# Muscle contributions to rowing performance

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## Summary

We characterize the whole-body musculoskeletal biomechanics of ergometer rowing through the combination of a comprehensive experimental dataset and muscle-driven simulations. Validity was evaluated by comparing simulated muscle activations to experimental EMG. Our main findings indicate that (1) quadriceps muscles consume the most energy while gluteus maximus fatigue most and (2) higher stroke rates shifts effort from distal lower-limb muscles in to upper-limb muscles.

## Introduction

Rowing is an endurance sport practiced in rehabilitative, recreational, and competitive settings. Technique and muscle coordination are key determinants of performance and musculoskeletal loading. However, the contributions of lower-extremity muscles to rowing are not well understood. To address this, we (1) collect a comprehensive dataset of ergometer rowing and (2) implement a musculoskeletal model and simulate biomechanical variables that are hard to measure. Our dataset is unique through the combination of motion capture, interaction forces, surface electromyography, and gas exchange.

## Methods

We collected data from 13 trained rowers, including marker-based motion capture, surface EMG from 14 muscles, interaction forces at the handle, feet, and seat, and gas exchange. Rowing trials were performed on a Concept2 ergometer at three relative intensities and three stroke rate variations around each rower's preferred stroke rate.

Since rowing is a whole-body movement, we integrated the lower limbs from the Rajagopal [2] model with the Seth shoulder and elbow model [1] (43 degrees of freedom, 152 muscles). Adjustments were made to muscle wrapping and muscle properties to improve physiological realism in highly flexed positions.

Musculoskeletal geometry was scaled using the OpenSim Scale Tool. Optimal fiber length and tendon slack length were adjusted using the Modenese et al. routine [3], while Handsfield equations [4] were applied to scale muscle volumes to reflect individual capacities. Simulation of a single rowing stroke was formulated as an optimization problem [5]: a muscle-driven simulation—subjected to measured external forces—was optimized to track motion capture markers while minimizing pelvis residuals and squared muscle activations (as a measure of effort).

## Results and Discussion

We present results as a case study for one of our subjects. Our model's predictions were validated by good agreement between simulated muscle activations and processed experimental EMG across 14 instrumented muscles. EMG was normalized to maximal values measured during a sprint performed at the end of the session. Mean absolute errors ranged from 0.05 (Soleus) to 0.15 (Gluteus Maximus), with correlations ranging from 0.31 (Biceps Brachii) to 0.86 (Gluteus Maximus).

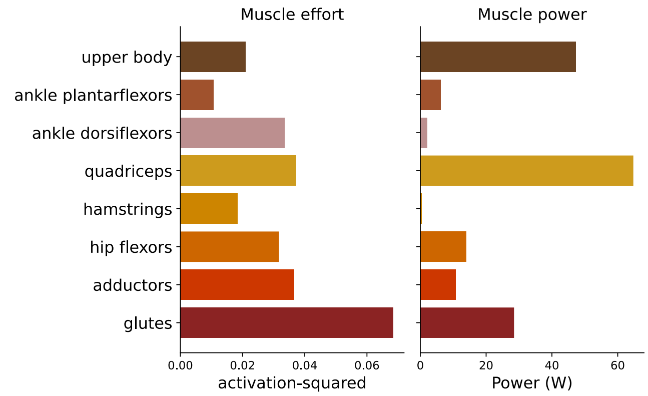


**Figure 1**: Distribution of muscle effort and generated power at preferred stroke rate and 50% of 2K time-trial ergometer power.

Muscle power and energy consumption analyses indicate that the quadriceps generate most of the power during rowing. In contrast, gluteus maximus emerges as a potential performance limiter, exhibiting the highest potential for fatigue as quantified by activation-squared measures. The hamstring muscles, staying at nearly constant length, have a low net positive power but transfer power from knee to the hip.

We found a shift in the muscular power at higher stroke frequency with less power generated by ankle plantarflexors and more power generated by the upper-body muscles. Hip and knee muscles worked at similar power and effort levels.

## Conclusions

We analyzed the musculoskeletal biomechanics of ergometer rowing through a combination of experiments and simulation. Our simulations clearly show what rower's qualitatively feel—quadriceps and glutes are the chief contributors to rowing power. We will continue to analyze upper-extremity contributions and effects on metabolic energy for all subjects.

## Acknowledgments

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## References

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