FES-Rowing

Training Guide

Draft Version 1: January 2007

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With Forwards by:

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FES-Rowing Training Guide

About this Guide

The FES-Rowing Training Guide was developed by *FESrowing Ltd*, www.fesrowing.com. It is designed for people with Spinal Cord Injury (SCI) to safely participate in Functional Electrical Stimulation (FES)-rowing training following initial training under the *FESrowing*™ Training Programme. This guide details the recommendations and protocols that have evolved to minimise the risk of injury. This guide also covers the operation and maintenance of the FES-rowing system and provides a comprehensive background to all known medical considerations.

As research progresses, updates to this guide will be issued. *FESrowing*™ would appreciate any comments or suggestions regarding the content of this guide to ensure that it is not only up to date, but easily understood and correct in its detail. Please contact Robin Gibbons on 44 (0) 77906 770423 or email fes@fesrowing.com.

Disclaimer

Disclaimer
The information within this guide is not intended to be a substitute for medical advice. By its very nature FES-rowing is an intense form of exercise and as such is physically demanding. This risk along with the other specified risks of FES-rowing detailed in this guide are designed to ensure that no harm can come of anyone wishing to take part in this form of exercise, by providing sufficient information for participants to safely manage these risks.

The author accepts no responsibility for illness or injury resulting from using this guide or any associated documentation.

Robin Gibbons
Director, *FESrowing Ltd*

Specialist Training Centres

ASPIRE National Training Centre, www.aspire.org.uk
London Regatta Centre, www.london-regatta-centre.org.uk
University of Alberta, Canada, www.ualberta.ca

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FES-Rowing Training Guide

Forward by the Author

This document is the first of its kind that attempts to deal with Functional Electrical Stimulation (FES) in association with assisted exercise. There have been a number of significant issues to solve before an attempt could be made to produce a document that is informative with content that follows health and fitness industry accepted standards, is correct neurologically, physiologically and that follows NHS protocols medically in terms of risk management. The mechanics and electrical devises used with the standard Concept2 model 'D' indoor rowing ergometer have are approved by the Brunel University Research Ethics Committee.

The first of the many issues is the fact that rowing coupled to the stimulation of paralysed muscles has never been done before. It is cutting edge fitness technology. FES has been used with recumbent cycling since the early 1980's, but its use where rowing in concerned was first conceived ten years later by Dr Garry Wheeler and Prof Brian Andrews, a research group at the University of Alberta, Edmonton, Canada in the early 1990's. Prof Andrews continued to develop this exciting earlier research when he took up a position at Brunel University in the late 1990's. In functional terms, FES-rowing has only been in existence in this country since early 2003 and used practically in mainstream leisure centre settings since October 2005.

The adapted Concept2 indoor rowing ergometer being used is a research prototype and as such is severely restricted in its available use to venues approved by Brunel University's liability insurance. A manufacturer is being sourced that is able to take on the design and production of a commercially viable FES indoor rowing system. In the interim, the availability, at least in the UK, is being extended by involving other university's working on FES assisted exercise projects as well as encouraging NHS Spinal Cord Injury Centres to adopt this unique opportunity to further the rehabilitation of people with spinal cord injury.

Although there has been a considerable amount of research into the use of an electrical current to stimulate paralysed muscle, this research is still on-going with new findings being made from time to time. The Brunel University research team continue to trial the best ways to train paralysed muscle in a safe and effective way. The training sections of this guide are based on the author's direct experience and involvement in the Brunel University research team since May 2003. They are also based on the application of the author's experience as a YMCA / RSA physical training instructor. The training errs on the side of safety to minimise risk to the participant as a consequence of the lack of feedback from individual's compromised sensory function.

The FES-Rowing Training Guide should therefore be considered purely as a guide. It is possible that as new research comes to light, changes to this guide will become necessary. In addition it is a vast subject. As a consequence, the author would appreciate any comments regarding the content of this guide from anyone participating in FES-rowing training or participating health professionals to ensure it is not only up to date, but meticulously correct in every detail.

Robin Gibbons, Brunel University

FES-Rowing Training Guide

Forward by Professor Brian Andrews, FES-Rowing Research Lead, Oxford Brookes University

Robin Gibbons has provided an excellent guide for those involved in FES-rowing in the community following initial training in the research environment. The guide represents an important step in the further development of FES-rowing that aims to offer future options for physical exercise, leisure activity and sport for those with spinal cord injury.

Many people with SCI have insufficient fitness to achieve and sustain the exercise levels that are known to reduce the risk for cardiovascular disease and type-2 diabetes in the general population. Whilst some can achieve these high aerobic exercise levels using their upper limbs, there are concerns for overuse injuries. However, exercise intensity, volume and limb loading, can be safely increased by involving the paralysed muscles using FES.

FES-rowing was developed as a whole-body, low impact, cardiovascular exercise in which the pulling actions develop upper limb muscles that oppose those involved in wheelchair propulsion. The latter may balance the force actions across the shoulder and help prevent or provide therapy for overuse injury. FES rowers have now successfully competed alongside able-bodied rowers, in international indoor rowing championships, over the Olympic 2,000m distance. Marathon distances have been attained and presently distances up to 50,000m have been officially recorded. Future developments anticipate increased performance, an internet connected club, home-based systems and the development of on-water programs.

Brian Andrews, Oxford University

FES-Rowing Training Guide

Forward by Dr Angela Gall,
Spinal Consultant, Royal National Orthopaedic Hospital

The role of exercise in improving health is well known in the general population. Exercise can reduce the risks of heart disease, high blood pressure, high cholesterol, obesity and diabetes. What is also increasingly recognised is that individuals with spinal cord injury are at greater risk of these conditions. Several scientific studies now have shown that sports and recreation can offer many physical and psychological benefits to those with SCI who participate. FES-rowing is one such opportunity and the intensity of the exercise individuals can achieve is higher than any other form of exercise for SCI individuals.

FES-rowing is relatively new and therefore we continue to learn about possible benefits and risks from further research. This guide has been carefully developed to ensure established rowers can move from the hospital / research environment and continue their exercise in the community and is comprehensive, with safety of prime importance. I look forward to seeing the benefits this form of exercise and recreation can bring.

Angela Gall, Royal National Orthopaedic Hospital

FES-Rowing Training Guide

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I would like to thank Prof Brian Andrews, Research Lead, Oxford Brookes University, Dr Angela Gall, Spinal Consultant, Royal National Orthopaedic Hospital, Dr Eva Carneiro, Specialist Registrar Sports and Medicine, London Deanery Programme, Dr Dries Hettinga, Research Investigator, Brunel University and Sara Wicebloom, IFI Training Co-ordinator for YMCA Fitness Industry Training for their professional help, advice, recommendations and time that they have so generously given towards the content of this guide.

I would also like to acknowledge the many institutions that have made this project possible; in particular the University of Alberta, www.ualberta.ca where the initial concept of this form of exercise was first borne and more recently Brunel University, www.brunel.ac.uk and Oxford Brookes University, www.brookes.ac.uk for the research that they have supported.

Many thanks too to Concept2 UK, www.concept2.co.uk for their unwavering support, encouragement and sponsorship especially with regard to the promotion and establishment of FES-rowing at the annual British Indoor Rowing Championships www.concept2.co.uk/birc/ in Birmingham since 2004, and the World Indoor Championships www.crash-b.org/ in Boston in 2006, the Charity DEMAND, www.demand.org.uk for their help in the design, manufacture and modification of the mechanical adaptations to the Concept2 rowing ergometer and the National Clinical FES Centre, Salisbury HNS Trust, www.salisburyfes.com for their help, technical advice and supply of their 4-channel 04CHS muscle stimulator.

Of course none of this research would have been possible without some serious funding. I would like to acknowledge the following charities that have so generously sponsored the FES-rowing project;

The Spinal Cord Injury Treatment Centre Society, Edmonton, Canada, www.scitcs.org
The Trusthouse Charitable Foundation, www.trusthousecharitablefoundation.org.uk
The David Tolkien Trust for Stoke Mandeville, www.buckshealthcare.nhs.uk/
The Henry Smith Charity, www.henrytrustcharity.org.uk
The INSPIRE Foundation, www.inspire-foundation.org.uk/

Finally, special thanks to two training centres that have helped support the initial transfer of this project from the research environment to the leisure community; the London Regatta Centre, www.london-regatta-centre.org.uk and The ASPIRE National Training Centre, www.aspire.org.uk. It was these two centres that supported the first pilot studies to investigate the viability of training SCI individuals using FES assisted exercise. The London Regatta Centre is also sponsoring the further development of this form of exercise on-water.

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1 Introduction

1.0 Limited Whole Body Training Effect

One of the many issues affecting people who suffer from paralysis is finding ways to keep fit and active and by so doing, maintain a long and healthy life. In individuals who have paralysed lower limbs, any sport or leisure activity involves the exclusive use of upper limbs. The muscle mass in the upper body is small compared to the rest of the body which has implications for the maximum intensity that can be achieved with an upper body exercise alone. This limited amount of active muscle mass is also being used for all other activities which increase the risk of upper body overuse-type injury. In view of these issues, exercise possibilities for persons with SCI are limited and this raises concerns for coronary heart disease, exercise-related diabetes and obesity. Further, the lack of weight bearing and active muscle-induced lower limb loading also results in a rapid loss of bone mineral density (BMD). FES-rowing therefore, offers a choice for individuals with SCI to adopt a more active life style and could play a role in reducing the risk of cardiovascular-related disease and loss of lower limb BMD.

Functional Electrical Stimulation
Electrical stimulation of paralysed limbs was an option that was first considered more than 25 years ago by a few extraordinary scientists. Research was conducted into the possibility of using FES for propelling a tricycle, stationary cycling, standing and even walking. However, over the years it has become clear that FES can also be used very successfully for health and fitness in a community based exercise setting.

FES will not be for everyone, but for others it will hold some interest in having two brand new activities to choose from, recumbent tri-cycling and rowing ergometry. Both have health benefits and both involve electrically stimulating the lower limbs. This guide has been written for those individuals who wish to take up FES-rowing. It is hoped that it will become more than just a training guide, rather a source of reference, which takes the rower through all aspects of FES-rowing, based on research that has come together over the last few years.

Under development
FES-rowing is still very much in its infancy and although the ASPIRE National Training Centre and the London Regatta Centre are both now offering FES-rowing training, the Concept2 based rowing system and the muscle groups being stimulated are still under development by the UK FES-Rowing Group currently based at Brunel University. In addition, there are also a number of manufacturing and production problems to overcome before a commercially viable system becomes widely available.

However, what has already become apparent is that the present 4-channel FES-rowing system appears to have very far-reaching health benefits over any other currently available FES system or activity for people with SCI. In addition, there is a less obvious psychological and emotional benefit, in that the individual affected is involved in an activity that is an ***able-bodied*** activity! Of even more significance is the fact that the individual also has the joy of an activity that enables them to use parts of their body that they had previously considered unusable! It is hoped to run a parallel study into the psychological benefits of FES-rowing in due course.

1.1 Health Benefits

Coronary heart disease, exercise-related diabetes, and obesity
FES-rowing was the result of extensive and ongoing research into finding a means of improving the general health of individuals with a SCI. It was reasoned that involving more muscle groups, in theory at least, should to enable an individual with SCI to work out at far higher levels exercise volume and intensity. The research centred on the hypothesis that if energy levels were high enough it may be possible for the risk of serious medical conditions like cardiovascular-related disease to be reduced, and if diagnosed early enough, possibly even reversed. This would give people with SCI another choice in combating these debilitating and possibly life-threatening conditions other than by the use of pharmaceutical intervention strategies.

Although only 30 or so individuals have been involved in FES-rowing in Canada, and 14 here in the UK, there are indications that significant increases in energy output are possible. One individual has increased oxygen consumption by over 60%, to almost 3.0 litres per minute, a very high value for someone with SCI and close to values in the general population.

Musculoskeletal health
Overuse syndrome of the upper limbs in SCI individual's is another condition that might be helped as a result of the unique forces being produced by the action of rowing. It is not uncommon for long-term wheelchair users to suffer from this condition. Essentially, nearly all power movements that are required of a wheelchair user, in both propelling and transferring require arm extension and the almost exclusive use of the muscles located on the anterior side of the trunk. FES-rowing is unique in that the action requires an arm flexion and the use of the muscles on the posterior part of the shoulder and trunk. As such, this action appears to help stabilize the shoulder girdle as well as helping to strengthen the muscles of the upper back with the retraction of the shoulder blades.

Of even greater clinical importance, FES-rowing may generate sufficient skeletal forces, particularly in the lower limbs, to improve BMD especially in the lower limbs. This may lead to a reduction in the high incidence of pathologic fractures seen in individuals with SCI which predominate in the area of the knee.

1.2 FES-Rowing is Born

Dr Garry Wheeler and Professor Brian Andrews co-invented and developed the early 4-channel FES-rowing system in the early 1990's. A rowing modality was chosen as a platform where voluntary upper body exercise could be concurrently used with FES-assisted lower limb exercise. It was believed that this exercise combination would optimise an individual's cardiovascular workout.

