a well-known and powerful control scheme to deal with the uncertainties, nonlinearities, and bounded external disturbances [1]. The main drawbacks of classical first-order SMC are principally related to the so-called chattering. The higher-order sliding mode (HOSM) approach has been actively developed over the last two decades not only for chattering attenuation but also for the robust control of uncertain systems with relative degree two and higher. In this work, we employ a second-order SMC for control of cycling cadence and evaluate its performance under different conditions of operation such as fatigue and external disturbance.

3. Methods

The main idea behind higher order sliding modes is to act on the higher order derivatives of the sliding variable, s , rather than the first standard sliding. The main problem in implementation of the HOSM is that any r -sliding controller keeping $s^r = 0$ needs $s, \dot{s}, \ddot{s}, \dots, s^{(r-1)}$ to be available. One of the known exclusions is a so-called "super twisting" 2-sliding controller, which needs only measurement of s . In this work, we use 2-SMC with super-twisting algorithm for control.

A model of rider-tricycle system developed in [2] is used for evaluating the control strategy. The model consists of two double pendulums, each consisting of a thigh and a shank and attached to a fixed point at the hip. Both pendulums have two degrees of freedom, which can be expressed as the hip and knee angles, but the endpoints are constrained to move on a circle around the center of the crank. Further details are described in [2].

4. Results

Figure 1 shows the results of cadence control using HOSM. It is observed that an accurate tracking control can be achieved using HOSM. Interesting observation is the fast convergence of the control strategy.

To evaluate the ability of proposed control strategy to external disturbance rejection and fatigue compensation, the muscle input gains were asymptotically decreased to 50% of its original value over 120 s and a constant torque in amount of 8 Nm was subtracted from the torque generated at the crank. Figure 1 shows the results of fatigue compensation and disturbance rejection.

5. Discussion and Conclusions

The results indicate the robustness of the proposed control system against muscle fatigue and external disturbances. In particular, no mathematical model of the system is required.

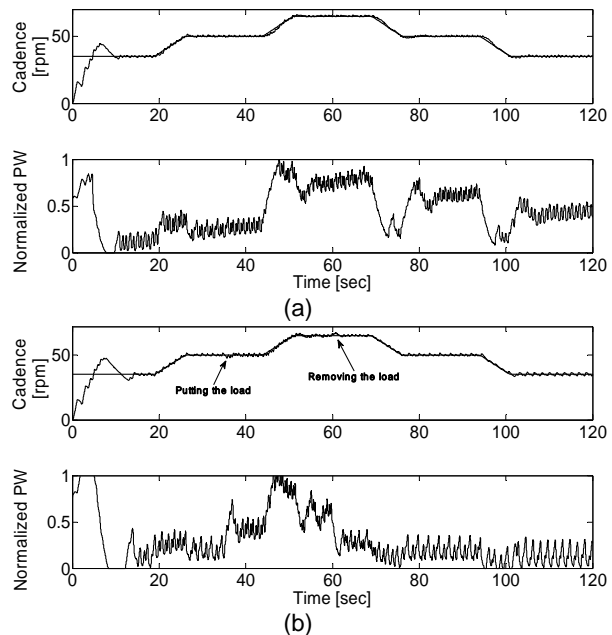


Figure 1: Control of Cadence using second-order SMC: (a) fatigue compensation, (b) disturbance rejection.

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The therapeutic benefits of electrically stimulating denervated muscle

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1. Introduction

Denervation of limbs results from trauma to peripheral nerves or spinal roots. It produces a paralysis more serious than that caused by upper motor neurone injuries. Severe muscle wasting and fibrofatty infiltration is followed, after about 12-18 months, by progressive necrosis. Because of the lack of cushioning the patient is at increased risk of developing pressure sores, and bones become osteoporotic. To stimulate such muscles electrically requires intense currents, but limited clinical trials produced such striking improvements that a 4-year multicentre trial was funded by the EC (Project "RISE").

2. Aims

This paper will review the results of the associated programme of animal experimentation designed to investigate what could be achieved by stimulating denervated muscles under closely controlled, highly reproducible conditions [1-5].

3. Methods

Selective motor branch denervation in the rabbit proved to be the experimental model most relevant to the human condition. Stimulus patterns were generated by an implantable device designed specifically for the study [4]. To reflect clinical reality, stimulation was applied to muscles with established denervation atrophy (mass about 40% of normal). Ten weeks after denervation, rectangular bipolar constant-current pulses, 20 ms per phase, at 20 Hz, with a duty cycle of 1s ON/2s OFF, were delivered in an hour-long daily session (24,000 impulses/day, Pattern 1). The response was studied after 2, 6, and 10 wks of stimulation. Another group was denervated for 39 wks and stimulated for 12 wks. We also examined the effect of doubling the impulses/day (Pattern 2), dividing the stimulation into two sessions of 30 min each (Pattern 3), using 20 times the amount of stimulation (Pattern 4), and delivering the same daily number of impulses in one third of the time (Pattern 5).

