KNEE JOINT MOMENTS DURING SPORTIVE CYCLING: A PILOT STUDY

Jonas Ebbecke[1], Josef Viellehner[1,2], Wolfgang Potthast[1]

[1]Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Cologne, Germany
[2]Institute of Outdoor Sports and Environmental Science, German Sport University Cologne, Cologne, Germany

This pilot study examines the impact of varying power outputs (157, 210, 262 W) and cadences (60, 80, 100 rpm) on knee joint kinetics in recreational cycling, aiming to understand the combined effects on knee moments across sagittal, frontal, and transverse planes. Conducted with two recreational cyclists, this full factorial study investigates mechanics through lower-body kinematics and pedal reaction forces. Results indicate varying knee joint moment patterns, especially an increasing external knee extension moment at higher power and cadence as well as a combined effect of both. The findings suggest an interaction between cadence, power output, and knee joint loading. However, limitations like the small sample size and participant performance level underline the need for more comprehensive research with a broader participant base.

KEYWORDS: cycling, joint moments, kinetics, knee.

INTRODUCTION: The biomechanics of cycling has been extensively investigated, including recent studies on pedalling kinetics determining parameters such as pedal reaction forces and joint moments. Yet, much of the existing work concentrates on clinical and rehabilitation cycling at relatively low power outputs, often below 100 W as well as low cadences of below 80 rpm (Gardner et al., 2015, 2016; Hummer et al., 2021; Lu et al., 2023; Redfield & Hull, 1986). This focus overlooks the dynamics of exercise-oriented cycling, where athletes generate power outputs exceeding 200 W. In addition to previous understandings, recent research by Bini (2021) extends the scope of investigation into exercise-oriented cycling, specifically assessing the influence of seat height on knee moments, thereby acknowledging the importance of three-dimensional knee load analyses regarding risk of injury and overload damage. Despite this progress, a gap remains in understanding the combined effects of cadence and power on knee kinetics. Fang et al. (2016) showed the separate effects of cadence and power on knee moments in clinical cycling. However, the interaction between cadence and power and their combined impact on knee moments during exercise-oriented cycling remains unexamined. This pilot study aims on bridging this gap by investigating knee joint moments in different exercise-oriented power and cadence conditions in a full factorial design. Thereby, we are paving the way towards a systematic understanding of knee mechanics, which is crucial for optimizing performance and reducing the risk of injury and overload damage in sportive cycling.

METHODS: Two male recreational cyclists (age: 26 ± 4.2 years; height: 1.86 ± 0.02 m; mass: 75.4 ± 6.6 kg) cycled at three different cadences (CAD_{low}: 60 rpm; CAD_{med}: 80 rpm; CAD_{high}: 100 rpm) and three different power outputs (P_{low}: 157 W, P_{med}: 210 W and P_{high}: 262 W). Power outputs were matched to the cadence conditions in order to result in the same mean crank torque of 25 Nm in three of the nine resulting trials (CAD_{low}/P_{low}; CAD_{med}/P_{med}; CAD_{high}/P_{high}; see Fig. 1). All conditions were randomized in order, and subjects were recorded for 30 seconds in each trial. The subjects cycled on a SRM ergometer [SRM GmbH, Jülich, Germany]. In order to create practice oriented conditions, the seat height was adjusted according to the Genzling method (Genzling, 1980), as this is a frequently used method in everyday cycling. The saddle setback was adjusted so that the centre of the knee joint was in a straight vertical line above the pedal axis at a crank angle of 90°. Lower-body kinematics were measured by means of a 15-camera motion capturing system [Qualisys AB, Göteborg, Sweden, 200Hz] and 28 markers reflecting markers attached to defined bony landmarks. Pedal reaction forces were measured on the right side using a custom-made instrumented cycling pedal (Ebbecke et al., 2023). Net joint moments as well as external knee adduction-abduction, flexion-extension and external-internal rotation moments were calculated in a simplified approach according to Kristianslund et al. (2014). This approach neglects the inertial properties of segments within the kinematic chain, under the assumption that their impact on knee joint moments is minor (Mai et al., 2022). The knee joint coordinate system was defined according to convention (Grood & Suntay, 1983). Moment curves were divided into pedal cycles and normalized to the crank angle. Due to the small sample size, interferential statistical methods were not used in this pilot study. The interpretation of the results is carried out qualitatively.

RESULTS: Peak net joint moments and standard deviations are summarized in Table 1. Peak moments increased with higher power and decreased with higher cadences. The analysis of knee joint moments about the three anatomical axes during cycling revealed distinct patterns across different power outputs and cadences (Fig. 1).