This early work was supported by a cohort of people with SCI and their friends which became known as the Spinal Cord Injury Treatment Centre Society (SCITCS). SCITCS initially set up an FES clinic in the Steadward Centre www.scitcs.org located in the University of Alberta where they established a commercially available ERGYS FES-cycle system from the USA in the 1980's. The ERGYS system was developed by the FES pioneer Gerald Petrofsky. However, FES-cycling only involves the legs and Wheeler & Andrews sought a practical whole-body exercise; the history of FES-rowing began.

Professor Andrews brought the initial FES-rowing concept over to the UK and with doctoral researcher Dries Hettinga continued to develop the idea along with their first FES-rower Rob

Holiday. Robin Gibbons was the next SCI rower to join the Brunel University research team, eventually replacing Rob Holiday in May 2003.

The first working prototype FES-rowing system

The first working prototype 4-channel FES-rowing system was completed a year later. It is this device that was first used by Robin Gibbons and Sol Solomou on 19 November 2004, when they made history by taking part in the annual British Indoor Rowing Championships

Figure 1: Brunel University's prototype FES-rowing machine.

(BIRC) in Birmingham. This FES-rowing system is now being used to establish the first FES-rowing training programme at the ASPIRE National Training Centre and the London Regatta Centre.

1.3 The FES-Rowing Guide

General

This guide is designed for individuals with SCI who wish to take part in FES-rowing. Although it is not a formal research project, detailed medical and performance records will be kept on all participants to accurately monitor an individual's progress and response to training. It assumes that an individual has no previous experience of FES and that they have no more than average wheelchair fitness.

At the present time, 4-channel FES-roping only involves the stimulation of the quadriceps and hamstring muscle groups. These and the voluntary upper limb muscles muscle groups that enable an individual with SCI to row are shown in red and blue respectively in Figure 1. It is hoped that future developments will incorporate gluteus, soleus, gastrocnemius and tibialis muscle groups and possibly even the trunk musculature for individuals that have higher level lesions. These muscle groups are also depicted in red in the illustration below but appear in parentheses to differentiate them from the muscles that are presently being stimulated.

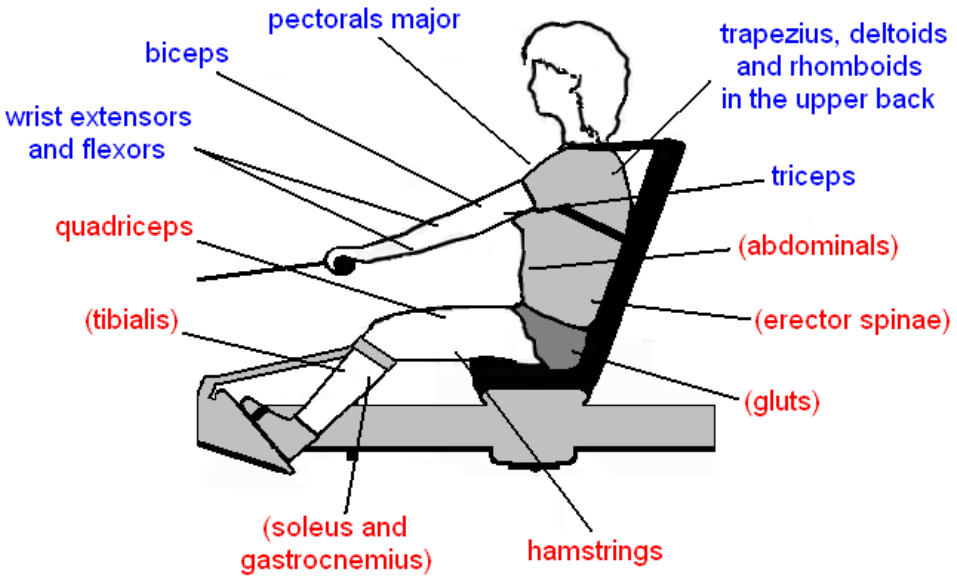

Figure 2: The primary muscle groups used when FES-rowing.
Red: FES-activated muscle groups; Blue: voluntary upper limb muscle groups; Red in parentheses: future proposed FES-activated muscle groups.

Medical
Chapter 2 covers the medical implications of using electrical stimulation. Detailed records will be kept on all individuals taking part in the FES-rowing programme to monitor progress throughout training. These records will also be used to help confirm the anticipated health benefits of FES-rowing in future research studies.

FES-training programmes
The training schedule in Chapter 4 is a performance-based programme. This is due to the fact that an individual's response to FES has a number of unknown variables associated with an individual's unique neurology. However, it is anticipated with three training session's per week, a trainee will be able to start rowing in approximately four weeks. It is possible in the case of individuals with more recent or complete injuries that some trainees will be able to commence the rowing at a much earlier stage than indicated in the training programme.

1.4 Motor Point Test

It should be noted that in some individuals FES will not work. During FES, an electrical current stimulates the nerves that supply the quadriceps and hamstring muscles. These motor nerves originate in the spinal cord. If these nerves are damaged, FES will not result in a muscular contraction. This could be the case in persons with low-level lesions starting at or below thoracic vertebrae T10. Such damage can also occur in people with extensive spinal cord damage below the level of their diagnosed lesion when the lesion is above the T10 level. A simple test will be performed as part of the joining routine to establish an individual's response to FES. This test is called a motor point test. Blood pressure and heart rate will also be monitored throughout the test for signs of autonomic dysreflexia particularly in individuals with lesions above thoracic vertebrae T6. It should be noted that even if the electrical stimulation does not initially work, a re-test is recommended as an individual's neurology, and therefore response to FES, can change over time.

2 Medical Issues

2.0 Ground Breaking Technology

FES-rowing is ground breaking technology. For the first time, an activity is now available for individuals with SCI to train at exercise intensities approaching those of their able-bodied counterparts. This requires a method of protecting participants from exercise-induced injury. In addition, some individuals may find the electrical stimulation very uncomfortable or even unacceptable. At the present state of development, it is not possible to cater for individuals who do not respond to electrical stimulation. For individuals with cervical level injury with weak hand and arm function, a procedure involving carers and family members has been successfully employed to activate the channel selection on behalf of the rower (Sub-section 3.2). In addition, specialist neoprene gloves with Velcro closure was successfully used to secure the hands to the FES-rowing ergometer handle www.activehands.co.uk/.

2.1 Joining Routine

There are risks associated with high intensity exercise for individuals with SCI. To limit these risks, anyone wishing to participate in an FES-rowing programme will be given a set of instructions which safely guide the individual through the issues to be addressed.

Joining Instructions
These instructions comprise a set of notes to guide the prospective rower and the rower's GP through the joining routine. In addition, the instructions will include a GP / Consultant Consent Form which the GP is requested to sign on successful completion of the consultation appointment. Although these notes are very comprehensive, should an a concern or a question arise, the volunteer should contact Robin Gibbons on 07906 770423 or email robin.gibbons@virgin.net.

2.2 Initial GP Consultation

In the first instance, all volunteers are requested to make an appointment with their GP. There are forms and guidance notes for the GP covering the specified issues that should be discussed with the individual wishing to participate in an FES-rowing programme. There are no absolute contraindications of trying FES-rowing however, volunteers should be aware of the potential risks involved and manage these risks appropriately. The following risks are should be discussed with the family GP (recommendations in bold print):

- FES-rowing is a high intensity form of exercise therefore the usual precautions in uncontrolled diabetes and coronary heart disease (CHD) apply. ***We recommend the following criteria be carefully considered: family history of CHD, cigarette smoking, hypertension, hypercholesterolemia, impaired fasting glucose, obesity and s sedentary lifestyle.***

- Males over the age of 45, and females over the age of 50 are deemed to be at greater risk of a cardiac related incident when participating in high intensity exercise and should be aware of this. ***Volunteers who are considered at significant risk are strongly recommended to undergo a thorough medical examination prior to volunteering for an FES-training study.***

- The risk of pressure sores and skin marking from sitting on a different surface and / or transferring on and off the rowing machine. ***Participants are to observe NHS skin care management recommendations which will have been discussed by an individual's spinal consultant and specialist skin viability nurse.***

- Whilst individuals with a SCI at or above T6 are taught to recognise the symptoms of autonomic dysreflexia and where necessary self-treat this condition, they should be aware that FES can cause this. ***Participants that are susceptible to this neurological response or who have a SCI at or above T6 are to ensure they have a supply of in-date vasodilation medication with them during a motor point test and if included in a study, ALL subsequent FES-training sessions.***

- Some participants may experience an increase in muscle spasms or neuropathic pain and should be aware of this.

- Normal range of motion at hips, knees and ankles is required in order to FES-row safely and effectively. ***Volunteers must be able to achieve full extension and flexion of both knee joints in addition to a normal range of motion in hip and ankle joints.***

- Transfer on and off the FES-rowing machine is a potential risk. ***Participants are to strictly observe current NHS transfer guidelines and recommendations.***

- There is risk of low trauma fracture in individuals with osteoporosis. ***Volunteers for an FES-training study are strongly recommended to be referred for a bone mineral density DXA scan if there is a concern a significant risk of osteoporosis exists in the lower limbs.***

- There is also an elevated risk of fracture due to the loading of bones in the leg and foot as a consequence of FES-induced muscle contractions when FES-training during a biomechanical assessment. ***Volunteers for an FES-training study are recommended to be referred for a bone mineral density DXA scan if there is a concern a significant risk of osteoporosis exists in the lower limbs.***

- DXA and pQCT scans use low dose radiation. As a consequence there is a slight increase in the risk of cancer with these forms of imaging. In the lower limbs, this is equivalent to approximately 3 hours of background radiation with DXA scans and 6 to 17 days of background radiation with pQCT scans. Background radiation is defined as the amount of natural radiation everyone is exposed to during the course of a year.

- ***FES-rowing is not suitable for individuals who have incomplete sensory function who may find the stimulation uncomfortable or even intolerable. It is also not suitable for individuals who suffer from severe autonomic dysreflexia. In addition it is not suitable for individuals with high-level lesions who cannot voluntarily fully flex their arms, or for individuals with low-level lesions who show no response to electrical stimulation.***

- Although FES-rowing has been used routinely in scientific studies since its début in 1993, to date, no known specific complications have been identified. However, as more people are becoming involved, it is possible that some side effects or complications may become apparent. ***As safety is our prime consideration,***

participants are asked to report any medical complications or adverse events that they may encounter during an FES-training study to the supervising research investigator as soon as practically possible.

On successful completion of the GP or Spinal Consultant consultation, volunteers for the FES-trained group should counter-sign the GP / Spinal Consultant consent form, and the Study Consent Form and contact Robin Gibbons at Brunel University on **07906 770423** or e-mail robin.gibbons@virgin.net to arrange a convenient start date. As the Study Consent forms are only valid for 6 months, any participant engaged on a longitudinal study will be asked to give their informed consent by signing subsequent consent forms.

As with any new exercise regime, there will be physiological changes experienced in individuals taking up FES-rowing. In some cases these could be far reaching and could be negative as well as positive. In view of this, the medical records will be reviewed at regular intervals to highlight any anomalies that need to be addressed.

2.3 Health and Fitness Checks

Two sets of records will be taken. The first will be used to determine any changes in the general health of the rower and the second to highlight changes in fitness.

Health Data
Detailed records will be kept on the following physiological parameters initially on joining, then as indicated in Table 1:

Test / Measurement / Assessment	Frequency
Height	On joining
Weighty	Monthly
Body Mass Index	Monthly
Thigh girth	Monthly
Resting blood pressure	Monthly
Resting heart rate	Monthly
Neuropathic pain	Monthly
Spasticity	Monthly
Muscular discomfort / pain	Monthly
Blood cholesterol	On joining / Annually
Bone mineral density	On joining / As required
Skin condition	After every FRS training session

Table 1: Health data records.
The body mass index is worked out by dividing the rower's weight in kgs by their height in metres squared. Any changes to perceived neurological pain, spasms, upper body muscular discomfort or pain and upper body joint discomfort or pain will be self reported on a scale of 1 to 10.

It is important that the glucose blood sugar and cholesterol level tests are conducted at the same time of the day usually during the morning after over-night "fasting" as the levels change markedly throughout the day, particularly after eating. A bone mineral density scan is requested, ideally within the month prior to starting FES-Rowing training. Thereafter, a further scan will be requested a year later to identify any changes to bone mineral density, as a percentage increase or decrease of the initial reading that has taken place as a result of the FES-Rowing training.

Fitness Data
The second set of records will be taken during and after each FES leg conditioning and FES-rowing training session (Table 2). This data will help determine any changes in the fitness of the rower:

Exercise frequency
Stimulation intensity
Total exercise time
Time to achieve 90^0 knee extension
Muscle strength (Medical Research Council assessment scale)
Knee extension angle
Total distance per training session
Total time
Average split time (time to row 500 m)
Average Watts (power output)
Stroke rate (number of strokes per minute)
Average exercise heart rate

Table 2: Top; FES leg conditioning data collection, bottom FES-rowing data collection.
Heart rate is taken at rest before, and again immediately after a workout. As heart rate will change very quickly after exercise, the quickest way to measure the number of beats per minute over 15 seconds if a heart rate monitor is not available.

