**Limiting radial pedal forces in cycling reduces maximal power output and efficiency**


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## Summary

It is suggested that trying to limit radial pedal forces enhances cycling technique and with that maximal average mechanical power output (*AMPO*) and efficiency. Here, we use a model of a human cyclists to show that, and to explain why, limiting radial forces is a bad idea: it has a detrimental effect on maximal attainable *AMPO* and decreases efficiency.


## Introduction

A cyclist's performance crucially depends on the average mechanical power output (*AMPO*) generated. Instantaneous mechanical power output of a cyclist equals the product of crank angular velocity, crank length and the tangential pedal force ($F_{tan}$; see Fig.1). Radial pedal forces ($F_{rad}$) do not contribute to this power, yet are produced by the cyclist. In the literature [1] and the "cycling field" (e.g., trainers/coaches), $F_{rad}$ is linked to suboptimal pedaling technique, with claims that reducing it improves *AMPO* and efficiency. Our goal was 1) to investigate if $F_{rad}$ indeed results from sub-optimal pedalling technique or is a by-product of optimal cycling, and 2) to understand the relationship between limiting $F_{rad}$ and maximal attainable *AMPO*.

## Methods

We used an optimal control musculoskeletal model of a cyclist consisting of 5 rigid segments, connected by frictionless hinges, driven by 9 Hill-type models of muscle-tendon complexes (see Fig.1). We optimized muscle activation for maximal *AMPO* during one full periodic cycle, while limiting $F_{rad}$ to various levels. We calculated the *Index of Effectiveness* (*IE*) [2]: cycle averaged ratio of $F_{tan}$ and $F_p$ , typically used as a measure of "pedalling technique".

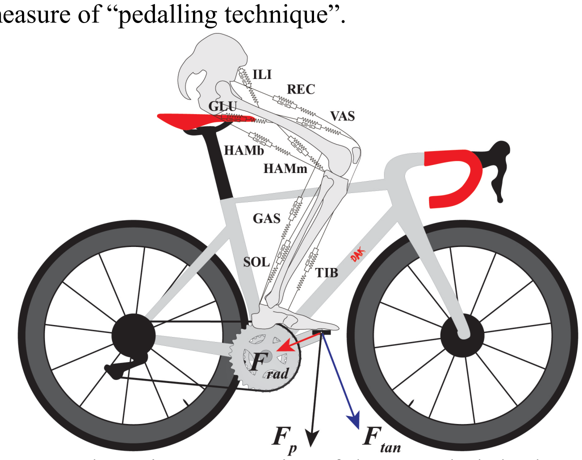


**Figure 1**: Schematic representation of the musculoskeletal cycling model. $F_p$ = pedal force. $F_{rad}$ and $F_{tan}$ radial and tangential components of $F_p$, respectively. GAS, m. gastrocnemius; GLU, m. gluteus maximus; HAMb, bi-articular hamstring; HAMm, mono-articular hamstring; ILI, m. iliopsoas; REC, m. rectus femoris; SOL, m. soleus; TIB, m. tibialis anterior; VAS, mm. vastii.

## Results and Discussion

*AMPO* dropped from 1115W without a limit on $F_{rad}$ to 528W when not allowing any $F_{rad}$ (Fig.2) Highest *IE* does not coincide with highest attainable *AMPO*, which shows that $F_{rad}$ is an unavoidable "by-product".

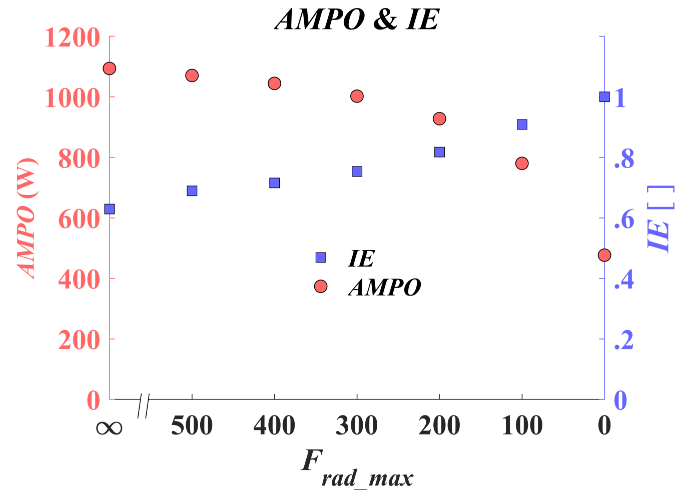


**Figure 2**: *AMPO* and *IE* as a function of allowed $F_{rad}$ ($F_{rad\_max}$) [3].

We calculated the power delivered and work done by all individual muscles in one full cycle (Fig.3). When limiting radial forces, substantial less positive power is produced by the muscles. In addition, more power is dissipated by muscles (negative power), resulting in a decrease in efficiency.

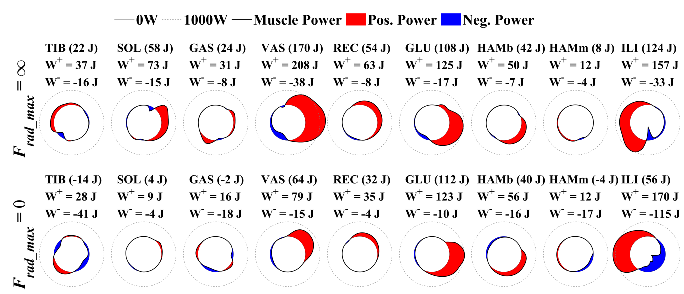


**Figure 3**: Instantaneous mechanical power and work delivered by each of the modelled muscles in one full cycle [3].

## Conclusions

Radial pedal forces are an unavoidable by-product of (*AMPO*) optimal cycling; limiting them leads to ineffective muscle use, resulting in greatly reduced power output and efficiency. Cyclists should not be trained to limit radial pedal forces.


## References

[1] Rossato M et al. (2009). *Int J Sports Med* **29**(9).
[2] Lafortune & Cavanagh, In: Biomechanics VIII-B, 1983.
[3] Kistemaker et al. (2023) *J Appl Fysiol* **134**:980-991.