Coactivation Index During Cycling: A Comparative Analysis Across Different Power Outputs

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Summary

This study investigates variations in the Coactivation Index (CI) of muscles acting on knee and ankle joint across different cycling power outputs using electromyography (EMG) data from 20 participants. The results indicate that as power output increases, the CI of the knee joint decreases, while the CI of the ankle joint increases. These findings demonstrate differential responses in antagonist and agonist muscle coactivation relative to power output, emphasizing the importance of considering motor control strategies in exercise prescription in athletic and rehabilitation settings.

Introduction

Muscle coordination during cycling is vital for optimizing performance and reducing injury risk [1]. The CI, measuring the ratio of antagonist-to-total muscle activity, reflects neuromuscular efficiency and joint stability [2]. However, its variation across different cycling power levels remains unexplored. This study uses EMG data to examine how CI changes at power output, focusing on the balance between flexor and extensor muscles at the knee and ankle joints. The findings aim to inform personalized training programs and enhance biomechanical efficiency.

Methods

This study included 20 recreationally active adults (8 males, 12 females) performing cycling trials on a stationary ergometer. Power levels increased in 20 W increments, starting at 40 W and continuing to each participant's maximum power, while maintaining a constant cadence. Bilateral EMG signals from seven lower limb muscles were recorded at 2200 Hz. The signals were preprocessed using filtering, rectification, and normalization to dynamic maximum voluntary contraction. Flexion and extension at the knee and ankle joints were quantified using the ratio of integrated EMG signals from flexor muscles to the total activity of flexors and extensors. The CI was derived using Eqs. (1) and (2):

$$\mathrm{CI_{knee}} = \frac{\mathrm{iEMG_{BF}} + \mathrm{iEMG_{G}}}{\mathrm{iEMG_{BF}} + \mathrm{iEMG_{G}} + \mathrm{iEMG_{RF}} + \mathrm{iEMG_{VM}} + \mathrm{iEMG_{VL}}} \quad (1)$$

$$\mathrm{CI_{ankle}} = \frac{\mathrm{iEMG_{TA}}}{\mathrm{iEMG_{TA}} + \mathrm{iEMG_{G}} + \mathrm{iEMG_{S}}} \quad (2)$$

CI values above 0.5 indicate flexor dominance, while values below 0.5 suggest extensor dominance [2]. The analysis focused on cycling phases where the knee and ankle joints generate high moments [3]. For the knee joint, this corresponds to the phase from 70° to 190° (measured from the top dead center), and from 180° to 315° for the ankle joint. These phases account for approximately 10% of the maximum moment for each joint, highlighting periods of significant mechanical demand.

Results and Discussion

The knee joint showed a significant decrease in CI as power levels increased for both sides. For the left knee, the CI decreased continuously from the lowest to the middle and highest power levels, with values of 0.74 ± 0.14, 0.63 ± 0.12, and 0.60 ± 0.14, respectively. A similar pattern was observed for the right knee joint (dominance leg), indicating a shift from flexor-dominant activity (CI > 0.5) at lower power levels to more balanced muscle contribution at higher levels.

The ankle joint displayed a progressive increase in CI with rising power levels on both sides, indicating extensor-dominant activity (CI < 0.5) at all power levels. CI values for the ankle were lower than those for the knee, with significant increases observed as power levels rose ($p < 0.05$).

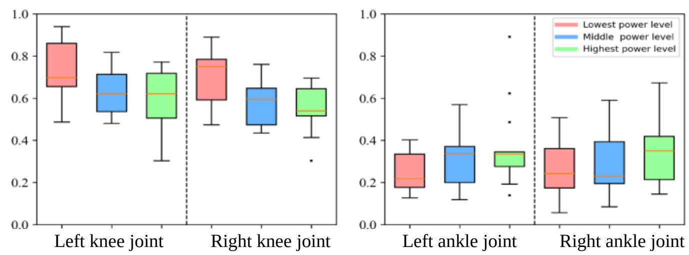

Figure 1 CI of knee and ankle joints across three power levels

Conclusions

The CI metric analysis revealed distinct contributions from the knee and ankle joints, highlighting joint moment adaptation with increasing power output. This study of CI can offer valuable insights for developing training strategies and rehabilitation protocols. Future research should investigate the effects of fatigue, cadence, and training interventions to further enhance performance and reduce injury risks.

Acknowledgments

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References

[1] M. J. Callaghan, et al., vol. 9(3). 226–236, 2005.
[2] E. Raj, and R. Palaniappan, Biomed Signal Process Control, vol. 95. 106455, 2024.
[3] C. Clancy, et al. Sci Rep, vol. 13(1). 21534, 202