Optimal control modeling reveals performance benefits of ankle immobility in cycling: Implications for para-cycling classification

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Summary

Para-athletes compete in classes determined by classification systems. The International Paralympic Committee (IPC) mandates the development of evidence-based classification systems for Paralympic sports, which minimize the impact of impairments on competition outcomes. The classification of ankle mobility impairments is a current issue in para-cycling. We employed an optimal control musculoskeletal model of a cyclist to investigate the impact of bilateral ankle immobility on the maximal average mechanical power output (AMPO) during one full revolution. The muscle activation-time histories of nine Hill-type muscle-tendon-complex models were optimized for maximal AMPO when sprint cycling at 120 rpm in two conditions: 1) bilateral ankle mobility, and 2) bilateral ankle immobility (fixed at 90°). Our findings showed an 8% increase in maximal AMPO when cycling without (1122 W) versus with (1038 W) ankle mobility. This might indicate that the current classification of (bilateral) ankle immobility should be revisited.

Introduction

In current para-cycling competition, cycling performance overlaps between athletes classified in C4 and C5 [1], the two least physically impaired cycling classes. Ankle mobility is a key determinant for classification in C4 (e.g., unilateral ankle immobility) or C5 (e.g., mild to severely impaired unilateral ankle mobility) [2]. Together, these factors suggest that ankle mobility impairments may be classified incorrectly in the current para-cycling classification system. In this study, we investigated the potential impact of bilateral ankle immobility on cycling performance, quantified by the maximal average mechanical power output (AMPO) during one full revolution.

Methods

We used a two-dimensional musculoskeletal model, comprising five rigid segments (repr. crank, foot, shank, thigh and pelvis) connected by frictionless hinge joints and driven by nine Hill-type muscle-tendon-complex models (repr. m. iliopsoas (ILI), m. rectus femoris (REC), mm. vastii (VAS), m. gluteus maximus (GLU), bi-articular hamstring (HAMb), mono-articular hamstring (HAMm), m. gastrocnemius (GAS), m. soleus (SOL), and m. tibialis anterior (TIB); Figure 1) [3]. The nine optimal muscle activations over time were identified using an optimal control approach such that AMPO is maximized in two conditions: 1) bilateral ankle mobility, and 2) bilateral ankle immobility (fixed at 90°).

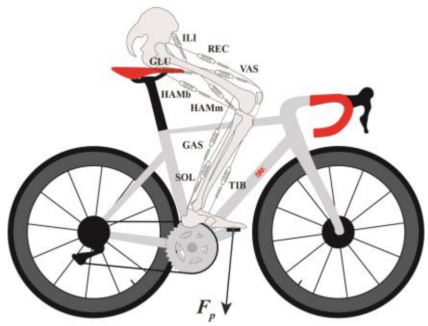

Figure 1: Musculoskeletal model of a cyclist.

Results and Discussion

Our findings showed an 8% increase in maximal AMPO when cycling without (1122 W) versus with (1038 W) ankle mobility. This relative difference depends on the relative strengths of the leg muscles; doubling SOL strength caused a 5% decrease in maximal AMPO when cycling without (1122 W) versus with (1176 W) ankle mobility.

These results may be explained by a trade-off between a decrement in power production by the plantar flexors with ankle immobilization and an increment in power production by other muscles because the immobilization mechanically solves a coordination problem [4]. Increasing SOL strength increases the power decrement of the plantar flexors with ankle immobilization and decreases the power increment of the other muscles, causing a reversal in the sign of the relative difference in maximal AMPO.

Conclusions

This study shows that bilateral ankle immobility may increase maximal AMPO. This might indicate that the current classification of this impairment should be revisited. We suggest careful testing of our model-based predictions trough experiments.

References

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