Time-Resolved Gait Efficiency Analysis Through Enhanced Metabolic Modeling

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Summary

Metabolic models allow us to investigate the muscular efficiency over time. Some allow for negative metabolic rates, which seems physiologically implausible. We adapted an existing model to overcome these problems by allowing the energy to be stored in titin filaments. The adapted model shows whole-body metabolic rates similar to the original model but prevents negative metabolic rates during eccentric contractions. This improves the accuracy of the efficiency calculation, allowing better insight into the efficiency over time.

Introduction

Until now, walking efficiency has only been assessed using measured metabolic rates [1], which limits analysis to the entire gait cycle and the entire body as a whole. In contrast, metabolic models enable the fine-grained calculation of efficiency per time point and per joint. These models have been shown to predict the whole-body metabolic cost well, but they do not include titin, which stores external energy during eccentric contractions, and/or allow the metabolic rate to become negative, which seems physiological implausible [2]. This results in an inaccurate prediction of the efficiency for single timepoints. In this study we take a first step in improving the calculation of efficiency by allowing energy storage in titin without producing negative metabolic rates.

Methods

Nine subjects were measured walking on a treadmill for five minutes at 1.3 m/s. Kinematics were recorded using an IMU-based suit (XSens MVN Link, Movella, Enschede, Netherlands) during the last two minutes. Pulmonary gas was measured over the last 3 minutes to provide a gold-standard comparison (MetaMax 3B, Cortex Biophysik GmbH, Leipzig, Germany). The input for the metabolic models was calculated from the recorded kinematics via an inverse dynamics simulation using the validated whole-body model Myonardo® (version 7.4.0, Predimo GmbH, Münster, Germany) [3]. For the original model an existing metabolic energy model was used, which implements titin but allows the metabolic rate to become negative [2]. This was adapted by storing parts of the external work during eccentric movements, which could then be used to perform work during subsequent concentric contractions without allowing negative metabolic rates. The calculated metabolic cost for the original and adapted model were then compared to the measured metabolic cost and the metabolic rate was used to calculate the efficiency (i.e., joint power divided by calculated metabolic rate per joint). Note that the efficiency may become negative since the joint power is negative during eccentric movements.

Results and Discussion

The preliminary results show a good agreement between the calculated and measured whole-body metabolic cost over the gait cycle for both the original (RMSE = 0.7863 J/kg/m) and adapted model (RMSE = 0.7860 J/kg/m).

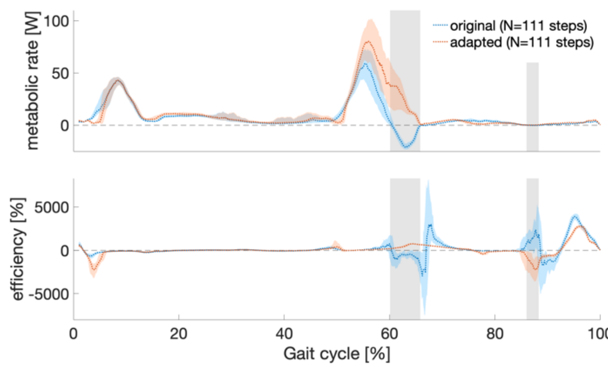

Figure 1: Median and quartiles (.25, .75) of the knee metabolic rate (top) and efficiency (bottom) over 111 steps of one example participant for the original (blue) and the adapted model (red).

The adapted model improves the efficiency calculations, as it prevents zero crossings in the metabolic rate (Figure 1, top, highlighted by grey bars) and thus high peaks in the efficiency (Figure 1, bottom). However, further improvement is needed, because, while efficiencies over 100% are plausible for single time points (due to energy storage in the titin and tendons), the amount seen here seems implausibly high. This will be addressed in future work.

Conclusions

To predict muscular efficiency per time point and per joint, this study implements a metabolic model that describes eccentric contractions by including titin, but does not allow negative metabolic rates. This may provide better insight into muscular efficiency over time.

Acknowledgments

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References

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