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Journal of Science & Cycling
Breakthroughs in Cycling & Triathlon Sciences

Conference Abstract
Science and Cycling Conference, Lille 2025

Optimization of the Foot/Pedal System through Custom-Molded Carbon Shoes for the Sprinters of the French National Track Cycling Team

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Received: 24 March 2025 **Accepted:** 1 April 2025 **Published:** 24 November 2025

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Keywords
sprint track cyclists; molded shoes; orthopedics; ergonomics; shoe-pedal interface

1 Introduction

This study aims to optimize the foot/pedal system ergonomics for world-class and elite international track cycling sprint specialists. Over the past decade, sprinters have been using custom-molded carbon shoes that do not adhere to any standardized optimization for the foot/pedal interface. The various foot-molding techniques used to date differ from one another and do not allow for the integration of orthopedic corrections. 70% of the French sprint team experienced non-traumatic lower limb injuries. The nature of these pathologies suggests the need for podiatric intervention, leading us to identify actual carbon-molded shoes as a potential cause. Currently, no studies have been conducted to validate any performance benefits of these custom-molded carbon shoes with orthopedic corrections for athletes.

The challenges faced by elite sprint cyclists require optimizing power transfer between the rider and the bike while also preventing injuries due to the high levels of mechanical stress. The objective of our study was to determine whether the development of carbon-molded shoes with proper biomechanical consideration for each athlete could reduce the risk of injury and improve performance.

2 Material and Methods

We evaluated two shoe conditions, carbon-molded shoes designed with proper biomechanical considerations, allowing for the integration of orthopedic corrections (CMC), and the traditionally used carbon-molded shoes (CT) using a multidimensional analysis framework (Fig. 1).

Cyclist performance was assessed by studying mechanical, biomechanical, and qualitative variables under standardized and ecological conditions. We developed a sprint-specific method to compare the performance of both conditions, investigating which setup allowed for higher force and/or velocity generation. First, a static pedaling motion analysis was conducted to validate the orthopedic corrections in the CMC shoes and compare them to the CT shoes. Second, during starting sessions, we applied the Statistical Parametric Mapping (SPM) (Pataky, 2012) method to compare the dynamic force patterns. A performance index (IDP) was developed for standing starts trials, calculated as the ratio between the impulse of the first three pedal strokes and the time achieved over 10 meters (Equation 1).

Additionally, a rate of force development (RFD) analysis was performed to characterize explosive force output during the first pedal stroke. This method was applied to force data collected from standing starts trials, where crank angle and gear ratio were standardized for each athlete in both conditions.

Finally, after a three-weeks usage period for each shoe condition, athletes completed a questionnaire using visual analog scales. This questionnaire aimed to assess qualitative variables such as comfort, foot, support, pedaling efficiency, and overall acceptability of the shoes.

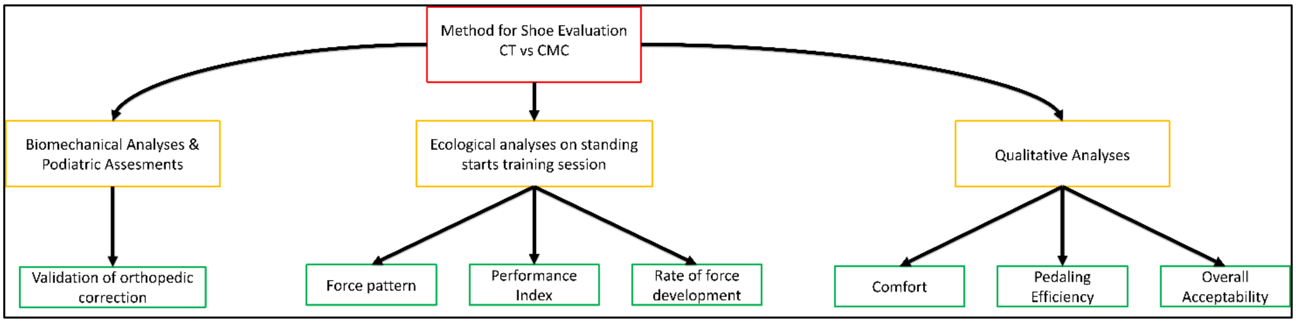

Figure 1. Summary of the methodology used to compare CT and CMC

$$Performance\ Index = \left(10 - \frac{Time\ over\ 10\ m}{1000 - (Average\ Impulse\ of\ 3\ Force\ Patterns)}\right) \cdot 1000$$

Equation (1)

3 Results

We implemented an athlete centered method, meaning that the analysis and data processing were conducted individually. To illustrate our findings, the results of a single case athlete were chosen. However, after compiling data from the nine athletes on the French national sprint team, we were only able to identify a general trend on certain variables.