2.4 Personal Checks

Skin condition
It is essential that all participants in the programme monitor their own skin condition during and immediately after each FES leg-conditioning (Figure 3) or FES-rowing (Figure 4) session. The main areas to be aware of during leg conditioning are the knee joint, feet and ankles, particularly when wearing ankle weights.

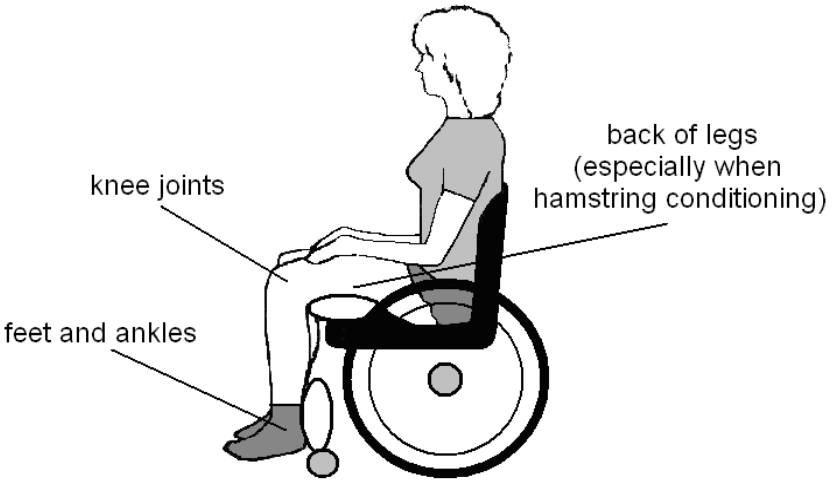

Figure 3: FES leg conditioning areas of skin vulnerability.

During FES-rowing the main areas of concern are the lower legs where the leg support straps are secured, the shoulders in the seat belt harness contact areas, the lower back and the buttocks in contact with the seat back and base. The seat base has a thin gel pad as standard. For most rowers this should be more than sufficient for the 30 minutes row. However, in participants who are known to suffer from pressure-related ulcers, a thicker gel pad may be required. In addition, all transfers off and on the FES-rower are strictly required to be in accordance with current NHS recommended practice. Finally, whilst arrangements will be in place to help with transfers, rowers should be mindful of their legs whilst transferring on and off the rowing machine.

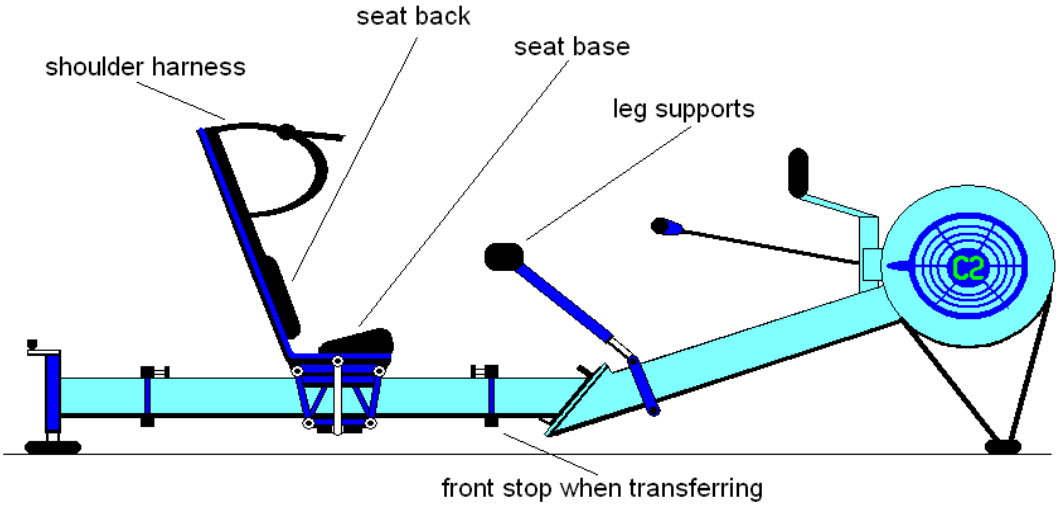

Figure 4: Concept2 FES-rowing machine areas of skin vulnerability.

Internal damage
Rowers are to check their legs, in particular the knee joint area, for any unusual swelling or bruising of the skin that could indicate internal tissue damaged during both leg conditioning and FES-rowing sessions.

Effect of electrical stimulation
Rowers should be aware that reddening of the skin under the electrodes is usual. This is caused by a local increase in blood flow as a result of the electrical stimulation. This effect only lasts for an hour or so after stimulation and is not harmful. Skin remaining red in excess of an hour after training may indicate an allergic reaction to the gel on the electrodes. In this case a different electrode can be tried. Contact Robin Gibbons on 07906 770423 to discuss.

Electrical stimulation, particularly at the higher intensities, can cause the bladder to go into spasm. For this reason, it is recommended that rower's completely empty their bladder prior to using FES.

Neuropathic pain and spasticity
Rowers are asked to be conscious of, and report, any changes in perceived neuropathic pain and / or spasticity that they experience. A self-assessed scale of 1 to 10 should be used. It is difficult to predict what the effect of FES has on the intensity and frequency of spasticity; some FES users might notice an increase in spasticity whilst others notice a decrease. Most FES users should experience a decrease in spasticity after an FES session as the muscle is fatigued. Some FES users that experience this condition report a correlation between neuropathic pain and electrical stimulation.

Muscle and joint discomfort or pain
Rowers are asked to report any changes in upper body muscle and / or joint discomfort or pain, again on a self-assessed basis from 1 to 10.

Autonomic dysreflexia
Individuals that experience autonomic dysreflexia should have the recommended in date medication available whenever electrical stimulation is being applied. It is essential that any FES session is terminated immediately if a rower feels a dysreflexia response. In most cases, cessation of the stimulation should stop the dysreflexic response.

2.5 Physiological Changes

Within a relatively short time after commencement of training, increases in lower limb muscular strength and endurance will be experienced. This combined with upper limb strength and endurance increases will result in an increase in energy output which in turn increases the demand on the cardiovascular system.

There also appears to be a number of peripheral benefits of the increased energy levels. A number of FES rowers have reported better breathing function particularly in those individuals with higher lesions who have paralysed intercostal muscles and who are solely reliant on their diaphragm for breathing. This appears to be the result of the increased training effect on the diaphragm and the muscles of the neck that are associated with the breathing function.

In addition, the increase in the use of the leg muscles appears to result in an increase in the capillarisation of the leg muscles. Although this has not yet been proven clinically, FES-rowers have reported warmer legs following chronic FES-training along with a more natural skin tone and hydration of the lower limbs. Further, the ability to change from an interval-training to a steady state non-stop FES-rowing regime would seem to suggest that the lactate build up in the rowers leg muscles is being cleared more efficiently due to improved circulation.

There also appears to be a significant amount of indirect stimulation of the peripheral, or synergist muscles of the lower limbs in addition to the quadriceps and hamstring muscles that are being directly stimulated. The abdominal muscles appear to be stimulated in a similar way.

Rowers also report that their shoulders feel more comfortable after chronic FES-rowing training. Although not scientifically proven, this would suggest that the upper limb rowing action has a stabilizing effect on the shoulder girdle due to arm flexion coupled to shoulder retraction. Analysis of the upper limb rowing action highlights the opposing action to the action in wheelchair propulsion and wheelchair transfers.

Finally, there are two other peripheral benefits of FES-rowing training. FES-rowers report that their digestive function appears to have been improved, which may be the result of better circulation generally coupled to the greater activity levels being maintained. Sleep patterns also appear to be improved. Again this may be the result of the greater activity levels being maintained coupled to a more relaxed state after exercising. Whilst these peripheral benefits are currently anecdotal, it is hoped they will be confirms in future scientific studies.

2.6 Stretching

As with any activity involving significant muscle activity, stretching before and after every FES leg conditioning or FES-rowing session is recommended to prevent injury, maintain optimal joint range of movement and promote better circulation. This section discusses recommendations for stretching the muscle groups used when FES-rowing (Figure 5).

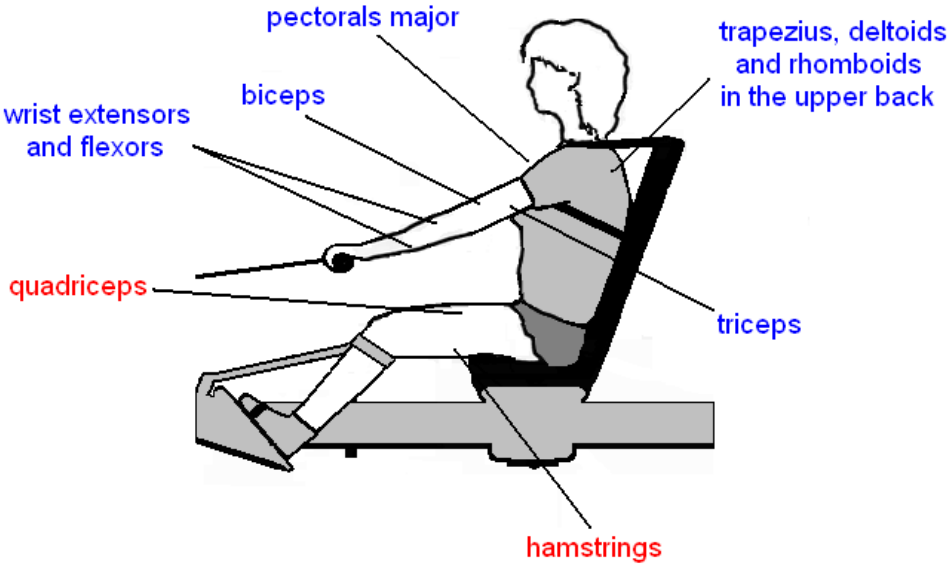

Figure 5: The primary muscles groups that are stretched when FES-rowing.
Red: stimulated lower limb muscles; Blue: voluntary upper limb muscles.

Stretching should be conducted with extreme caution to prevent any damage to muscle fibre and connective tissues especially in the lower limbs where minimal or no sensory feedback. Stretching feels good when it is done properly. Never use ballistic or "bouncing" technique when stretching, enter the stretch gently and with complete control. Each pre exercise stretch should be held for 10 to 20 seconds to prepare the muscles and joints for work and 30 to 40 seconds after exercising to maintain joint flexibility. The stretches should be held with just enough tension to maintain the natural flexibility in the joins being worked. Never try to move the joint beyond its natural limits.

The stretch reflex
All muscles are protected by a mechanism called the stretch reflex. If muscle fibres are stretched too far, a nerve reflex responds by sending a signal to the muscles to contract; this keeps the muscle from being injured. Whilst this is easily accomplished with preserved sensation, it is problematic in SCI, and especially complete injury. For this reason conducting a stretch on a paralysed limb should be done with even greater care.

Standing
If it is possible, standing both before as well as after FES leg conditioning or FES-rowing is one of the best ways of stretching out the legs. If this is not possible, the legs can be stretched out in the following ways.

Hamstring stretch
The basic hamstring stretch involves one leg at a time. This gives the rower complete control over the stretch especially if he or she has little truck stability. Ideally, the toes of the limb being stretched should be held to deepen the stretch along the back of the leg. The

alternative technique involves both legs, which also has the advantage of stretching the lower back too (Figure 6).

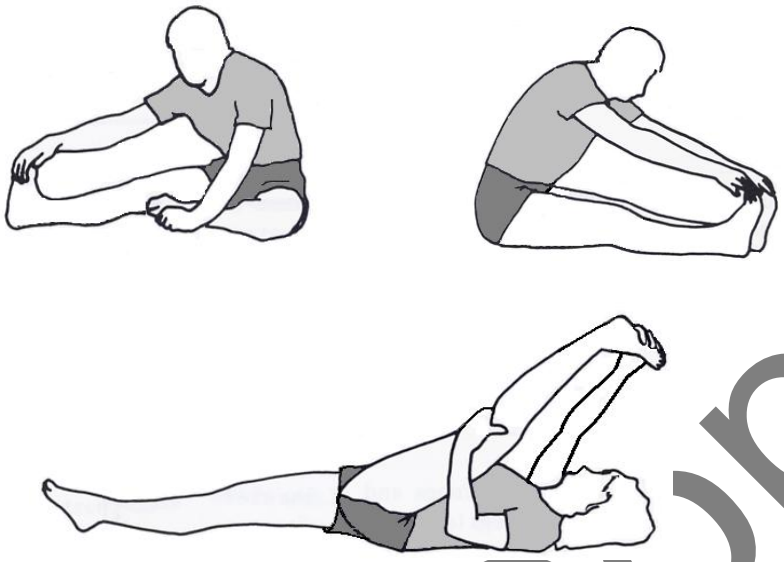

Figure 6: Hamstring stretches.
Top left, single hamstring stretch; top right, double hamstring stretch; bottom, alternative single hamstring stretch.

An alternative hamstring stretch technique involves lying on a bed or on a cushioned mat. Each leg is alternatively held by the toes to help flex the foot. The leg is held straight above the chest, or for those with good flexibility, over the head. One hand will be needed to prevent the legs bending at the knee.

