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Conference Abstract

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Effects of small cadence variations on joint mechanics in highly trained track cyclists

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Abstract

A track bicycle's gear ratio (and consequently, cadence) can influence muscle force production, shortening speed, and activation rate, ultimately affecting joint-specific power transfer to the crank, energy cost and fatigue. However, the impact of small, practical cadence adjustments on joint mechanics during fatiguing, race-specific intensities in the aerodynamic position remains unknown. Understanding how joint power is distributed during pursuit-specific workloads may reveal strategies cyclists use to sustain high power under fatigue. This study examined the effects of small cadence variations (preferred, ±5 rpm) on joint mechanics (power, angular velocity, and moment) using statistical parametric mapping to identify where within the pedal stroke differences occurred, and to explore the interaction between joint torque and angular velocity in generating joint power. Thirteen highly trained track cyclists completed three 2-min constant work rate trials at individual pursuit race intensity. Higher cadences (+5 rpm) increased hip and knee joint moments concentrated around the crank cycle's transition phases (i.e. top and bottom dead center) where higher angular velocities demanded greater neuromuscular control. Ankle moment differences were larger than hypothesized, decreasing during the downstroke and increased during upstroke, suggesting a key role in managing faster proximal-segment angular velocities through stabilization and transmitting forces to the crank. These findings highlight the value of time-series analysis for revealing cadence-specific biomechanical adaptations that are typically overlooked by discrete metrics, highlighting the importance of individualized cadence selection in pursuit cycling.

Keywords

individual pursuit cycling; aerodynamic position; statistical parametric mapping; performance fatigue; joint power

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1 Introduction

Pursuit cyclists are required to sustain high power outputs in an aerodynamic position for approximately 4-5 min under accumulating fatigue on a single, fixed gear bicycle (Broker et al., 1999; Faulkner and Jobling, 2020). Small gearing changes are common during competition and alter cadence by small margins (<5 rpm) and in turn, the cadence–torque relationship underpinning power production. It is currently unknown how these small changes in cadence under pursuit-specific workloads influence joint power production. Understanding these effects are important for gear selection to optimize power sustainability in elite pursuit cycling.

2 Material and Methods

2.1 Participants

Ten male (18.1 ± 1.4 y, 181.7 ± 5.4 cm, 73.5 ± 9.6 kg) and three female (20.3 ± 4.0 y, 170.2 ± 3.3 cm, 62.4 ± 5.4 kg) trained cyclists competing at national or international junior/U23 levels volunteered during the track cycling pre-season. Participants had ≥2 y involvement in an Australian state-based sports institute cycling program, completed ≥5 cycling and ≥1 resistance training session per week, and were healthy and injury free. Written informed consent was obtained, ethics approval was granted by the Edith Cowan University Human Research Ethics Committee, and procedures were conformed to the Declaration of Helsinki.

2.2 Design

A within-subject repeated measures experimental design was used, with each cyclist completing three cycling bouts at different cadences to assess cadence-dependent differences in joint mechanics.

2.3 Methodology

Participants attended the biomechanics laboratory once and completed 2-min constant work rate (CWR) trials at preferred (pref) and ±5 rpm, based on their most recent individual pursuit performance. This cadence range reflects typical competition gearing adjustments (~2 gear inches). The trials were separated by 30 min and completed in a randomized, counterbalanced order. A 10-s maximal sprint was performed immediately before and after each CWR trial and the difference was used to quantify performance fatigue.

Cycling was performed in an aerodynamic position on an electromagnetically-braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands), adjusted to each cyclist's pursuit bicycle setup. Three-dimensional right-leg kinematic data were captured using six Vicon Vantage motion capture cameras (Oxford Metric Vicon, Oxford, UK), and radial and tangential crank forces were measured using instrumented crank arms (Axis Cranks, Swift Performance, Australia). Kinematic and kinetic data were sampled at 100 Hz and synchronized using Vicon Nexus software (v 2.12.1).

Joint moments and powers were computed using inverse dynamics based on standard rigid-link segment Newton-Euler mechanics (van Ingen Schenau et al., 1990; Elfman, 1939; De Leva, 1996; Martin and Brown, 2009). Joint mechanics were ensemble averaged every 6° over 20 pedal revolutions over the final 30 s of each CWR cycling trial. Data processing was performed using custom-written software.