Across all studied indices, the results indicate that CMC shoes do not enhance performance during standing starts, despite observed changes in pedaling biomechanics and subjective variables.

3.1 Mechanical Variables

In Figure 2, where the torque Production is characterized, no significant difference in the first three pedaling patterns between the two conditions were reported. We observed the same pattern and the same mechanical performance for the ten standing starts realized.

3.2 Biomechanical Variables

Orthopedic corrections significantly influenced the observed biomechanical variables, particularly the lateral oscillations of the knee and ankle joints. Analysis of joint angles revealed distinct modifications, an increase in lateral knee oscillations and a decrease in lateral ankle oscillations were observed with the use of CMC compared to CT.

Specifically, the magnitude of lateral oscillation for the right knee was approximately 21.3 ± 9.3 mm with CMC, while the left knee showed about 23.7 ± 8.6 mm. In contrast, with CT shoes, the right knee exhibited a lateral oscillation magnitude of approximately 14.4 ± 2.1 mm, and the left knee about 10.9 ± 1.7 mm. For the ankle, CMC shoes resulted in a lateral oscillation magnitude of approximately 10.4 ± 2.2 mm for the right ankle and 4.9 ± 3.6 mm for the left ankle. This represents a substantial reduction compared to CT shoes, where the right ankle lateral oscillations were about 27.5 ± 8.4 mm and the left ankle oscillations were approximately 30.9 ± 3.9 mm (Fig. 3). These findings suggest biomechanical adaptation consistent with the objectives of orthopedic intervention, notably enhanced ankle joint stability and increased knee motion.

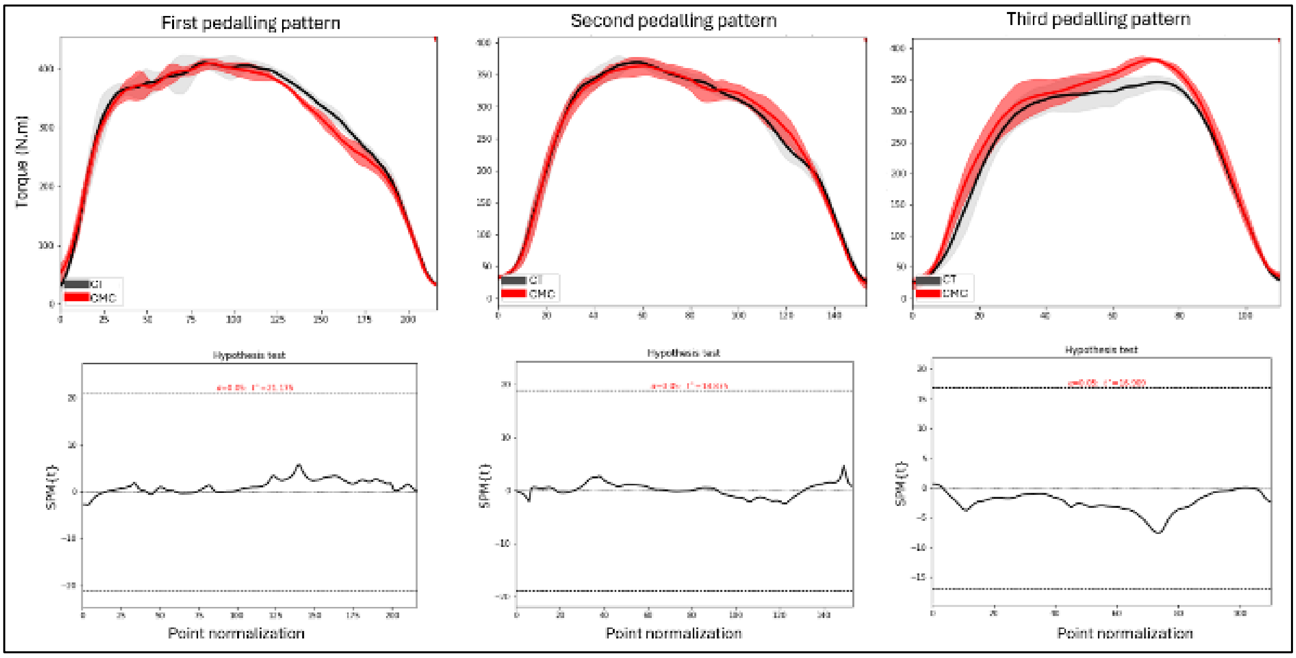

Figure 2. SPM comparison of the first three pedaling patterns during starts trials

