MUSCULOSKELETAL MODELS NEED HAMSTRING MOMENT ARMS SCALED FOR INDIVIDUAL SUBJECTS

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INTRODUCTION

Neuromuscular electrical stimulation (NMES) may be used to provide cycling exercise for people with Spinal Cord Injury (SCI). Forward dynamic modelling has previously been used to predict appropriate NMES firing patterns for SCI individuals (Gföhler and Lugner, 2000). The purpose of this study was to explore the effectiveness with which a generic model may provide stimulation parameters for the hamstring muscles of individual subjects.

METHODS

Six subjects with complete motor SCI pedalled a motor driven, near-isokinetic cycle ergometer with NMES applied to the hamstring muscles. Forces applied to the pedals were measured, and NMES onset angle altered systematically to find the firing pattern that provided maximum power output for each individual. NMES firing angles that maximised power output were determined for each subject, utilising a regression equation based on both firing angle and trial number to account for progressive fatigue.

A forward dynamic model of the hamstring muscles was developed to predict pedal forces resulting from NMES (Sinclair, 2001). The model utilised a "Hill-type" muscle model to predict muscle forces from stimulation patterns, and a kinematic model based on anthropometric measurements for each subject. The relationships between limb and muscle kinematics, muscle forces and joint torques were calculated using hamstring moment arms at the knee reported by Buford et al. (1997) and at the hip from Visser et al. (1990). The model assumed isokinetic cycling at 50 rpm.

RESULTS AND DISCUSSION

The ergometer was not completely isokinetic. Consequently, there was acceleration of the ergometer after NMES cessation that produced an overshoot as crank torque declined. This overshoot accounted for much of the difference between measured and modelled results.

There was considerable variation between subjects in the pattern of crank torques produced by NMES. By contrast, the model predicted consistent results for all subjects. Correlations between measured and modelled crank torques varied averaged 0.47, within a range 0.17 to 0.83. There was little correspondence between measured and modelled firing angles that would maximise power output. The average error in predicted onset angle was 34º (range 22 – 53º).

Anthropometric differences between subjects were not able to account for the variation in results, indicating that muscle properties must vary for a model to predict individual results. Modelled horizontal pedal forces were in the wrong direction for some subjects, suggesting that the hamstrings were not pulling back at the knee as forcefully as was predicted by the model (Fig 1). Other subjects displayed a complex pattern of crank torque not predicted by the model (Fig 2), while others were well matched to modelled data.

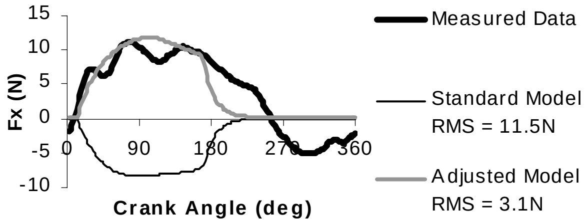

Figure 1: Measured and modelled crank torques for subject 4, with NMES firing angles between 0º and 120º.

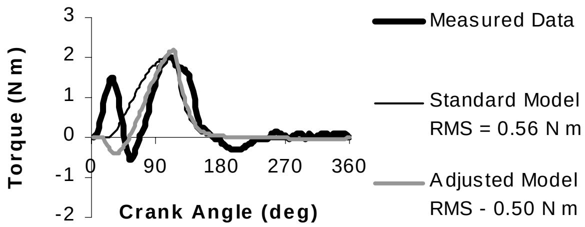

Figure 2: Measured and modelled crank torques for subject 1, with NMES firing angles between 0º and 90º.

The model was adjusted for individual subjects by scaling the knee moment arms to match measured and modelled pedal forces from a single trial. Knee moment arms were reduced to an average of 85% of those reported by Buford et al. (range 60% – 125%). This improved correlations between measured and modelled crank torques to an average of 0.67 (range 0.49 – 0.93). Furthermore, fitting moment arms to a single trial allowed the model to operate over a range of stimulation firing angles, and better predict the firing angles that would maximise power output for individual subjects (average error 17º, range 5º – 30º). Similar results could be achieved by changing either hip or knee moment arms; the direction of forces on the pedal being determined by the ratio of hip to knee moment arms.

SUMMARY

NMES applied to the hamstring muscles produced individual variations in pedal force patterns that were not predicted by a generic muscle model. Adjustment of moment arms about the knee or hip improved the model's ability to predict individual crank torque curves, with adjustments based on a single trial then being able to predict results across a range of NMES firing angles. These findings indicate that individual variation in the relative size of hamstring moment arms about the hip and knee must be considered if models are to make accurate predictions of muscle activation patterns for individual subjects.

REFERENCES

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