<u>Reducing fatigue of electrically-evoked contractions after a spinal cord injury</u>

Background:

When neuromuscular electrical stimulation (NMES) is used to generate contractions of muscles paralyzed by a SCI the benefits are many. NMES can help restore function to assist with activities of daily living or enable participation in exercise programs. The physiological benefits can be substantial and include improved muscle quality, bone mineral density and cardiovascular fitness. Together the enhanced function and physiological benefits improve quality of life for individuals living with a SCI.

Currently, the greatest impediment to the benefits and wide-spread use of NMES is rapid contraction fatigue. The experiments described in this proposal will compare four types of NMES for reducing contraction fatigue of the quadriceps muscles during cycling in individuals who have a motorcomplete SCI. A "traditional", commercially-available, type of NMES will be compared with three “prototype” NMES protocols.

Objectives:

- <u>Short term:</u> Identify the NMES protocol that generates the most fatigue resistant contractions during cycling for individuals who have a motorcomplete spinal cord injury (SCI).
- <u>Long term:</u> Based on a sound understanding of how electrical stimulation and voluntary commands generate contractions of human muscle, develop an optimal NMES protocol for reducing contraction fatigue and improving muscle quality for individuals who have a SCI.

Methodology:

This research program comprises 80 experiments that will be conducted over 2 years. Each participant will take part in 4 sessions, at least one week apart. A different NMES protocol will be tested in each session. The presentation order of the trials in all experiments will be randomized for each participant to avoid order effects.

Participants:

Twenty individuals over the age of 18 years who have a motor-complete (AIS A or B) SCI will be recruited. A sample size of 18 would provide sufficient statistical power. Twenty participants will be recruited to account for potential participant withdrawal.

Stimulation and recording techniques:

- <u>Torque</u>: A strain gauge will be used to record isometric extension torque.
- <u>Electromyography</u>: Muscle activity will be recorded using surface EMG electrodes over the vastus medialis and lateralis muscles.
- <u>Neuromuscular electrical stimulation</u>: NMES will be applied to generate contractions of the quadriceps. The NMES will be controlled by a computer and delivered using a

stimulator through self-adhesive electrodes. The NMES will be delivered over the femoral nerve or quadriceps muscle belly repetitively.

Four NMES protocols will be assessed:

1) Traditional NMES (tNMES): The tNMES protocol will be delivered using the NMES parameters that come standard with the RT 300 bike. NMES will be delivered between two electrodes placed on the muscle belly using a relatively narrow pulse duration.

2) NMES over the femoral nerve trunk (nNMES): The nNMES protocol will be applied over the nerve trunk with a 1 second pulse duration, generating contractions via reflex pathways. EMG will be monitored to optimize the placement of the stimulating electrodes to evoke H-reflexes. These experiments will represent the first test of contraction fatigue when nNMES is delivered to generate contractions of the quadriceps and using stimulus durations that are optimal for evoking H-reflexes.

3) “Interleaved” NMES: The iNMES protocol combines mNMES and nNMES. Every other stimulus pulse will be alternated between the mNMES and nNMES sites. The proposed experiments will be the first test of the fatigue resistance of quadriceps contractions generated by iNMES during cycling.

4) "Sequential" NMES: The sNMES protocol is a modified type of tNMES in which every fourth stimulus pulse will be rotated between the four electrodes over the quadriceps muscles with a large return electrode placed on the back of the leg.

Research Protocol:
Each experimental session will be conducted in three parts:

Part 1: Baseline assessments of reflex excitability and torque-generating capacity
The participant will have the following baseline measures assessed in their own chair:

- *Peak Twitch Torque (PTT)*: Stimulus amplitude will be increased incrementally until peak torque no longer increases.
- *M-wave and H-reflex recruitment curves*: Recruitment curves will be constructed from stimuli delivered over the femoral nerve to provide a baseline assessment of reflex excitability.
- *Torque-frequency relationships*: Each type of NMES will be delivered at five frequencies (10, 20, 30, 40 and 100 Hz) and two intensities. For the iNMES and sNMES protocols the frequencies represent the "net" frequency applied to the whole muscle.

Part 2.Contraction fatigue during NMES-assisted cycling

After initial baseline measures, participants will be transferred back into their wheelchairs to start the cycling trials using the RT300 bike. NMES will be set to produce an initial cycling cadence of 30 rpm. Each cycling trial will continue until the cadence drops below 15 rpm. The primary outcome measure will be "ride time", defined as the time over which cadence decreases to below 15 rpm. Other measures of fatigue will include "virtual" ride distance and cycling cadence over time. Energy expenditure (kCal/hr) will also be compared.

Part 3.Post-fatigue measures of torque-generating capacity

Immediately after the cycling, PTT and torque-frequency measures will be repeated as described for Part 1. The time between the end of the cycling trials and the start of the post-fatigue measures will be recorded for each participant. Data from these trials will provide information about fatigue mechanisms and how fatigue alters the torque generating capacity for each protocol.

Significance

This research program comprises the first series of experiments designed to compare the fatigue resistance of contractions evoked by four types of NMES and will provide the first ever test of fatigue during two of the protocols (nNMES and iNMES) for activating the quadriceps muscles. The results have the potential to minimize rapid contraction fatigue, the main impediment to participation in NMES programs for individuals living with a SCI. The ultimate goal is to maximize the benefits of NMES-based programs and make them accessible for more individuals. The SCI population is among the most sedentary in the world and a leading cause of death is cardiovascular disease. The results of these experiments will provide the groundwork for the development of future NMES protocols to reduce fatigue.