The influence of cost-functions on the prediction of muscle activations and coordination in musculoskeletal simulation of movement

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Summary

This study examines how cost function selection influences predicted muscle activations. We simulated gait and cycling using two cost functions, one containing an activation term, and one with both an activation and a metabolic term. Maximal shortening velocity (6<Vmax<10) was varied to investigate the influence of fibre type distribution. Incorporating a metabolic term into the cost function significantly altered muscle activations, while changing Vmax had negligible effects on activation with both cost functions. The results demonstrate that predicted muscle activations are highly sensitive to cost function selection. Thus, carefully considering cost function selection in musculoskeletal simulations is important to capture physiological muscle recruitment strategies.

Introduction

Musculoskeletal models rely on optimization principles to predict muscle activation patterns, yet the relative influence of cost function design versus physiological parameters remains debated. While activation-based cost functions are widely used, their omission of metabolic energy expenditure has raised questions about physiological fidelity. Conversely, metabolic cost formulations account for fiber-type-specific energy demands but introduce computational complexity. This study investigates whether predictions depend more on cost function selection (minimization of activation or metabolic cost) or fibre-type proportion (Vmax variations) in Hill-type muscle model.

Methods

We modified an existing muscle redundancy solver package [1] to account for the differential properties of slow-twitch and fast-twitch muscle fibres. The cost function was updated to include a metabolic cost term [2]:

$$J = J + w_{\text{Act}} \cdot 0.5 \cdot \left(\frac{\sum e_k^2}{N_{\text{Muscles}}} + \frac{\sum a_k^2}{N_{\text{Muscles}}} \right)$$
$$+ w_{\text{Tres}} \cdot \frac{\sum a_{Tk}^2}{n_{\text{DOF}}} + w_{\text{Vm}} \cdot \frac{\sum v_{Mtilde_k}^2}{N_{\text{Muscles}}} + w_{\text{Edot}} \cdot \frac{\sum \dot{E} \cdot h}{N_{\text{Muscles}}} \quad (1)$$

Where: w_{Act}, w_{Tres}, w_{Vm}, and w_{Edot} are weighting factors, e_k and a_k are excitations and activations, respectively. a_{Tk} represents the activation of reserve actuators, v_{Mtilde_k} is the normalized muscle velocity, $\dot{E}$ is the metabolic energy rate, $N_{Muscles}$ is the number of muscles, n_{DOF} is the number of degrees of freedom.

We applied this enhanced cost function to simulate activations during experimentaly measured walking and cycling (cadence of 80 and 140 r/min), focusing on how the Hill type muscle model interacts with various cost functions. Particular attention was paid to the soleus and gastrocnemius muscles, which have different proportions of muscle fibre types [3].

Results and Discussion

The results show that the gastrocnemius activation is very high at a high cadence with the metabolic term and less at a low cadence. This result is compatible with [4], which proved that the gastrocnemius is better suited for high-speed tasks.

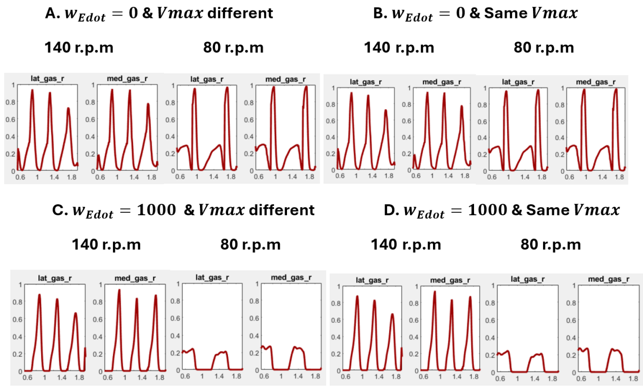

Figure 1: Prediction of muscle activations of the lateral gastrocnemius (lat_gas_r) and medial gastrocnemius (med_gas_r) in different cases and cadences.

Conclusions

This analysis demonstrates that muscle activations are highly sensitive to the inclusion of a metabolic term to the cost function. Fibre type distribution has minimal influence on predicted activations

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