PREDICTING THE EFFECT OF PULSE DURATION ON FATIGUE DURING ELECTRICALLY STIMULATED NON-ISOMETRIC CONTRACTIONS

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INTRODUCTION

Functional electrical stimulation (FES) is increasingly used by individuals with paralysis to regain functional movement, but muscle fatigue can limit the applicability of this technology. Mathematical predictions of power loss during electrically stimulated muscle contractions are essential when trying to not only minimize fatigue, but also determine the relative contributions of force and velocity to fatigue. Our previous mathematical model of non-isometric muscle fatigue for electrical stimulation induced, seated leg extensions accounted for the effect of applied load, but not the effect of pulse duration [1]. Therefore, our objectives were: 1) model muscle fatigue at different pulse durations and 2) experimentally validate the model with new subjects and thus predict the effect of pulse duration on fatigue.

METHODS

Experiments were conducted using a computer-controlled stimulator that sent trains of pulses to surface electrodes on the thighs of 25 able-bodied human subjects. Isometric and non-isometric non-fatiguing and fatiguing leg extension ankle forces and/or knee angles were measured. A 4.5 kg load was applied to the leg during the general non-isometric measurements. Five pulse durations were tested: 600, 400, 250, 200 and 170 µs. Model parameters were identified by minimizing the sum of squares error between the model and observations. Predictive accuracy was determined from linear regression analyses of the maximum angular displacement and angular velocity. Data from approximately half of the subjects and data from the previous study which predicted the effect of load on fatigue [1], were used to validate the model.

RESULTS AND DISCUSSION

The equation for one of the non-isometric fatigue model parameters required modification. The remaining two non-isometric fatigue model parameters were found to be unnecessary and were removed. The parameter that was modified is a function of other parameters within the model, therefore additional measurements from the subject are not needed to identify this parameter. During validation testing, we predicted the fatigue at the other two pulse durations in the development subjects, at all five pulse durations in the validation subjects from this study, and at one pulse duration but different applied loads in ten subjects from the previous study. More than 63% of the variability in the measurements was explained by the new force-fatigue model (Fig. 1). Day-to-day differences in the number and types of muscle fibers recruited, in the initial conditions, and in the resting position of the free swinging leg before each contraction may have contributed to the random error.

![Figure 1: Average linear regression coefficients of determination (r²; ± 95% confidence limit).](image-url)
CONCLUSIONS

Dynamic fatigue was reasonably well predicted at different pulse durations by the new non-isometric force-fatigue model. This model can help scientists investigate the etiology of non-isometric fatigue and engineers improve the task performance of FES systems.

REFERENCES