Quadriceps stretch
The quadriceps can be stretched out from a sitting position. Gently bend one leg backwards as shown in the following illustration. Ensure the foot of that leg is not turned outwards to prevent strain on the knee joint of that leg. Leaning back will increase the stretch over the front of the thigh. A more advanced technique involves rolling over so that the chest is to the floor. Push up using the arms will stretch out the quadriceps muscles of both legs at the same time. This position has the advantage of stretching out the abdominal muscles as well as the wrist flexors when the hands are palms face down as illustrated.

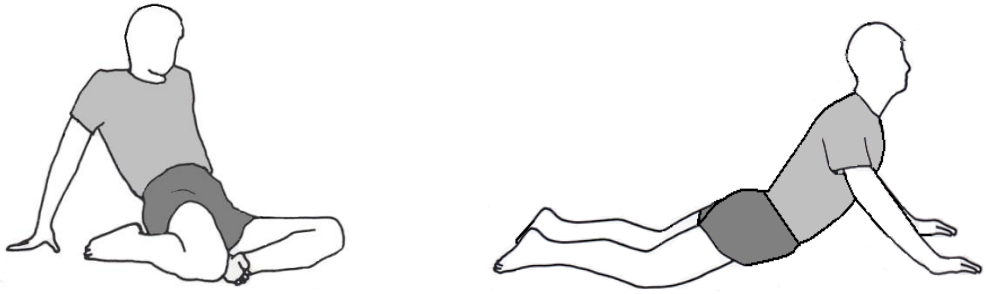

Figure 7: Quadriceps stretches.
Left: basic quadriceps stretch; right: alternative quadriceps stretch.

Upper back, shoulder, biceps and triceps stretch
The upper back and arms are ideally stretched out before transferring off the FES-rower (Figure 8). The trepezius, deltoids and rhomboids in the upper back should be stretched out by bending forward to lie over the legs whilst reaching down to the floor or foot support. The biceps should be stretched out by alternatively reaching behind the seat with each arm, thumbs uppermost. Alternatively holding the shoulder harness or seat back behind the head with each hand will effectively stretch out the rowers' shoulders and triceps.

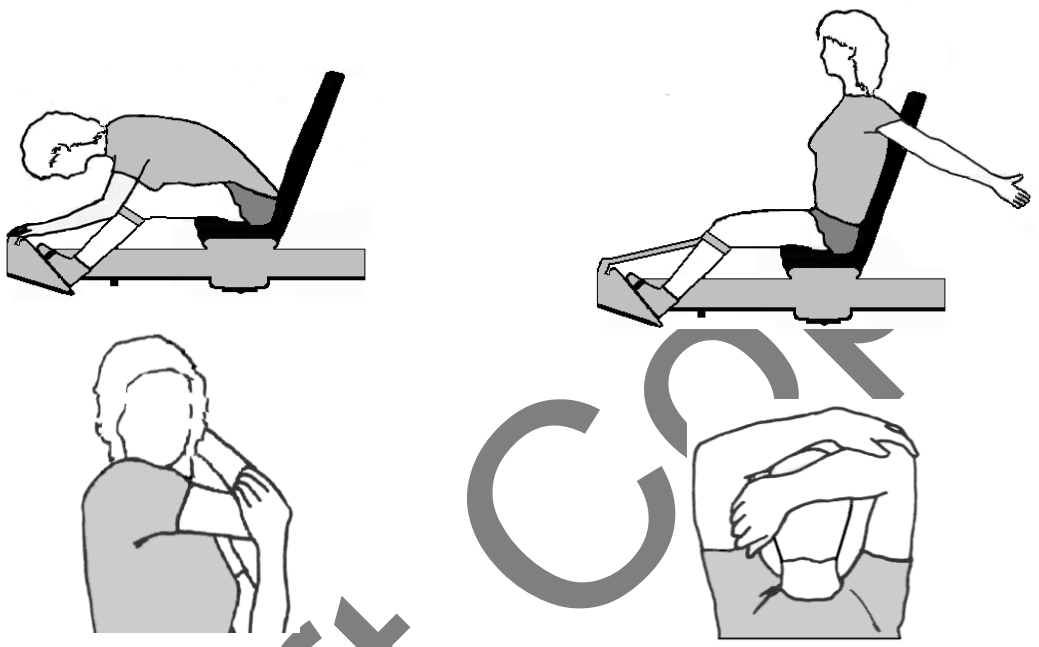

Figure 8: Upper left: upper back; upper right biceps; lower left: shoulder stretch; lower right: triceps stretch.

Safety Notice 1: Stretching

Never stretch balistically.

Hold each pre exercise stretch statically for 10 to 20 seconds and hold post exercise maintenance stretches for 30 to 40 seconds.

Hold stretch with just enough tension to maintain the natural flexibility
in the joins being worked.

2.7 Fluid intake and Diet

As with any physical activity requiring significant increases in exercise intensity and volume, the intake of fluids becomes essential. Rowers should be aware of their level of hydration. By the time a rower experiences a dry mouth they are already dehydrated! Rowers are encouraged to have a 500 ml bottle of water readily available to steadily hydrate themselves as they row.

Although it is not within the remit of this guide to cover recommended changes to an FES-rower's diet, it is recommended rowers maintain a balanced diet. For those exercising competitively, changes in nutrition will become necessary to optimise exercise potential.

2.8 Psychological Changes

It has become evident that a strong psychological effect results from participating in this form of centre based exercise. Even without accurate psychological measures, there have been a number of noticeable positive attitude changes witnessed in virtually every individual who has taken up FES-rowing. These changes appear to have been brought about to a large extent by the "feel good" factor of participating in an ***able-bodied*** activity.

These feel-good factors are further enhanced by the improve body image, especially in the shape of the FES-rower's legs which has been brought about by the increased muscle bulk and tone. This appears to result in an increase in confidence of the individual. In addition there is almost certainly an increased sense of well being brought about by the endorphins released as a consequence of the exercise. Again, this appears to be further enhanced by the individual feeling healthier and fitter. Rowers also report feeling that they have more energy and as a consequence are better able to cope with the daily grind of life in a wheelchair.

Although the psychological effects are beyond the remit of this guide, it is proposed future studies will address the psychological benefits of this form of exercise.

3 FES-Rowing System Component Operation

3.0 Introduction

The core of Brunel's 4-channel FES-rowing system is a standard Concept2 Model D indoor rowing ergometer and an Odstock 4-channel muscle stimulator. This section covers the operation and adjustment of the adapted components and Odstock 4-channel muscle stimulator. It is also hoped to eventually take this activity on water by adapting a rowing scull with a lightweight variation of the current indoor rowing ergometer adaptations. The design and operation of this system is beyond the remit of this guide, but will be reported on the www.fesrowing.com website in due course.

3.1 Concept2 Ergometer Adjustments

There are two components on the Concept2 ergometer that should be adjusted to a rower prior to a training session. This is particularly important with a device that is being used in a public venue by multiple users. Firstly, the footplate stretcher straps should be secured over each foot so that foot flexion is not restricted. Secondly, the resistance level of flywheel air-dam resistance should be set by positioning the lever on the right hand side of the air-dam flywheel casing. A range of 1 and 9 is selectable. Level 2 or 3 has been found to be optimal for the novice rower, or high-level cervical injuries. This can be increased as the fitness levels improve. Level 4 is widely recognized as being more closely representative of the level of resistance felt when on-water rowing. Accurate setting of air-dam resistance is accomplished via the PM3 computer. Although slightly differing selections are required dependant on the age of the display, the final selection can be found under the "Drag Factor" page.

3.2 FES-Rowing System Adapted Component Operation and Adjustment

There are four adapted components fitted to the FES-rowing system: rear monorail height adjustment unit, front and rear end stop units, seat assembly, and leg support unit (Figure 10).

Monorail height adjustment unit operation
The rear monorail height is adjusted by rotation of a handle on top of a trailer-type screw jack assembly. This enables the monorail to be inclined forwards to enable gravity to assist the return of the seat unit to the catch position (Figure 10).

> ***Adjustment***
> For injuries up to C6, a 4^0 inclination has been found to optimise return to catch without causing premature fatigue of the quadriceps during drive. This is equivalent to a rear monorail height of 40 cm. For lesions above C5, a 5^0 inclination, equivalent to a rear monorail height of 45 cm, is more optimal (Figure 10).

End stop units
The end stops are sprung-loaded, both to absorb the impact of the seat assembly, and help assist the deceleration and acceleration of the seat unit in the transition from end of drive to start of recovery, and catch to start of drive (Figure 10). The end stop positions are determined by individual rower leg length.

Adjustment

The spring-loaded end stops are secured to the monorail by a double clamp. The front end stop is secured when the rower's knee joint is positioned vertically above the ankle joint at catch. The spring-loaded rear stop is secured at a point that prevents the rowers knee joints over-cantering at end of drive. This prevents the knees 'locking out". Consideration should be given to the compression of the springs at the extreme forward and rearward positions.

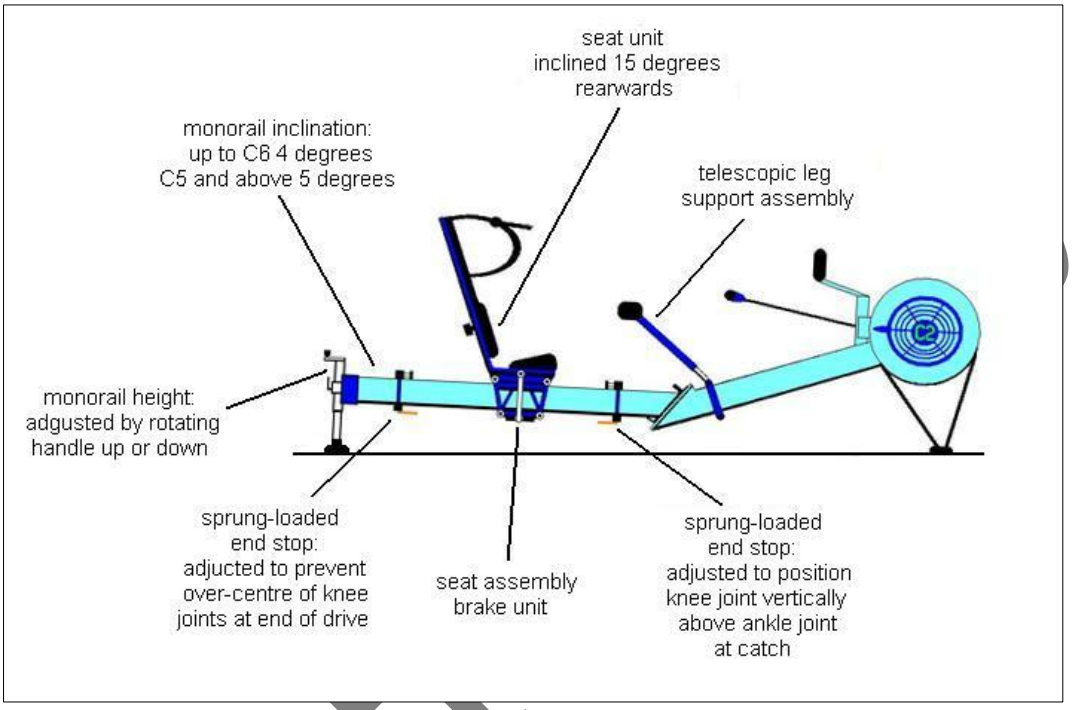

Figure 10: Adapted components on the Concept2 FES-rowing system.

The rear monorail height is adjusted to a 4^0 inclination (40 cm) in injuries up to C6, and 5^0 inclination (45 cm) in injuries at and above C5. The rear end stop is secured to prevent over-centre of the knee joints at end of drive; the front end stop is secured when the knee joint is positioned vertically above the ankle joint.

Seat assembly

The seat and harness assembly has been designed to accommodate male and female rowers with good hand and arm function. The unit has two sets of rollers; the upper set bear the weight of the seat assembly and rower, the lower set counter lateral and longitudinal forces exerted on the seat assembly during transfer or forces on the rower during the rapid accelerations at end of drive and catch.

The seat unit is inclined 15^0 rearwards to more comfortably support the trunk and prevent the shoulders taking the full weight and movement of the trunk at the extremes of travel. The monorail inclination also reduces the shear forces on the rower's buttocks during changes of direction. A thin gel seat squab is used on the seat base for pressure relief of the 30 minute row. Individuals who suffer from pressure sores should consider a more appropriate swab (see sub-section 2.4).

Seat assembly harness

The seat assembly supports a harness that comfortably secures the rowers trunk when rowing. They are a two-strap design similar to a rucksack and are suitable for female, as well as male rowers. The upper straps are secured at the top of the seat back frame, and the lower straps onto the seat back frame just below the rower's shoulders. A horizontal front strap holds the two shoulder straps the correct distance apart. This design allows the rower's shoulders to safely support the trunk during the high horizontal forces during drive.

Adjustment
The harness is adjusted via rucksack-type buckles on the shoulder and horizontal straps.