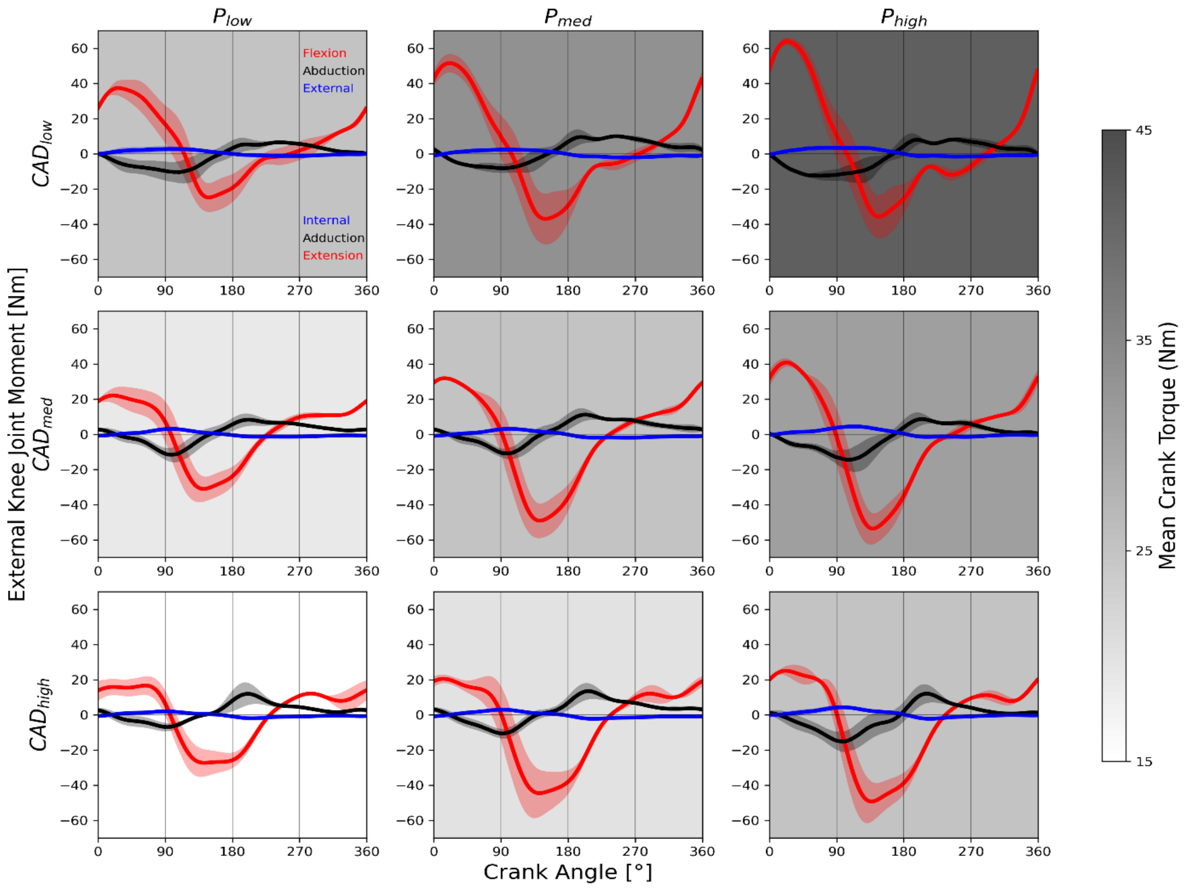

Figure 1: External knee adduction-abduction (black), flexion-extension (red) and external-internal rotation (blue) moments ± std normalized to crank angle in three different power and cadence conditions. Background color represents the resulting mean crank torque.

When examining the external flexion-extension moment, peak moments generally increased with higher power outputs and decreased with higher cadences. When considering the relationship between peak flexion moment and peak extension moment, a change between CAD_{low} and CAD_{med} can be seen. At 60 rpm, the external flexion moment dominated, whereas at CAD_{med} and CAD_{high}, the external extension moment was more pronounced in all power conditions. In the P_{high} and CAD_{high} condition, cadence and power effects combined so that the difference between peak knee flexion moment and peak knee extension moment was the greatest. Therefore, maximum peak flexion moment was found to be 63.9 ± 2.2 Nm in the CAD_{low}/P_{high} condition, whereas maximum peak extension moment was found to be 53.8 ± 8.9 Nm in the 100 rpm/262 W condition. Furthermore, it is apparent that the transition from an

