Forward dynamic modelling of cycling for people with spinal cord injury.

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B.P.E. (Hons.)
M.Ed. (Physical Education)

A thesis submitted for the degree of Doctor of Philosophy

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November, 2001

Abstract

A forward dynamic model was developed to predict the performance of Spinal Cord Injured (SCI) individuals cycling an isokinetic ergometer using Neuromuscular Electrical Stimulation (NMES) to elicit contractions of the quadriceps, hamstring and gluteal muscles. Computer simulations were performed using three inter-connected models: a kinematic model of segmental linkages, a muscle model predicting forces in response to stimulation, and a kinetic model predicting ergometer pedal forces resulting from muscle stimulation.

Specific model parameters for SCI individuals were determined through measurements from isometric and isokinetic contractions of the quadriceps muscles elicited using surface stimulation. The muscle model was fitted to data resulting from these isolated experiments in order to tailor the model's parameters to characteristics of muscles from SCI individuals. Isometric data from a range of knee angles were used to fit tendon slack lengths to the rectus femoris and vastus muscles. Adjustments to the quadriceps moment arm function were not able to improve the match between measured and modelled knee extension torques beyond those using moment arms taken from available literature. Similarly, literature values for constants from the muscle force - velocity relationship provided a satisfactory fit to the decline in torque with angular velocity, and parameter fitting did not improve this fit. Passive visco-elastic resistance remained constant for all velocities of extension except the highest (240 deg s^{-1}). Since knee angular velocities this high were not experienced during cycling, a visco-elastic dampener was not included within the present cycling model.

The rise and fall in torque following NMES onset and cessation were used to fit constants to match the rate of change in torque. Constants for the rise in torque following NMES onset were significantly altered by changes in knee angle, with more extended angles taking longer for torque to rise. This effect was small, however, within the range of angles used during cycling, and consequently was not included within the cycling model. The decline in torque after NMES cessation was not affected by knee angle. A period of five minutes cyclical isometric activity of the quadriceps resulted in torque declining by more than 75% from rested levels. The activation time constants were largely unaffected by this fatigue, however, with only a small increase in the time for torque to decline, and no change in rise time or the delay

between stimulation changes and resulting torque changes. The cycling model, therefore, did not incorporate any effect for changes in activation timing with fatigue.

Performance of the full model was evaluated through measurements taken from SCI individuals cycling a constant velocity ergometer using NMES elicited contractions of the quadriceps, hamstring and gluteal muscles. Pedal transducers measured forces applied to the pedals for comparison between measured and modelled values. A five minute period of continuous cycling using just the quadriceps muscles produced similar results to those found for isolated knee extension. External power output dropped by 50% over the five-minute period, however there was no change in the pattern of torque production with fatigue.

Cycling experiments were conducted using single muscle groups across a range of NMES firing angles. Experimental protocols were designed to seek the firing angles for each muscle that maximised power output by that group. Changes in power output in response to firing angle changes were not large, however, in comparison to the effects of cumulative fatigue and inconsistent power output between trials. This lead to large uncertainties in the determination of those firing angles that maximised power output by each muscle. Results suggest that NMES firing angles to maximise power output by the quadriceps muscles were relatively similar for each subject. For the hamstring muscles, however, substantial differences were observed in the range of firing angles that maximised power output. Results for the gluteal muscles were variable, with some subjects not applying any measurable torque to the cranks, even with maximal stimulation applied.

The model produced a good match to experimental data for the quadriceps muscles, both in the shape of pedal force curves and the firing angles that maximised external power output. The individual variability in hamstring responses was not, however, predicted by the model. Modification of the relative size of the hamstrings' moment arms about the hip and knee substantially improved the match between measured and modelled data. Analysis of results suggests that individual variability in the relative size of these moment arms is a major cause of variation in individual's response to hamstring stimulation. There were apparent limitations in the model's ability to predict the shape of crank torques resulting from stimulation of the gluteus maximus muscle. It is suggested that further research be conducted to enable modelling of this muscle using a range of fibre lengths and moment arms.

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Acknowledgments

I would like mostly to thank my family, Jane, Tom and Louise, for having the patience to wait for this thesis to be complete. Jane, particularly, has offered her support by shouldering the load and shielding me from the ever-present question: “when”. I love you all and promise to spend more of my weekends with you from now on.

My parents have managed to instil a respect and desire for learning without me ever being conscious of their teaching. Their ability to do this impresses me no end and I love them a lot.

Numerous staff from the Faculty of Health Sciences have assisted with this journey. My supervisors, Richard Smith and Glen Davis, have given their valuable time in editing this document. Ray Patton and Tim Turner have kept the equipment running and my face smiling. Che Fornusek has freely offered his time and expertise to develop the ergometer interface; may his release from studentship come quickly. Many others have offered their support and encouragement. Thank you all.

My subjects deserve special thanks, as their sessions were long and tedious. They have given most freely of their time and I couldn’t have done this research without them. Their generosity and good humour is an example to us all.

Candidates Certificate

I, Peter Sinclair, certify that the work contained within this document is my own and has not been submitted to another university or institution as a part or whole requirement for any higher degree.

Peter James Sinclair

Date ___________