Seat assembly brake unit
The seat assembly brake, located on the right-hand side of the seat assembly, has two functions. It enables the safe transfer on and off the FES-rowing system, and it allows the rower to interval train (see sub-section 4.2). When interval training, the brake is applied by the rower to lock the seat at end of drive when the novice rower wishes to transition from FES-rowing to arms-only rowing. This position enables the rower to continue rowing using arms-only exercise with the handle clear of the rower's knees. The brake is applied by pulling the brake handle upwards, and released by pushing the handle downwards.

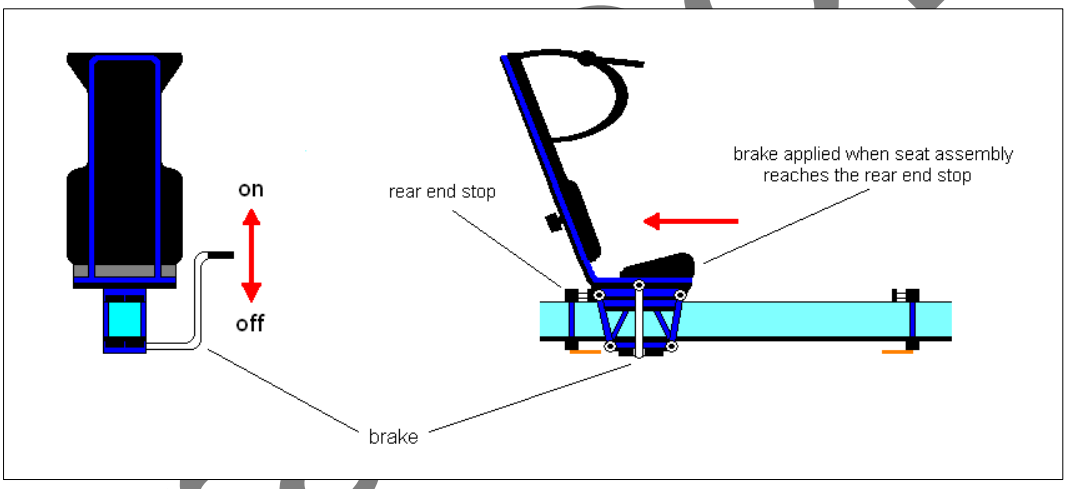

Figure 12: Seat assembly brake unit operation.

Telescopic leg support unit
Cushioned pads are secured to the rowers' legs below the knee, but above the broadest section of the calf muscle, by Elasticated Velcro closures. The cushioned pads are hinged to a telescopic strut that accommodates the change in distance of the lower legs as the rower moves backwards and forewords along the monorail (Figure 10). Under no circumstances should the telescopic leg support assembly be used to pull the seat assembly forward on the monorail; this action will result in assembly failure.

Adjustment
The cushioned pad straps should be firmly secured with the Velcro fasteners, but not so tight to cause a restriction in circulation, or skin damage.

3.3 FES-Rowing System Maintenance

The FES-rowing system integrity should be routinely checked prior to a training session. Of particular importance is the condition of the seat harness and the cushioned leg support strapping on the end of the telescopic legs support unit. Any defects should be reported to Robin Gibbons on 07906 770423 before using the equipment.

Safety Notice 3: FES-Rowing System

Ensure adequate clothing to protect the skin of the shoulder from chafing on the seat belt straps. If necessary, extra clothing or belt covers can be used to ease pressure under the straps.

A thin gel pad is provided for protection against skin breakdown whilst sitting on the rowing machine. However, if a rower is susceptible to this condition, further advice should be sought from the appropriate training Supervisor.

Ensure the padded straps of the leg supports, which are secured below the knee, are not so tight as to damage the skin of the leg.

Footwear giving good protection and support, particularly to the ankles, is strongly recommended due to the movement and pressure being generated as a result of the rowing action.

Extreme caution should be exercised when transferring on and off the FES-Rowing machines. For individuals with careers, transfer should only be attempted with their career present. For all other rowers, ensure a gym instructor knows you are using the FES-Rowing machine.

A thick towel is to be used to over the front stop and monorail when transferring on and off the rowing machine to avoid damage to the skin of the lower legs. Also ensure adequate support from a stable wheelchair whilst transferring.

Under no circumstances should the leg support unit be used by the rower to pull themselves forward on the monorail, otherwise failure of the telescopic joint could result.

The FES-rowing systems should only be used as detailed in this guide. Their use is for individuals who have been approved to join the FES-rowing programme, or who have graduated from the programme and who are either under instruction or being supervised by an appropriately trained fitness instructor.

3.4 The Odstock 4-Channel Muscle Stimulator

The 4-channel Odstock 04CHS muscle stimulator is used for both FES leg conditioning and FES-rowing (Figure 12). Under no circumstances should the stimulator be used on the upper limbs or trunk. The stimulator has two sets of controls, one internally under the battery, the other external. The most important of the internal controls comprise the frequency and pulse width of the stimulation. This will be pre-set at 50 Hz and 450 µs respectively, and should not be changed.

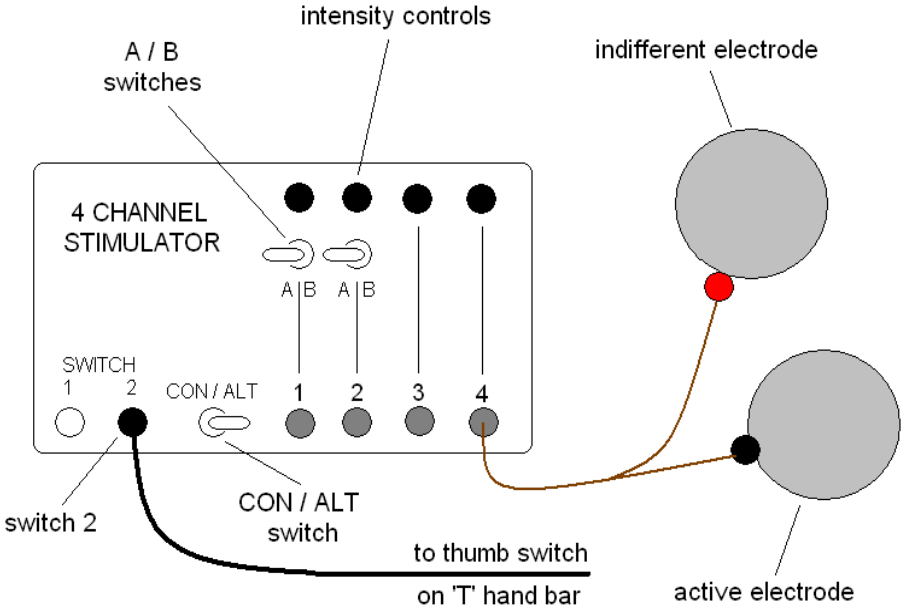

Figure 12: Odstock 4-channel muscle stimulator.
Note: only one set of electrodes are shown for clarity.

Battery
The stimulator is powered by alkaline 9-Volt PP3 battery. The battery is located under a sliding cover on the back of the stimulator. With continuous use, the power output will drop significantly as battery runs down. This will have a detrimental effect of muscle conditioning. It is recommended the PP3 battery is changed every 4 weeks particularly when maximal intensities are being used. A mains powered adaptor is being sauced.

Intensity controls
The four intensity controls adjust the amplitude or intensity of the stimulation of each channel by rotation of four channel controls linearly from 1 through to 9. Level 9 is equivalent to 115 mA.

A / B switches
During leg conditioning and FES-rowing, the four channels are connected in pairs. This is achieved by selecting the two A / B switches to A. This action pairs Channels 1 & 2 and 3 & 4. There is one exception to this, when engaged in interval training. See *Interval training*.

CON / ALT switch: leg conditioning
When leg conditioning the CON / ALT switch is selected to ALT. In this configuration, the automatic stimulator programme controls stimulation to the four channels at 5 repetitions per leg per minute or one repetition every 12 seconds.

Some participants experience induced contraction in muscles not being directly stimulated. These co-contractions can affect the training of the quadriceps muscles being conditioned. To prevent this occurring, quadriceps muscles are conditioned first. During quadriceps-only conditioning, only channels 2 & 4 are used. This allows alternate knee extension ensuring better balance whilst leg conditioning (Figure 14).

Once 90^0 knee extensions are possible for 10 minutes, hamstring conditioning is integrated into the training sessions. When stimulating quadriceps and hamstrings, channels 1 & 2 stimulate the left hamstring and right quadriceps and channels 3 & 4 stimulate the right hamstring and left quadriceps (Figure 15). In this configuration, one leg extends whilst the other flexes ensuring optimum balance whilst exercising. The level of the stimulation given to the hamstrings is limited to level 6 (or at least 2 levels below that of the quadriceps) to minimise unwanted co-contractions and to prevent tissue damage due to the hamstrings working isometrically; that is they are under contraction without associated joint movement.

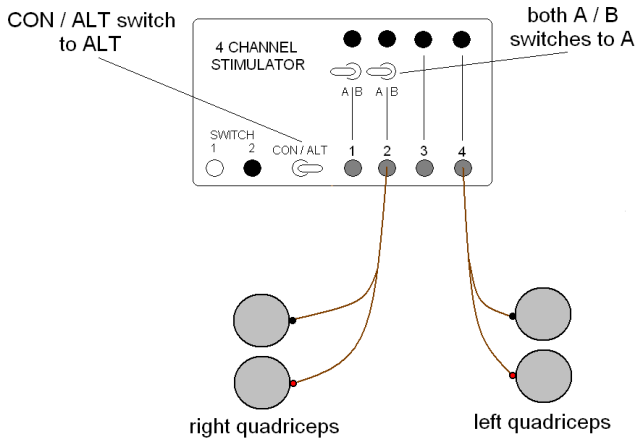

Figure 14: Stimulator controls when quadriceps only conditioning.

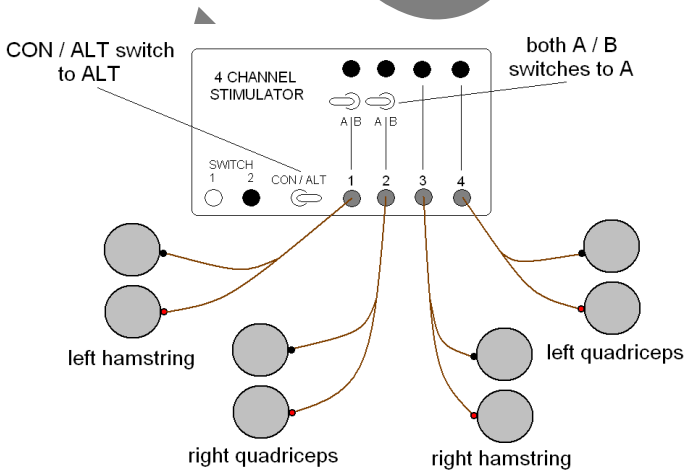

Figure 15: Stimulator controls when quadriceps and hamstring conditioning.

CON / ALT switch: FES-rowing

During FES-rowing, the CON / ALT switch is selected to CON. In this configuration, a bi-pole thumb-activated switch mounted on the ergometer handle is connected to the stimulator via the “switch 2 socket” (Figure 16). The handle mounted switch enables the rower to select appropriate channels. Pressing the switch selects channels 3 & 4 activating the quadriceps muscles, and releasing the switch selects channels 1 & 2 activating the hamstring muscles. In individuals with limited or weak hand function, “attendant” switching has been successfully employed to remotely select appropriate channels in sync with the rower’s voluntary upper

limb pulling action. With minimal instruction, this protocol produces a similar rowing action to that of an individual with full upper limb function.

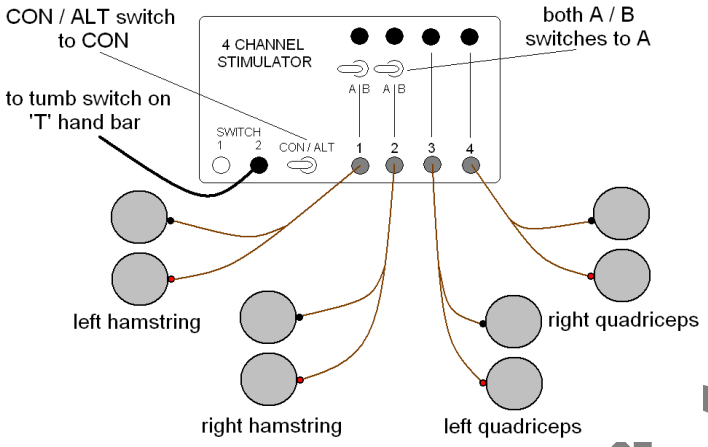

Figure 16: Stimulator controls when FES-rowing.

Interval training

The brake located on the right-hand side of the seat assembly enables the rower to transition from FES-rowing to arms-only rowing. As the brake is applied the A / B switches are selected to B, which de-selects channels 1 & 2 to the hamstrings (Figure 17). If this action is missed, the hamstring muscles will be continuously stimulated due to the fact that the handle mounted switch is a bi-pole design; that is releasing the switch selects channels 1 & 2 stimulation the hamstring muscle group. Therefore, if the A / B switches are not selected to B the hamstrings will remain selected and therefore continuously stimulated resulting in premature hamstring muscle fatigue.