external flexion moment to an extension moment at a crank angle of about 90° occurred more rapidly at higher cadences in all power conditions.
The abduction-adduction moment exhibited less variation in general. In the power phase of the pedal stroke (0 – 180°), an external adduction moment was predominant, whereas in the recovery phase (180 – 360°), an external abduction moment was detected. Peak abduction moments were highest in the P_{med} conditions, reaching the maximum of 13.6 ± 4.5 Nm in the CAD_{high} trial. Higher cadences led to higher abduction moments in all power conditions. Peak knee adduction moments were highest in the P_{high} conditions, showing a maximum of 15.3 ± 5.8 Nm in the CAD_{high} trial.
The internal-external rotation moment showed the lowest magnitude of all moment curves. In the power phase, an external rotation moment was predominant, whereas in the recovery phase, an internal rotation moment was detected. Peak external rotation moments were highest in the P_{high} conditions, reaching the maximum of 4.5 ± 0.7 Nm with CAD_{med}. Higher power led to higher external rotation moments at all cadences, but CAD_{med} led to the highest moments in all power conditions. Peak knee internal rotation moments were highest in P_{med} conditions, showing a maximum of 2.3 ± 0.5 Nm with CAD_{high}.

Table 1: Peak net joint moments in 3 different power and cadence conditions.

	P_{low}	P_{med}	P_{high}
CAD_{low}	39.9 ± 4.9 Nm	55.6 ± 2.7 Nm	65.2 ± 2.3 Nm
CAD_{med}	34.8 ± 4.6 Nm	51.1 ± 8.9 Nm	56.1 ± 7.1 Nm
CAD_{high}	33.4 ± 3.4 Nm	47.8 ± 12.1 Nm	52.0 ± 10.1 Nm

DISCUSSION: The results of this pilot study suggest that both power output and cadence influence knee joint moments during cycling. In general, the net joint moments are within a reasonable range and, considering higher workloads, similar to previous findings (Ericson, 1986; Fang et al., 2016). The observation that the peak net joint moments increased with higher power and decreased with higher cadences output can be explained by classical mechanics and has already been described in the literature (Ericson, 1986; Fang et al., 2016). However, even for cadences and power outputs with the same mean crank torque, the knee mechanics differ from each other. This phenomenon is especially evident especially the increasing prominence of the external knee extension moment with increasing cadence and increasing power. Fang et al. (2016) as well as Thorsen et al. (2020) reported a similar effect at relatively low workloads, although they were unable to show any combined effects due to their study designs. The effect can be explained by a temporal shift of the pedal reaction forces as a function of the crank angle. The vertical force component loses prominence in the 0 – 90° range but gains strength in the 90 – 270° range. Whether this is related to the performance level of the cyclists remains to be clarified and requires further investigation. It is possible that more experienced cyclists with better technical movement execution are able to coordinate their power production at high cadences in a similar way as in low cadences resulting in a later or no occurrence of this effect.
The increase in abduction-adduction moments with cadence suggests that frontal plane knee loadings become more significant at higher pedalling rates as well as higher power outputs. This also indicates that more technical and physically demanding cycling leads to an increase in external knee moments. Similar findings were reported (Fang et al., 2016; Shen et al., 2018; Thorsen et al., 2020), but no combined effects of cadence and power were shown before.
The internal-external rotation moment is the least described knee moment in the literature, probably due to its small contribution to the net joint moment. Nevertheless, similar values as in this study were reported previously (Shen et al., 2018). The lower magnitude of these moments compared to the other axes suggests that rotational moments are less relevant regarding cycling performance but might be critical with respect to injury prevention. However, understanding these moments is essential for comprehensive knee mechanics analysis.
The limitations of this study include the small sample size of only two recreational cyclists, which may not be representative of the larger population of sportive cyclists. In addition, the individual saddle height and knee joint moments were determined using simple yet practicable

approaches. Recognizing the existence of more complex methods and their influence on the results of this study, confidence in the adequacy of the chosen methods to answer the research question remains.

CONCLUSION: This pilot study offers a first step towards a better understanding of the biomechanics in sportive cycling, particularly in understanding how varying power outputs and cadences impact knee joint kinetics. The different observed knee moment patterns confirm the separate influences of cadence and power output already described in literature and provide additional insights into combined effects of both. Our future research will expand on these preliminary findings by incorporating a larger sample size. Such a study could potentially provide further systematic insight into the nuances of knee mechanics during sportive cycling and would ultimately contribute to improved performance strategies and injury prevention methods in this demanding sport.

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