2.4 Statistical Analysis

Time-continuous joint angular velocity, moment and power data across the crank cycle (0-360°) were analyzed using Statistical Parametric Mapping (SPM1D) (www.spm1.org) in Python (v 3.12.4, Pataky, 2012) to assess cadence-related differences.

3 Results

Mean power output of the sprint performed immediately after the CWR trial was significantly lower (p=0.015) for RPM+5 (8.8 W·kg^{-1}) than both RPM-5 (8.4 W·kg^{-1}) and preferred (8.4 W·kg^{-1}) conditions. Non-fatigued sprints before the CWR trials did not differ (p>0.05). Performance fatigue was thus higher for RPM+5 (34%) than RPM-5 (32%) and preferred (31%) conditions.

Significant differences (p<0.01) were observed for all hip and knee variables (joint angular velocity, moment and power), whilst only ankle joint moment differed between cadences (Figure 1).

Hip— RPM+5 elicited higher hip angular velocities during both extension (5-170°) and flexion (214-345°) phases (SPM{F}(2,24), Fmax=112.4, p<0.01). Hip extensor moments were greater around top dead center (350-22°, Fmax=17.4), accompanied by greater hip extension (0-63° and 148-153°) and flexion power (340-354°, Fmax=29.0).

Knee— RPM+5 increased knee angular velocity during extension (1-144°) and flexion (201-326°, Fmax=184.6, p<0.01). Knee flexor moments (188-218°, Fmax=22.8) and knee flexion power (188-225°, Fmax=28.6) were also higher for RPM+5.

Ankle—Plantar-flexor moments were lower for RPM+5 during the early downstroke phase (23-106°, Fmax=60.4) as the ankle transitioned from dorsiflexion to plantarflexion, but higher during the upstroke (203-296°) while the ankle remained in a dorsiflexed position.

