Mechanical efficiency during sub-maximal cycling is underestimated because negative muscular power is ignored

Roeland T. Vos, Maarten F. Bobbert, **Dinant A. Kistemaker**
Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, Netherlands
Email: r.t.vos@student.vu.nl

Summary

We aimed to study the influence of negative mechanical muscular power on mechanical efficiency estimates during sub-maximal cycling. We identified muscle stimulations for a musculoskeletal model of a cyclist at different combinations of cadence and average mechanical power output. In all conditions, the average amount of negative mechanical muscular power was substantial, with the average across conditions being -84.6W (56.4%). Correcting experimentally observed gross efficiency values for negative power led to substantial increases, with the average increasing from 16.9% to 27.5%. These results suggest that currently used measures of the mechanical efficiency during sub-maximal cycling likely underestimate the true muscular mechanical efficiency, because they ignore the influence of negative mechanical muscular power.

Introduction

The muscular mechanical efficiency plays an important role in various aerobic tasks. Muscular mechanical efficiency has frequently been studied in sub-maximal cycling, using the average mechanical power output (AMPO) and the rates of oxygen consumption and carbon dioxide production. In this approach, it has implicitly been assumed that the average amount of positive muscular mechanical power (AMPO$^+$) equals AMPO, or in other words, that the average amount of negative muscular mechanical power (AMPO$^-$) is zero. However, results from simulation studies suggest that AMPO$^-$ is non-negligible during cycling [1,2]. It is currently unclear how large the influence of AMPO$^-$ would be on mechanical efficiency estimates during sub-maximal cycling.

We first aimed to estimate AMPO$^-$ during sub-maximal cycling at different combinations of cadence and AMPO. We then used our estimates of AMPO$^-$ to investigate the influence of AMPO$^-$ on mechanical efficiency estimates. This was done by correcting experimentally obtained gross efficiency (GE) values from the literature for the effects of AMPO$^-$.

Methods

We used a 2D musculoskeletal model of a human cyclist [1,2]. The inputs of the model, the muscle stimulations over time, were identified for 4 cadences (60-120RPM) and 5 levels of AMPO (50-250W) by optimizing them with respect to a cost function based on muscle fatigue [3].

We used the estimated AMPO$^-$ values to correct experimentally obtained GE values for the effects of AMPO$^-$. First, we subtracted the metabolic power due to AMPO$^-$ from the total metabolic power, using the observation that muscles have an efficiency of -120% while performing negative work [4]. We then multiplied GE obtained from the previous step by the ratio between AMPO$^+$ and AMPO.

Results and Discussion

AMPO$^-$ was substantial in all conditions, with the average across conditions being -84.6W (56.4%). AMPO$^-$ was also found to increase with increasing cadence and was independent of AMPO.

Corrections for AMPO$^-$ led to a substantial increase in GE (Figure 1), with the average increasing from 16.9% to 27.5%. In the literature, GE has been found to decrease with increasing cadence and increase with increasing AMPO [5,6,7,8]. After correcting for AMPO$^-$, both relationships disappeared.

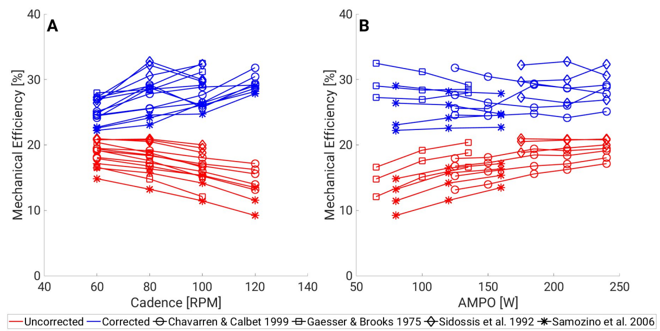

Figure 1: GE with and without [5,6,7,8] correcting for AMPO$^-$, plotted as a function of either the cadence (**A**) or AMPO (**B**).

Conclusion

Due to neglecting the influence of AMPO$^-$, current measures of *in vivo* muscular mechanical efficiency likely underestimate the true muscular mechanical efficiency during sub-maximal cycling.

References

[1] Kistemaker DA et al. (2023). *J. Appl. Physiol.*, **134**(4): 980-991.

[2] van Soest AJ and Casius LJR (2000). *Med. Sci. Sports Exerc.*, **32**(11): 1927-1934.

[3] Gidley AD et al. (2019). *Comput. Methods Biomech. Biomed. Eng.*, **22**(1): 11-20.

[4] Abbott BC et al. (1952). *J. Physiol.*, **117**(3): 380-390.

[5] Chavarren J and Calbet JAL (1999). *Eur. J. Appl. Physiol. Occup. Physiol.*, **80**(6): 555-563.

[6] Gaesser GA and Brooks GA (1975). *J. Appl. Physiol.*, **38**(6): 1132-1139

[7] Sidossis LS et al. (1992). *Int. J. Sports. Med.*, **13**(5): 407-411.

[8] Samozino P et al. (2006). *Eur. J. Appl. Physiol.*, **97**(1): 140-140.