NOVEL MUSCLE FATIGUE MODEL FOR PREDICTING METABOLIC INHIBITION AND LONG-LASTING NONMETABOLIC COMPONENTS

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Introduction

Computational muscle force models are designed to mathematically capture the intricacies of movement mechanics and the variables affecting force generation. The models offer valuable insights into fields such as biomechanics, sports science, ergonomics, and rehabilitation. Modeling muscle fatigue is a complex task due to its nonlinear nature, task-specific characteristics, and variations across muscles and joints. The literature has introduced different approaches to fatigue modeling. Among them, the three-compartment controller (3CC) model [1] represents an advancement over previous models by allowing to handle time-varying force profiles. Nevertheless, the authors have identified limitations in the application of this model to predict muscle forces during high-intensity exercises [2] and suggest a modification to the existing model.

Methods

The novel model is composed of four compartments. The muscle active (*Ma*) and recovery (*Mr*) states have been maintained from the 3CC, while the fatigue compartment (*Mf*) has been divided into two parts (Figure 1): the short-term fatigued state (M_f^S), linked to metabolic inhibition; and the long-term fatigued state (M_f^L), mimicking central fatigue and potential microtraumas. The sum of percentages of motor units in the four compartments equals 100%, and the flows between the four compartments are mathematically described as differential equations.

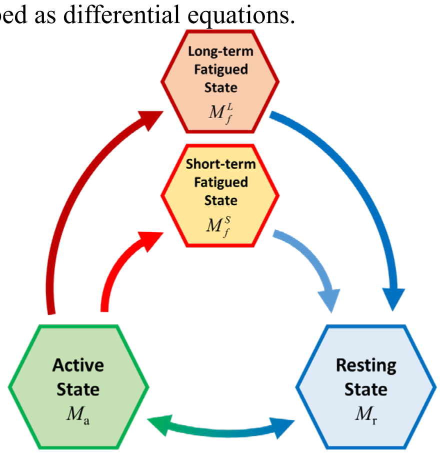

Figure 1: Schematic representation of the novel four-compartment controller mathematical fatigue model.

Results

The outcomes derived from the classical 3CC approach were used as a reference point in this study to validate the new model. The accuracy of both approaches in simulating muscle fatigue during short-duration and long-duration exercises was evaluated. The root-mean-square error (RMSE) was computed between the modeled results and the experimental forces measured from seven subjects to quantitatively validate the new method. The mean values of RMSE across subjects are represented in Table 1. The 4CC model exhibited a strong correlation in both exercises, while the 3CC model showed good correlation in one type of exercise only. The paired sampled t-test revealed statistically significant differences (p < 0.2%) between the 4CC model and its predecessor.

Table 1: Model comparison.

	3CC	4CC
Mean RMSE (%)	18.4	5.1

Discussion

Through recent experimental measurements during both short and long-duration exercises, the authors validated their approach and also demonstrated the limitations of the classic 3CC in handling different time-varying force profiles. As a limitation of the study, the experiments focused on isometric contractions of the elbow flexors. The use of a single joint was intentional, as the authors plan to investigate in future work how central fatigue generated by a single joint can affect the fatigue of other joints.

References

1. L. A. Frey-Law, J. M. Looft, and J. Heitsman, "A three-compartment muscle fatigue model accurately predicts joint-specific maximum endurance times for sustained isometric tasks," J. Biomech., vol. 45, no. 10, pp. 1803–1808, 2012, doi: 10.1016/j.jbiomech.2012.04.018.
2. F. Michaud, L. A. Frey-Law, U. Lugrís, L. Cuadrado, J. Figueroa-Rodríguez, and J. Cuadrado, "Applying a muscle fatigue model when optimizing load-sharing between muscles for short-duration high-intensity exercise: A preliminary study," Front. Physiol., vol. 14, Apr. 2023, doi: 10.3389/fphys.2023.1167748.

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