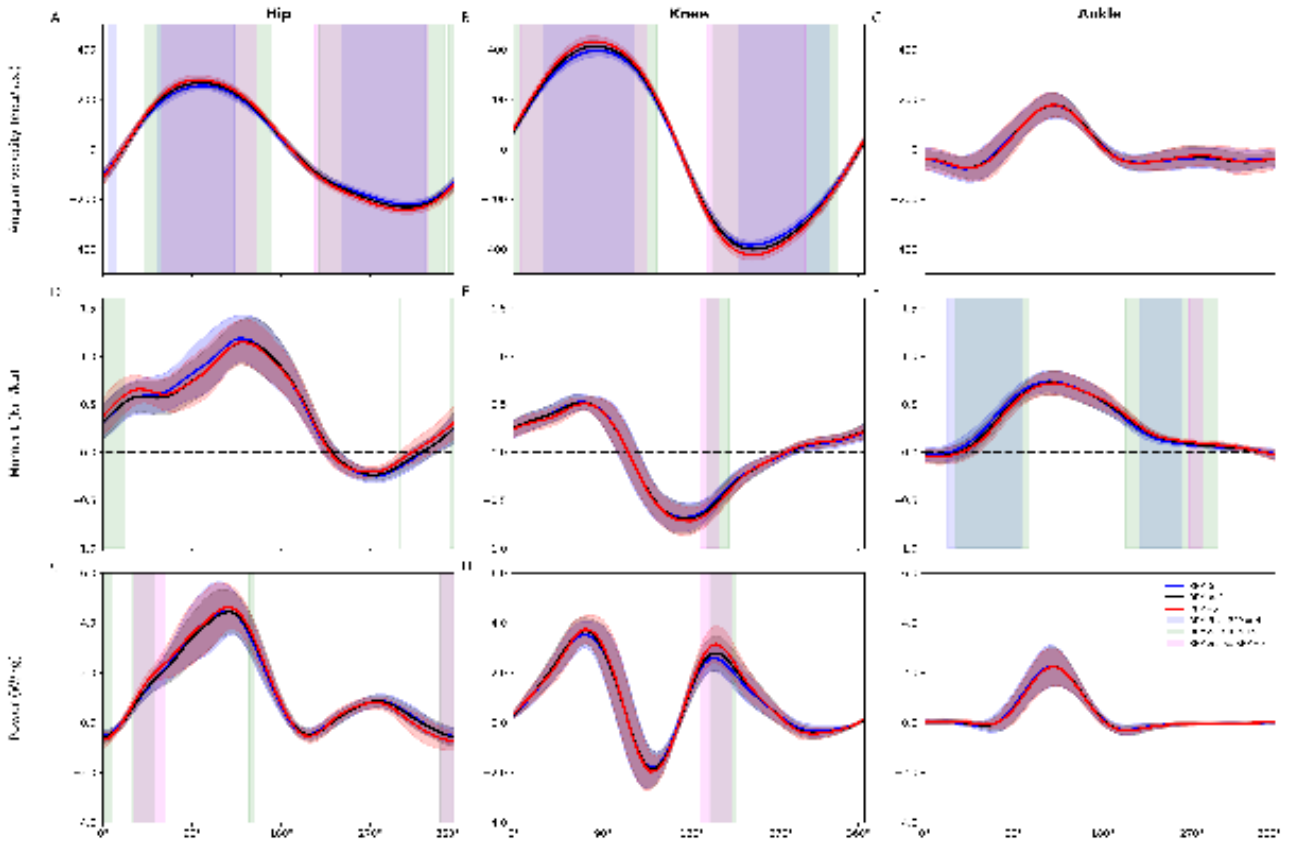


Figure 1. Mean (± SD) joint mechanics data across the crank cycle (0-360°) at three cadence conditions (preferred, ±5rpm). Columns indicate hip, knee and ankle joints and rows indicate angular velocity, joint moment and joint power. Significant differences (p<0.01) between cadence conditions are highlighted during the corresponding periods. Overall, RPM+5 exhibited higher hip and knee angular velocity, higher knee flexor and hip extensor moment and power, lower plantar flexor moment (downstroke) and higher plantar flexor moment (upstroke) than RPM-5 and RPMpref at distinct phases of the pedal stroke cycle.

4 Discussion

Small, practical cadence adjustments (±5 rpm from preferred) influenced joint mechanics in trained pursuit cyclists during fatigued, aerodynamic cycling. Cadence effects were joint specific and occurred at distinct phases of the crank cycle. Higher cadences increased hip and knee angular velocities and were accompanied by greater hip extensor and knee flexor moments and power. However, these differences cannot be reduced to a simple one-to-one relationship between joint moment, angular velocity and joint power. Instead, the timing and direction of these differences suggests a more complex redistribution of mechanical power across joints.

At the hip, increased hip flexion power at higher cadences coincided with a larger hip extensor moment around top dead center. This suggests that the hip extensors (rather than the hip flexors, which operate in a shortened position in the aerodynamic posture (Savelberg et al., 2003; Turpin and Watier, 2020; Dorel et al., 2009)) may have acted eccentrically to decelerate the rapidly flexing thigh and facilitate a smooth transition into hip extension (Husband et al., 2024). Similarly, higher cadences increased knee flexion power during the upstroke, associated with both an increased angular velocity and knee flexor moment. This pattern likely reflects a coordinated proximal-distal energy transfer through the biarticular hamstrings, which cross both the hip and knee joints and may store and release elastic energy under higher angular velocities (van Ingen Schenau, 1990).

In contrast, the ankle plantar flexor moments decreased during the downstroke (during plantar flexion), and increased during the upstroke (while maintaining a dorsiflexed position). These findings suggest a stabilizing or energy-transmission role for the ankle, rather than a primary power-producing function.

5 Practical Applications

Temporal analysis revealed joint-level adaptations that discrete joint-power metrics may overlook. Even small increases in cadence meaningfully altered joint-level mechanics, supporting more individualized cadence (gearing) choices and joint-specific strength and conditioning programming. Biomechanical assessment during fatigued, aerodynamic cycling is suggested for future testing procedures to better understand and refine individual technique and optimize performance in pursuit events.

6 Conclusions

Small increases in cadences altered lower-limb biomechanics of highly trained track cyclists under race-specific conditions, revealing coordinated and potentially compensatory strategies that are not captured by discrete or joint-power metrics alone. These findings highlight the importance of integrating individualized biomechanical assessments alongside physiological testing to optimize power sustainability and technique in pursuit cycling.

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Conflicts of Interest: The authors declare no conflict of interest.

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