4. Results

Stimulation restored the wet weight of the denervated muscles to values not significantly different to those of normal, innervated controls. Cross-sectional area increased from 38% to 66% of normal, and maximum isometric tetanic force rose from 27% to 50% of normal. Shortening velocity and power were significantly elevated. Light and electron microscopic examination revealed marked improvements in the size, packing, and internal organization of the

stimulated-denervated muscle fibres. However, 10 wks' stimulation failed to restore control levels of excitability or excitation-contraction coupling, probably because of unresolved changes in ultrastructure. Mitochondrial density was higher in both denervated and denervated-stimulated muscles, but fatigue resistance was still poor. Results were similar when 39 wks' denervation was followed by 12 wks' stimulation [1]. There was no observable difference in outcome for any of the patterns studied (Patterns 1-5) [3].

5. Discussion and Conclusions

Irrespective of pattern, long-term electrical stimulation delivering sufficient daily impulse activity significantly restored muscles with established denervation atrophy. The marked increase in muscle mass, also seen clinically, confers important secondary benefits; these include better skin cushioning, with less risk of pressure sores, and enhanced appearance and self-esteem. If intervention is commenced early, force generation recovers sufficiently for short periods of standing and even walking between parallel bars. Such activity offers additional benefits: greater mobility, better blood supply to muscle and skin, improved cardiovascular fitness, and increased bone mineral density.

6. Acknowledgements

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Modelling and Control of Paraplegic Knee Joint

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1. Introduction

In order to develop a suitable control strategy for the FES to move the leg correctly, a proper model of stimulated muscle has to be used at the simulation stage. Characterization of electrically stimulated joint is complex because of the nonlinearity and time varying nature of the system with interdependent variables. The method of the FL appears very useful for modelling and control when the process involved is too complex for analysis by conventional quantitative techniques or when the available sources of information are uncertain. In this paper a model structure of the knee joint is formulated with genetic optimization using fuzzy logic (FL) using experimental data and FL controller is developed accordingly.

2. Aims

The aim of this paper is to describe about modelling and control of paraplegic knee joint using FL and genetic algorithm (GA).

3. Methods

The subject participating in this work was a 48 year-old T2&T3 incomplete paraplegic male with 20 years post-injury with height = 173cm and weight = 80kg.

3.1 Modelling

The anthropometric inertia parameters of the subject's lower limb and passive viscoelasticity were optimised based on passive pendulum test [1]. Then, the active properties including muscle activation and contraction are modelled using fuzzy system based on electrically stimulated leg test. The shank-quadriceps dynamics are modelled as the interconnection of passive properties and active properties. The total knee-joint moment is given by [2]

$$M_i = M_a + M_g + M_s + M_d \quad (1)$$

where M_a refers to an active knee joint moment, M_s is the knee joint elastic moment and M_d is the viscous moment representing the passive behaviour of the knee joint. In this study the $M_i - M_g$ is represented by equation of motion for dynamic model of the lower limb and $M_s + M_d$ is represented by a fuzzy model as passive viscoelasticity.

3.1 Control

FES induced movement control is a significantly challenging arena for researcher. The control problem is to design a fuzzy controller such that

the knee joint tracks the desired trajectory as closely as possible for all time in spite of the uncertainties and non-linearities present in the system.

4. Results

The estimated knee joint model consists of the passive muscle properties, active muscle properties and segmental dynamic of lower limb as shown in Figure 1 are exhibited good prediction capabilities.

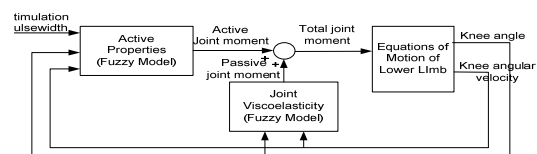


Figure 1: A knee joint model

Thus a model developed can be utilized as platform for the simulation of the system and development of control approaches. The optimised Mamdani type fuzzy logic controller with two inputs error and derivative of error is used to follow a reference trajectory. The control system shows good performance, with a small error between the actual and reference trajectories with less than 3° .

5. Discussion and Conclusions

A new approach of modelling the knee joint of a paraplegic has been presented. The active and passive properties of muscle model are modelled with fuzzy system by optimizing the membership functions, weight rules and scaling factors using GA. An optimized FL controller has been developed to regulate the amount of stimulation pulsewidth to move the leg to the desired knee joint trajectory. A generic methodology has been presented that can be adopted for accurate model and control of the knee joint specific to individuals with SCI.

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