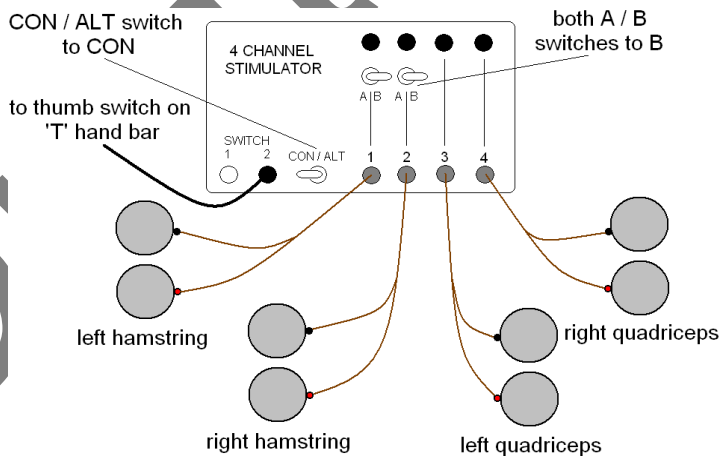

Figure 17: Stimulator controls when arms-only rowing.

When the brake is released, the A / B switches must be selected to A, allowing the hamstring muscles to be stimulated when the handle mounted switch is released. Failure to select A will result in both quadriceps and hamstring muscle groups being stimulated when the handle mounted switch is pushed. Although this is not harmful, the rower will experience a severe drop in performance as the hamstring muscles will contract with the quadriceps

Electrodes

The electrodes are connected to the stimulator via leads that are plugged into each of the 4 sockets on the front of the stimulator. Seven centimetre adhesive electrodes are attached to the rower's legs which should be prepared with a damp cloth to remove any oil-based moisturising cream or dead skin.

Odstock 4-channel muscle stimulator operational limitations

The Odstock 4-channel muscle stimulator should only be used as instructed or as described in this guide. Its use is strictly limited to the stimulation quadriceps and hamstring muscles. In addition, the precautions in Table 3 should be observed when using the Odstock 4-channel muscle stimulator.

1	Avoid handling the electrodes while the intensity controls are switched on. This is to prevent the electrical stimulation inadvertently affecting other areas of the body. There is a theoretical, but in practice never reported possibility that the electrical stimulation may affect the heart if the current path is directly across the chest. Always turn off the intensity controls before the electrodes are removed.
2	Do not use the stimulator in the vicinity of water. A damp cloth should be used for cleaning. Do not use spirit based cleaners.
3	Always wash and dry the skin carefully when the electrodes have been removed. Do not use skin creams or moisturisers on or near the electrode sites.
4	A slight reddening of the skin under the electrode is normal. This should fade after an hour once the electrodes have been removed. If stimulation causes long term marking of the skin, discontinue use and seek medical advice.
5	Do not place electrodes over broken skin or shave the area under the electrodes as this may cause a skin irritation.
6	In some cases spastic tone can be affected by the electrical stimulation. If any adverse changes to spasticity are experienced, discontinue use and seek medical advice.
7	Some high level spinal cord lesion individuals may suffer an autonomic response either during or after electrical stimulation. If headaches or sweating occurs or if blood pressure, bowel or bladder is affected, discontinue the exercise and seek medical advice.
8	Do not use or operate dangerous machinery or drive while using the stimulator.
9	Do not use the stimulator within three metres of physiotherapy short wave diathermy equipment.
10	When removing the leads from the stimulator, hold the plugs, never pull on the lead.
11	The safety of electrical stimulation in pregnancy has not been determined.
12	Do not use with implanted electronic devices such as cardiac demand pacemakers, without specialist medical supervision.
13	Not to be used by individuals who have poorly controlled epilepsy.

Table 3: Precautions when using the Odstock 4-channel muscle stimulator.
Extract from the Odstock 4-channel Operation Manual.

Maintenance

Apart from checking the electrical leads that connect the electrodes to the stimulator, there is no maintenance to do except to replace the PP3 batteries. Regular checks should be made on the condition of the adhesive surface of the electrodes. Both of these items will make significant reductions in performance if neglected. In addition, it is possible to theoretically damage the skin if the fabric of the electrode makes direct contact with the skin. Replacement electrodes can be purchased at cost from Brunel University. Please contact Robin Gibbons on 07906 770423.

Do not use a stimulator that either fails or develops a functional abnormality. The fault should be reported to Robin Gibbons on 07906 770423 in the first instance. For further information, contact the Department of Medical Physics and Biomedical Engineering, Salisbury District Hospital, Salisbury, Wiltshire, SP2 8BJ. www.salisburyfes.com.

Safety Notice 5: Stimulator Safely

Do not use a stimulator that either fails or develops a functional abnormality. Any failures should be reported to Robin Gibbons on 07906 770423.

Only use this stimulator and electrodes to stimulate the muscles of the legs. ***Do not*** use on the trunk or arms.

Do not handle the electrodes whilst the intensity switches are on.

Do not use the stimulator in the vicinity of water. Always wash and dry skin carefully after removing electrodes.

Do not place electrodes over broken skin.

Discontinue stimulation if spasticity adversely affected.

Discontinue stimulation if an autonomic response is experienced.

Do not drive whilst using the stimulator.

Always hold the plugs when removing the leads. **Do not** pull directly on the electrical leads.

Do not use if pregnant, or pregnancy suspected.

Do not use with implanted electronic devises.

Not for use by individuals who suffer poorly controlled epilepsy.

3.3 Electrodes

Motor point test

Optimal muscle contraction is achieved by electrically stimulating an area called the motor point of the muscle (Figure 18). This is an area on the skin close to a point where the peripheral nerves enter the muscle belly.

The exact location of a motor point differs from individual to individual and from one leg to the other. This point will initially be determined by a researcher or FES-trained physiotherapist. In some individuals locating the motor points can be problematic, particularly if excess fat underlies the skin. It is also recommended having the motor points being periodically checking as they can move as muscle bulk increases with regular FES-training.

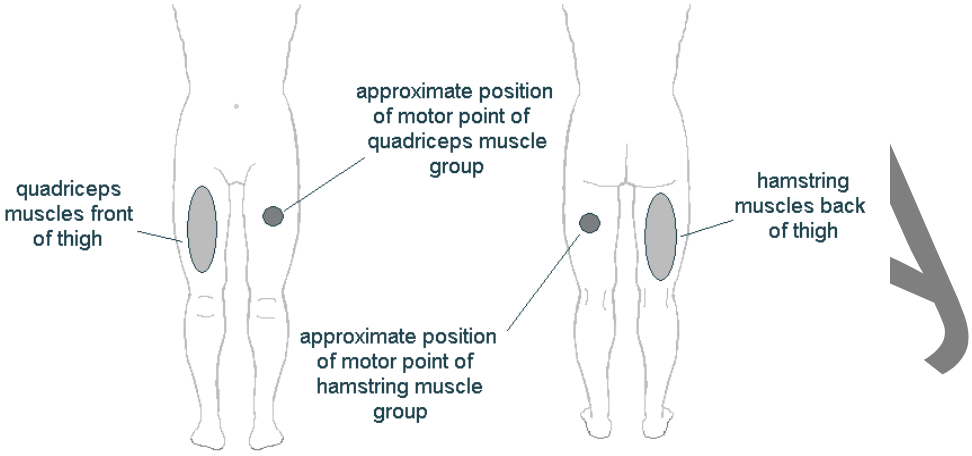

Figure 18: Location of quadriceps and hamstring muscle motor points.

Quadriceps electrode placement

The indifferent electrode (red lead) is placed anterior-medially above the knee. The active electrode (black lead) is placed anterior-laterally at approximately mid-thigh over the motor point of the muscle (Figure 19).

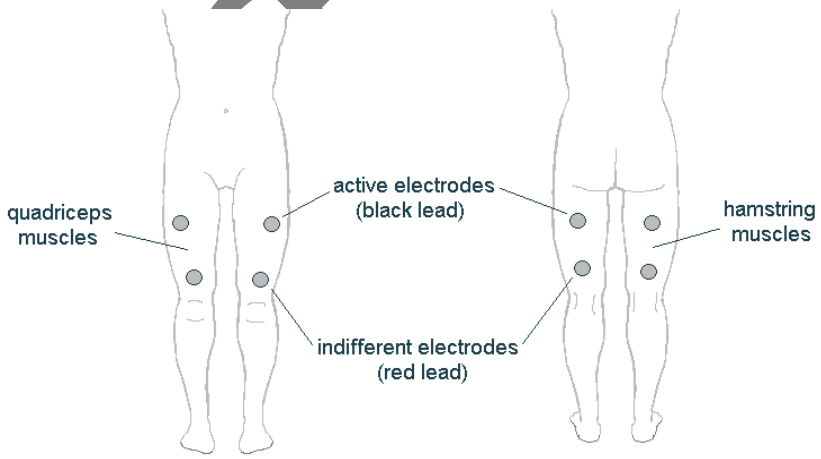

Figure 19: Quadriceps and hamstring electrode placement.

The active (black) quadriceps electrode is place anterior-laterally above the knee; the indifferent (red) quadriceps electrode is placed laterally above the motor point of the lateral quadriceps muscle. The active and indifferent hamstring electrodes are place posterior-centrally above the knee and mid thigh respectively.

Hamstring electrode placement

The indifferent electrode (red lead) is placed posterior-centrally above the knee (Figure 19). The active electrode (black lead) is placed posterior-centrally over the centre of the muscle

belly, approximately 5 cm above the indifferent electrode. Regular checks should be made behind the leg when hamstring conditioning to prevent any pressure related skin breakdown.

Safety Notice 5: Electrode Handling

Never place electrodes over broken skin.

Never use damaged electrodes as they could result in burning of the skin.

Regularly check the skin behind the leg for marking under the electrodes and leads when sitting.

3.5 Setting up the Odstock Muscle Stimulator

The present stimulator, the 04CHS supplied by the Medical Physics Department at Salisbury District Hospital www.salisburyfes.com has 4 amplitude or intensity adjustable channels. In view of the anticipated diversity of participants' physiologies as well as the unknown speed at which their paralysed muscle adapts to electrical stimulation, the instructions that are given for the setting up of the stimulator are recommendations and as such should be used as guidelines only.

The stimulator is set up slightly differently depending on whether the rower is leg strengthening or FES-Rowing. There are internal controls located under the 9-volt battery compartment at the back of the stimulator. These are pre-set and should not be touched. The external controls located on the front of the stimulator are set up as follows.

3.6 FES Leg Conditioning

This phase is best achieved from either a sitting position or a lying down position on a bed or couch with lower legs hanging over the edge. During the Introduction to FES leg conditioning Phase 1 (Figure 21), only the quadriceps muscles are stimulated. In individuals who have serious atrophy of their leg muscles, contraction of the quadriceps muscles is the aim; leg movement is secondary. With regular leg strengthening, movement will eventually be achieved. Once this point has been reached, the rower should progress to FES leg conditioning Phase 2.

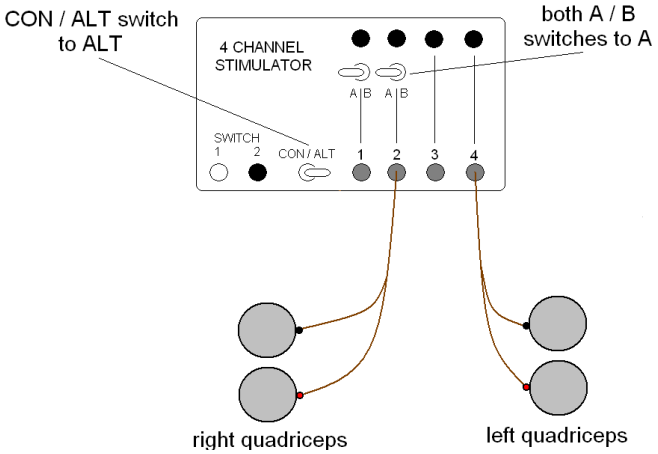

Figure 21: Stimulator controls when initial FES leg conditioning.

There are two aims of FES leg conditioning Phase 2 (Figure 22). The first is to condition the quadriceps sufficiently to achieve full extension of the lower legs. The second is to initiate and integrate hamstring strengthening. It should be remembered that the quadriceps muscles are far stronger than the hamstrings, so intensity levels will vary markedly between the two muscle groups. In addition, because the hamstrings are under an isometric contraction: that is, they are being prevented from moving when stimulated, only the minimum intensity level to just contract the muscle should be used. For the maximum workout, progress to Leg Strengthening Phase 3 using 1kg leg weights. In all phases, the external controls on the stimulator should be set up as follows:

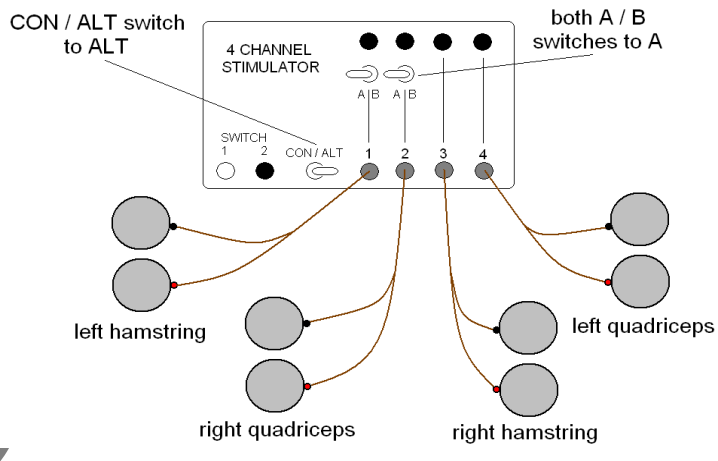

Figure 22: Stimulator controls when FES leg conditioning Phase 2 & Phase 3

Note 1
Use the minimum intensity level to achieve a contraction of the quadriceps muscles. Movement of the lower leg is the secondary aim.

