How Do Imposed Movement Parameters Affect Average Muscle Power Output?

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Summary

The maximal attainable average mechanical power output (AMPO) depends on movement parameters – such as cycle frequency and muscle length excursion. Despite the importance of AMPO, it is unclear how movement parameters interact to maximize it. Using experimentation and modelling, we identified the influence of imposed movement parameters on the maximal attainable AMPO for both rat m. gastrocnemius medialis and human m. quadriceps femoris.

Introduction

Periodic movement tasks – such as cycling, rowing and speed skating – critically depend on the average mechanical power output (AMPO) that the muscles produce. Despite the importance of AMPO, little is known about the relation between movement parameters and AMPO. For example, how do cycle frequency, the ratio of shortening vs. lengthening time and muscle length excursion affect the maximal attainable AMPO?

In this study, we combined *in situ* experiments on rat m. gastrocnemius medialis and *in vivo* experiments on human m. quadriceps with Hill-type muscle-tendon-complex (MTC) modelling and simulations to study the relationship between movement parameters and the maximal attainable AMPO.

Methods

We first predicted the effect of movement parameters – cycle frequency, FTS (fraction of the cycle time spent shortening; an FTS 0.35 indicates that MTC is shortening 35% of the cycle time) and MTC length excursion – on the maximal attainable AMPO using Hill-type MTC models for rat m in which MTC length over time was fully imposed. gastrocnemius medialis and human m. quadriceps femoris. Based on these predictions, we identified 26 experimental conditions for an *in situ* experiment on rat gastrocnemius medialis and 9 for an *in vivo* experiment on human m. quadriceps femoris.

In an *in situ* experiment in rats, we dissected m. gastrocnemius medialis free connected it to a servomotor and placed a cuff-electrode on n. tibialis. This way, MTC length and activation were controlled. For each specimen, we performed experiments to estimate the muscle properties. This allowed us to predict and compare AMPO for each rat individually with experimentally measured AMPO.

In an *in vivo* experiment in humans, MTC length changes of m. quadriceps femoris were imposed by a knee dynamometer. Consequently, participants could influence their AMPO only by changing their muscle activation. Participants received feedback on their cumulative mechanical work per cycle, which they aimed to maximize. As muscle properties of each participant were unknown, we normalized measured AMPO to z-scores for each participant individually and compared them to predicted AMPO.

Results and Discussion

Measured and predicted AMPO in both the *in situ* (r^2>0.98) and the *in vivo* (r^2=0.95) experiment correlated extremely well, indicating that we could accurately predict the effect of movement parameters on the maximal attainable AMPO in both a well-controlled and a less controlled experiment.

For rat m. gastrocnemius medialis, we predicted that AMPO peaks at ~3 Hz, an FTS of ~0.87 and a MTC length excursion of ~9 mm (~ 70% of optimum muscle fiber length; Fig. 1A). For human m. quadriceps femoris, we predicted that AMPO peaks at ~1.6 Hz, an FTS of ~0.75 and an MTC length excursion of ~8 cm (~85% of optimum muscle fiber length; Fig. 1B). Notably, for both muscles, a wide range of conditions yielded AMPO values close to the peak value (Fig. 1). The optimal cycle frequency and MTC length excursion substantially interacted across various contraction conditions in order to maximize AMPO (data not shown). Specifically, as the MTC length excursion increased, the optimal cycle frequency decreased. On the other hand, the optimal FTS was relatively constant across all cycle frequencies and MTC length excursions studied (see Fig. 1).

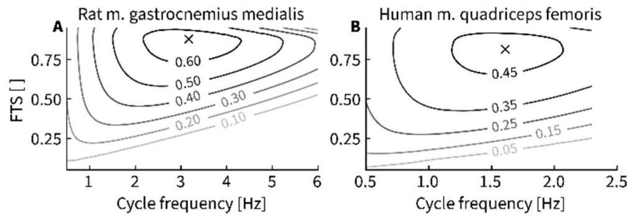

Figure 1: A) Predictions of maximal attainable AMPO (depicted by contour lines) as a function of cycle frequency and FTS for rat m. gastrocnemius medialis at a MTC length excursion of 9 mm (A) and for human m. quadriceps femoris at a MTC length excursion of 8 cm (B). AMPO was normalized to the product of optimum muscle fiber length and maximal isometric force.

Conclusions

Our experimental results were accurately predicted by our Hill-type MTC model for both the in situ and the in vivo experiment. This indicates that we could accurately predict the effect of imposed movement parameters on the maximal attainable AMPO. We predict that, in order to maximize AMPO, both rat m. gastrocnemius medialis and human m. quadriceps femoris should spend substantially more time shortening than lengthening, independent of cycle frequency and MTC length excursion.

References