Note 2
Use the minimum intensity level to achieve a good contraction of the quadriceps muscles to initiate movement of the lower legs. As the muscles become fatigued, the intensity controls

can be gradually increased up to level 9 to continue to raise the legs for as long as possible. As the muscles become trained, a lower level of intensity will enable the same leg movement. The aim eventually is to achieve a straight leg extension.

Note 3
When leg strengthening in a sitting or lying down position, the hamstrings are under an isometric contraction; that is, they are being prevented from moving when stimulated. In view of this, only the minimum intensity level should be used to cause a just noticeable contraction of the muscle. As a guide, the intensity controls for the hamstrings should be set at least two levels below those controlling the quadriceps.

3.7 FES-Rowing

The quadriceps muscles are significantly larger and stronger than the hamstring muscles. The significance of this is that relative intensity levels will differ markedly dependant on the muscle group being stimulated. For guidance, set the hamstring intensities two levels below those of the quadriceps. The following settings should be used:

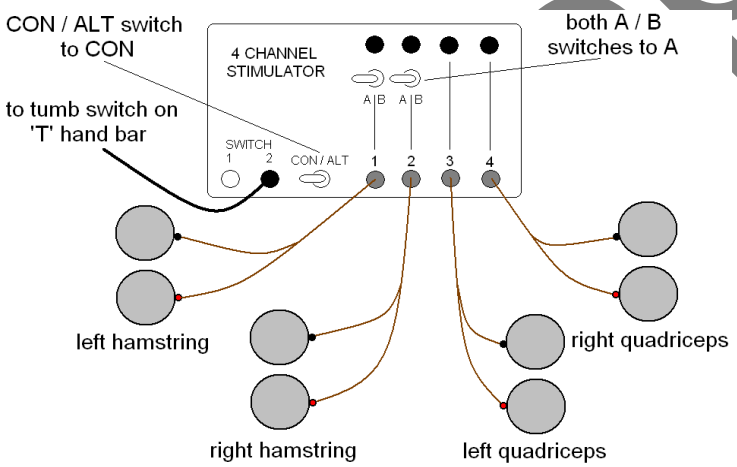

Figure 23: Stimulator controls when FES-rowing.

Note 1
In most SCI individuals, the hamstring muscles will not be strong enough on their own to pull the rower back to the catch position. In view of this and to avoid over-stimulation, intensity levels should be set lower than those of the quadriceps. As a guide, the hamstring intensities should be set two levels below those of the quadriceps.

Note 2
It should be remembered, when arms-only rowing, Channels 1 & 2 should be switched off by positioning the A / B switches to position B.

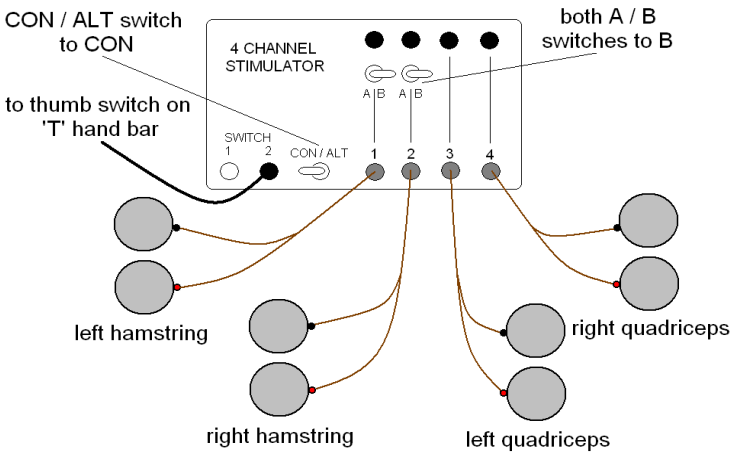

Figure 24: Stimulator controls when arm-only rowing.

Note 3
Use the minimum level of intensity to achieve a good contraction of the quadriceps muscles. As the muscles become fatigued, the intensity controls can be gradually increased up to level 9 to continue to raise the legs for as long as possible. As the muscles become trained, a lower level of intensity will enable the same leg movement.

3.8 Clothing

Although any comfortable sports clothing may be worn to row in, there are a number of practical issues to take into account. It is recommended that shorts be worn, as they will give the best access to the legs for the placement of electrodes. In individuals with high lesions that have vertebrae that protrude, a quilted body warmer is strongly recommended to protect the skin covering the area in contact with the seat back. Rowers should also be cautioned on the wearing of too much clothing, due to the rapid increase and sustained high temperatures experienced as a result of FES-Rowing. In addition, if not wearing tops with sleeves, wrist bands may be required to prevent the inadvertent shorting out of sweaty arms against the electrodes on each leg!

Footwear giving good protection and support, particularly to the ankles, is also strongly recommended due to the movement and pressure being generated through them as a result of the rowing action.

Finally, rowers are strongly recommended to bring with them a thick towel to cover the front stop and monorail during transfers on and off the rowing machine, and a damp cloth to clean and dampen their legs prior to the placement of the electrodes.

4 Training Programmes

The way paralysed muscle adapts to electrical stimulation is still being researched. What has become apparent is that it appears easier to train paralysed muscle for power rather than endurance. A paralysed muscle can still deliver significant power, but will have minimal or no endurance. FES muscle conditioning is aimed at both muscle growth and increased endurance while maintaining muscle power. The response of the paralysed muscle to electrical stimulation will ultimately determine at what point an individual enters the training programme.

The different combinations of these factors will also determine how much and for how long an individual will be able to row. In addition, training sessions are designed to enable an individual to gradually build up the time that they are exposed to the electrical stimulation particulary in individuals with very weak muscles through disuse or in individuals who suffer from autonomic dysreflexia. The period that the individual is exposed to the electrical stimulation can be increased as the skin becomes used to the stimulation as well as the electrode gel. Also, in individuals with part sensory impairment, the sensation experienced due to the electrical stimulation should reduce the longer it is used. This is in part due to the endorphins released as a consequence of the stimulation. In individuals that find the stimulation uncomfortable, training sessions can be initiated at low intensity levels and gradually increased over a period of a few minutes as the endorphins are released and sensory habituation occurs. In view of these issues, the following programmes should be used as a guide.

Muscle fatigue and electrical stimulation
One phenomenon of electrical stimulation is that it causes all muscle fibres being stimulated to contract at the same time. The significance of this is that the electrically stimulated muscle will fatigue earlier. Apart from the introduction phase of leg strengthening, the point at which the leg cannot rise to the horizontal position is the point used to determine the point of failure and as such the point at which the exercise should be stopped.

The initial programme assumes an individual has been long-term paralysed, experiences minimal spasms and does not respond well to electrical stimulation. With this in mind, the training programme has been split into two separate phases: leg strengthening and FES-Rowing.

4.1 FES Leg Conditioning

Quadriceps-only conditioning
Quadriceps can be considered the “engine” in rowing. These muscles are conditioned first t This first phase is purely for the benefit of individuals who have serious atrophy of the leg muscles. Initially, only a mild contraction may be experienced which is not sufficient to raise the lower leg. However, this will be sufficient to begin the strengthening process. Eventually, after several sessions, leg movement should be experienced. The aim of this initial leg-strengthening phase is to achieve a 90-degree lower leg raise. As a reminder, the external stimulator controls are set as follows:

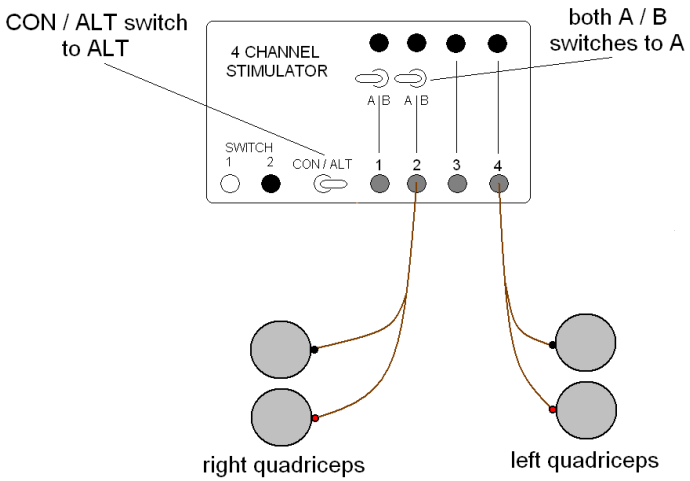

Figure 25: Stimulator controls quadriceps-only conditioning.

Exercise	Quadriceps can be conditioned from a sitting or supine position. In leg conditioning ATL mode, the stimulator delivers 5 stimulation currents to alternate quadriceps every minute.
Endurance	Maximum 10 minutes per session or until no contraction of the quadriceps muscles is experienced.
Frequency	Three exercise bouts on alternate days every week.
Stretching	10 minutes stand before and after each training session recommended. If standing not possible, independently stretching recommended (see sub-section 2.8).

Table no: Quadriceps-only conditioning.

Quadriceps and hamstring conditioning

The external stimulator controls are set up as in FES leg conditioning Phase 1, except that intensity controls 1 & 3 are used for the hamstring muscles as follows:

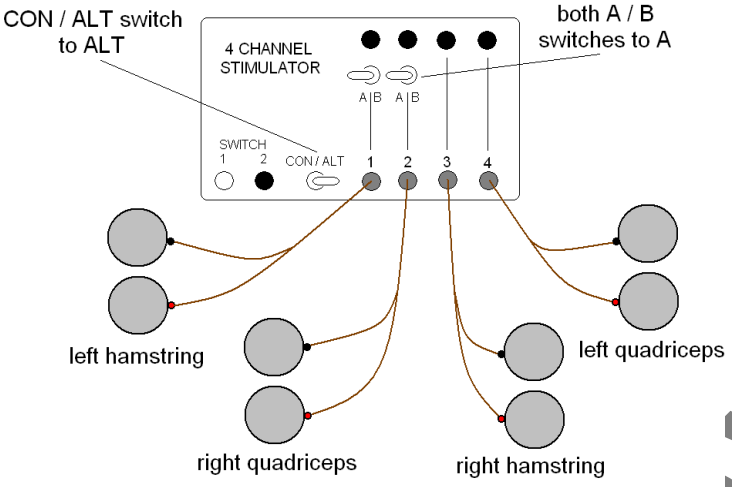

Figure 26: Stimulator controls quadriceps and hamstring conditioning.

Exercise	Quadriceps can be conditioned from a sitting or supine position. In automatic mode (ALT) the stimulator will deliver 5 repetitions per leg per minute. Proceed to quadriceps and hamstring conditioning when 90^0 knee extensions are possible for 10 minutes.
Endurance	Maximum 60 minutes per session or until no movement of the legs is experienced.
Frequency	Three sessions per week with at least one day off in between sessions.
Stretching	If possible, stretch legs by standing for 10 minutes before and again after each training session.

Table no: Quadriceps and hamstring conditioning.

Safety Notice no: Leg Conditioning

Ensure legs are rising in the correct sagittal (forward facing) plane to avoid unnecessary wear of the knee joint.

Continuously check for any abnormalities in the legs particularly the knee joint.

Ensure adequate cushioning underneath the legs.

Ensure footwear provides adequate foot protection and ankle support.

Regularly check the skin behind the leg for marking under the electrodes and leads when sitting.

4.2 FES-Rowing

Before discussing rowing training a description of the FES-Rowing technique should be given.

Initial adjustments to the FES-owing system prior to training
As a reminder, the following adjustments should be made prior to rowing:

Seat back (1)	Set for shoulder height
Seat back (2)	Set for distance from seat
Resistance	Initially 2 (4 is rowing standard resistance)
Foot plate	1 to 2 holes showing depending on foot size
Front stop	Lower leg vertical
Rear stop	Knee joint not 'locked out'
Rear height of rail	35 cm +/- 5 cm

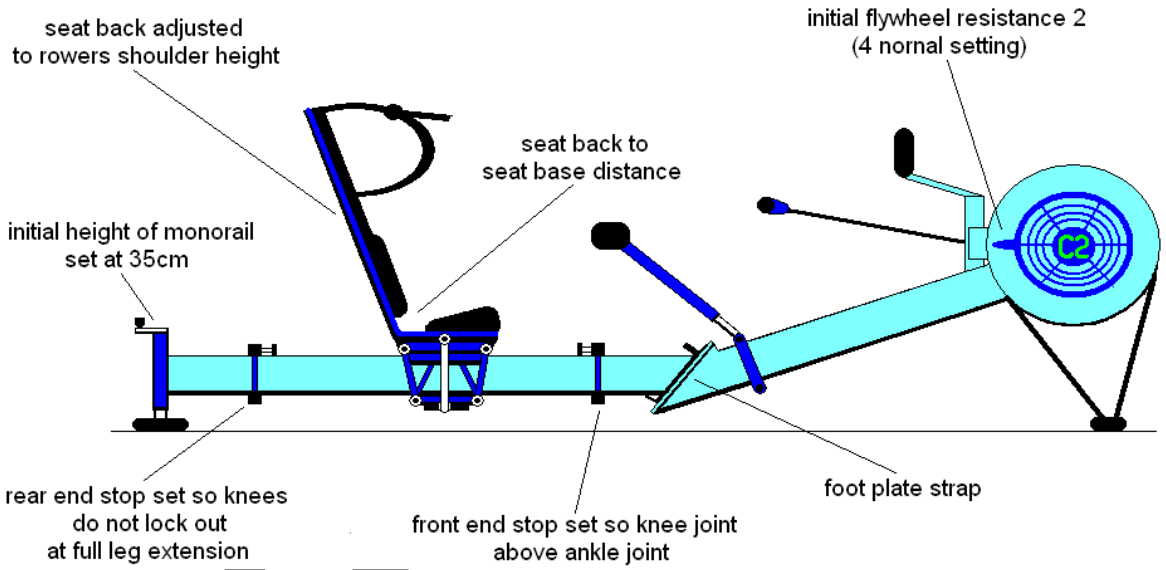

Figure 27: FES-rowing system adjustments prior to training.

FES-rowing technique
Inevitably, as good as any adaptation may be, it can never accurately replace the body's own natural movement. At the present time, the only muscle groups being stimulated are the quadriceps and hamstrings. This, and the nature of the stimulation, makes for very jerky, mechanical-like movements of the legs.

In addition, it is estimated that the work load ratio of the upper body to lower body of the adaptive rower to that of their able-bodied counterpart, is reversed at 60% arms to just 40% legs at best. In individuals with higher neck lesions, it is estimated to be closer to 50%. The significance of this is that the adaptive rower cannot overlap leg extension with arm flexion; otherwise their legs would collapse. Furthermore, in people with high lesions, movement of the trunk cannot aid the rowing action as in the case of an able-bodied rower.

Clearly, rowers will develop their own unique technique, but as a guide the adaptive rowing technique will be leg extension followed by arm flexion where the leg extension is controlled by pressing the thumb control on the 'T' bar handle of the rowing machine. With practice, a reasonably fluid rowing action can be found!

Interval training

The physiology, circulation and response to electrical stimulation in some individuals will prevent non-stop exercise of the legs. In these circumstances, the rower can adopt a split exercise regime. This involves using a combination of FES-Rowing and arms-only rowing. This is achieved mechanically with the use of the seat brake. See Chapter 3 section 3.1 The Prototype FES-Rowing Machine / Seat Brake. Electrically, it is achieved by switching off Channels 1 & 2 supplying the hamstring muscles by switching the A / B switches to position B. See Chapter 3 section 3.2 The Stimulator / Interval Training.

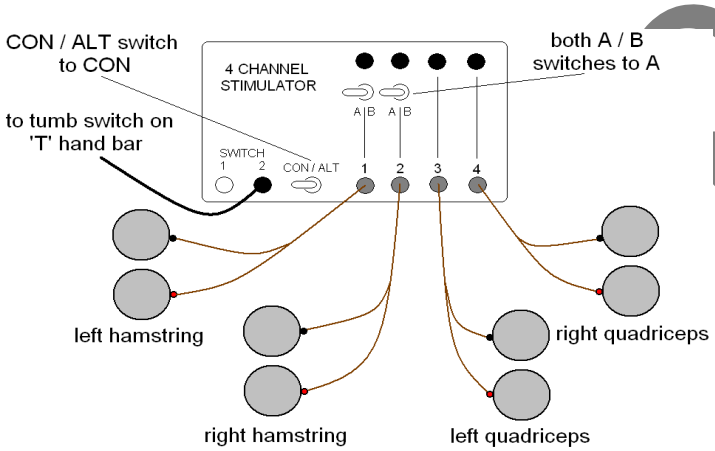

Figure 28: Stimulator controls when FES-rowing.

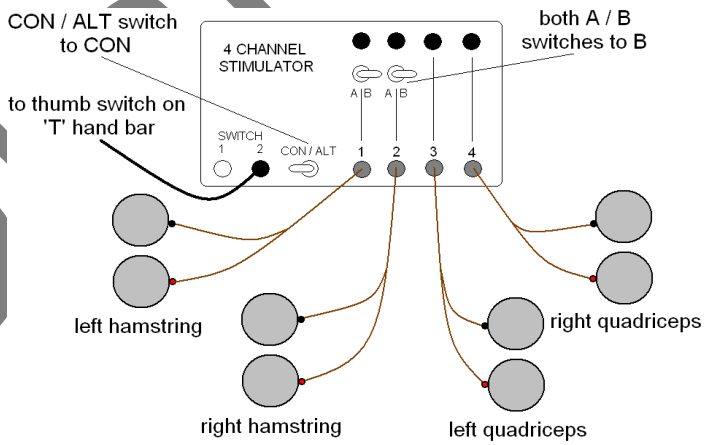

Figure 29: Stimulator controls when arm-only rowing.

Lactic acid

It is anticipated that most rowers will require engaging in an interval exercise regime, as this gives the legs time to clear the amount of lactic acid which builds up as a consequence of the muscle contraction combined with poor circulation. Initially, the target is distance in rowers with weak legs relative to strong arms and shoulders. As the legs get stronger with better endurance, the aim is to switch to time in the interests of the overall health benefits.

Fluids
Although energy levels at early stages in training are relatively low, as the distances and times increase the requirement to replace fluids becomes more critical. Rowers should ensure that they have water available and remember that when their mouth feels dry, they are already dehydrated!

4.3 Basic FES-Rowing Training Programmes

A rower's physiology, susceptibility to spasms and the ability of their paralysed muscle to adapt to electrical stimulation will be central to how far or for how long they will be able to row. For example, it is possible that an individual is able to row non-stop from the outset and, as such, would not need to engage in the interval exercise regime where the rower alternates between FES-Rowing and arms-only exercise. The significance of this is that it is impossible to lay down a definitive programme of training. With this in mind, the following programmes are completely flexible and should be used as a guideline only.

Programme	***Regime***	***Distance***
Beginners	15 sec FES-Rowing / 15 sec arms-only rowing	1000 m
1	30 sec FES-Rowing / 30 sec arms-only rowing	2000 m
2	40 sec FES-Rowing / 20 sec arms-only rowing	2000 m
3	50 sec FES-Rowing / 10 sec arms-only rowing	2000 m
4	Non-stop FES-Rowing	2000 m

Frequency Three sessions per week with at least one day off in between sessions.

Stretching Stretch arms and shoulders before transferring off the rowing machine as follows:

Biceps: alternately reach arms behind seat just below shoulder height with thumbs uppermost for 40 seconds.

Upper back: lying over straight legs, reach down towards the floor for 40 seconds.

If possible, stretch legs by standing for 10 minutes immediately after each session.

Resistance The resistance of the flywheel should initially be set at level 2. Level 4 is widely recognized as the level of resistance that most closely represents that which is felt whilst on-water rowing.

Table no: FES-rowing training programme.

Safety Notice no: FES-Rowing Training

Extreme caution should be exercised
when transferring on and off the rowing machine.

A thick towel is recommended to cover the
Front stop, footplate and monorail whilst transferring.

ensure adequate support from a stable wheelchair
When transferring.

Ensure channels 1 & 2 are switched off by positioning
the A / B switches to position B when engaged in
the arms only phase of interval training.

STOP exercise if any contraindications in heart function
or a dysreflexic response are experienced.

Ensure footwear provides good foot protection and ankle support.
Continuously check for any abnormalities in the legs
especially the knee joints.

Check skin immediately after rowing for any marking around
the lower legs where the leg supports are secured,
and all areas of skin in contact with the seat and seat back.

Regularly check the skin behind the leg for marking
under the electrodes and leads when sitting.

4.4 Advanced FES-Rowing Training Programs

For health benefits, the rower should aim to increase their rowing sessions to 30 minutes. With this in mind, once the rower has achieved the initial 1000 m, they should switch to timed sessions. The distance rowed will depend on the fitness level of the rower, but should gradually increase as the fitness level increases.

Programme	***Regime***	***Endurance***
1	30 sec FES-Rowing / 30 sec arms-only rowing	30 mins
2	40 sec FES-Rowing / 20 sec arms-only rowing	30 mins
3	50 sec FES-Rowing / 10 sec arms-only rowing	30 mins
4	Non-stop FES-Rowing	30 mins

Frequency Three sessions per week with at least one day off in between sessions.

Stretching Stretch arms and shoulders before transferring off the rowing machine as follows:

Biceps: alternately reach arms behind seat just below shoulder height with thumbs uppermost for 40 seconds.
Upper back: lying over straight legs, reach down towards the floor for 40 seconds.

If possible, stretch legs by standing for 10 minutes immediately after each session.

Resistance The resistance of the flywheel should initially be set at level 2. Level 4 is widely recognized as the level of resistance that most closely represents that which is felt whilst on-water rowing.

Safety

Extreme caution should be exercised when transferring on and off the rowing machine.

A thick towel is recommended to cover the Front stop, footplate and monorail whilst transferring.

ensure adequate support from a stable wheelchair When transferring.

Ensure channels 1 & 2 are switched off by positioning the A / B switches to position B when engaged in the arms only phase of interval training.

STOP exercise if any contraindications in heart function or a dysreflexic response are experienced.

Ensure footwear provides good foot protection and ankle support.

Continuously check for any abnormalities in the legs especially the knee joints.

Check skin immediately after rowing for any marking around the lower legs where the leg supports are secured, and all areas of skin in contact with the seat and seat back.

Regularly check the skin behind the leg for marking under the electrodes and leads when sitting.

4.5 High Performance FES-Rowing

As with any sport, to get maximal performance it is recommended a rower cross-train. The two most complementary activities to take part in are swimming and weight training. The combination of these activities provides a variety of differing actions through the shoulder girdle, which will help to stabilize and strengthen all associated joints.

Swimming

Where swimming is concerned, a backstroke style provides the greatest benefit as it not only strengthens the muscles of the shoulder joint, but also helps to keep the flexibility in the shoulder's universal joint. Having said that, any swimming style is good all round exercise, particularly in view of the fact it does not cause impact damage to tissues. A 30-minute swim three times a week is recommended to optimize the benefits of the exercise.

Weight training

All the usual muscle groups of the upper body can be worked on using an endurance type, weight training exercise regime. This can easily be determined by first finding the maximum weight a muscle can move its associated joint through its full range of action. Reduce this weight by 40%. With this new weight, the muscle being targeted should be capable of working through two sets of 15 repetitions of the exercise with a 60 second rest period between sets. Ensure the quality of movement is retained through to the 15th repetition. If this is not possible, reduce the weight further.

Once again, to optimize the full benefit of this exercise, three training sessions every week are recommended. For further advice contact Robin Gibbons. Suggested paired exercises are:

- Bicep curls / triceps pushes
- Lateral pull downs / shoulder press
- Arm row / chest press
- Pec deck press / bent over fly's

5 Record Keeping

FES Instructors / Supervisors at the ASPIRE National Training Centre and the London Regatta Centre are responsible for keeping records of all trainee rowers, which will then be held by the Team Captain / FES-Rowing Instructor at ASPIRE. These records will be used, with the permission of each rower on the training programme, by Brunel University and the ASPIRE National Training Centre to evaluate the performance of all rowers, and by so doing help to prove the health benefits of FES-Rowing. This data will then be used to promote the activity to other spinal units and eventually the mainstream leisure industry.

5.1 Health Data

Two different, although interrelated, sets of records will be taken. The first are the physiological parameters as discussed in Chapter 2, Medical Issues. These records define the changes in health of the individual as a result of participation in adaptive rowing exercise. The monthly, self-analysed personal checks conducted by the rower will also be integrated into these records, including a thorough check of skin condition after every training session. This data will be presented on Health Data forms. See Annexe B. The following data will be collected at the intervals indicated:

Overall height	initially only
Overall weight	monthly
Body mass index	monthly
Thigh girth	monthly
Blood pressure (resting)	monthly
Heart rate (resting)	monthly
Neuropathic pain	monthly self-assessed 1 to 10
Spasms	monthly self-assessed 1 to 10
Muscular discomfort or pain	monthly self-assessed 1 to 10
Joint discomfort or pain	monthly self-assessed 1 to 10
Glucose blood sugar	6-monthly
Cholesterol	6-monthly
Bone mineral density	annually

Skin condition	after every session

5.2 Fitness Data

The second set of records will be taken during and after each leg strengthening and FES-Rowing training session. This data will be presented on Leg Strengthening and FES-Rowing Fitness Data forms. See Annexe C and D. This data defines the changes in fitness of the rower:

Total distance per session

Total time

Split time (the average time to travel 500m)

Watts (power output)

Stroke rate (number of rowing strokes per minute)

Average working heart rate