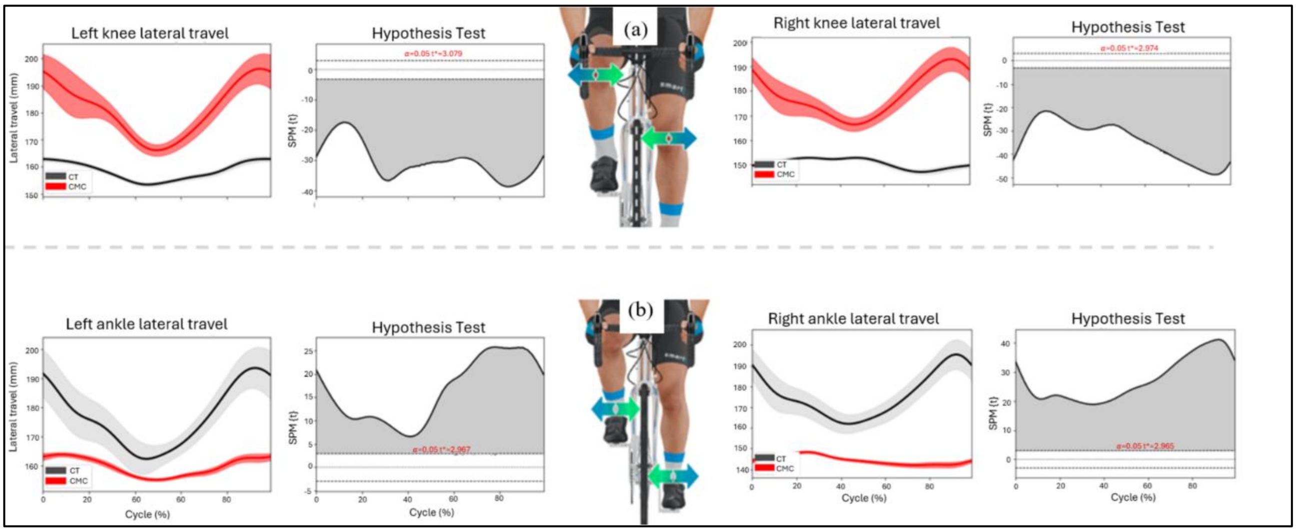

Figure 3. Comparison of lateral knee (a) and ankle (b) oscillations during CMC and CT

3.3 Performance Index Variables

In this case study, a definitive statistical conclusion regarding the performance index could not be drawn due to the limited number of standing starts (10). No major difference was observed between CMC and CT conditions showing respectively a mean IDP of 7.08 ± 0.09, compared to 7.04 ± 0.16 (Fig. 4). This index was specifically designed to identify the best standing start performance for each trial.

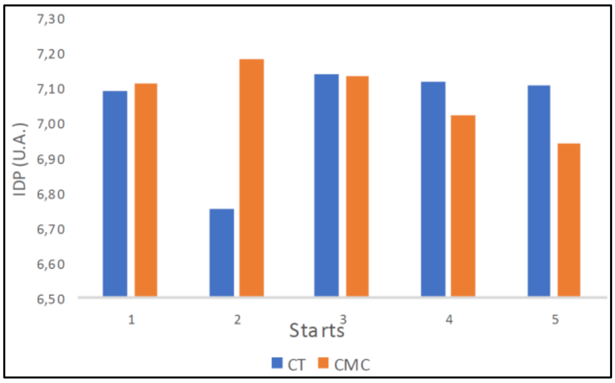

Figure 4. Performance index for standing start between CMC and CT

3.4 Rate Force Development

Like the performance index, the individual case study did not allow for the identification of a statistically significant difference in Rate of Force Development (RFD) between conditions. However, a discernible trend in RFD was observed for each shoe condition across specific time windows. For the [0 ms – 50 ms], [50ms-100ms], and [0 ms - 100 ms] time windows, RFD values were higher with CMC shoes. Notably, both conditions exhibited a maximum RFD within the [50 ms – 100 ms] time window, where the athlete produced 15232 N·s^{-1} with CT shoes and 17053 N·s^{-1} with CMC shoes (Fig. 5).

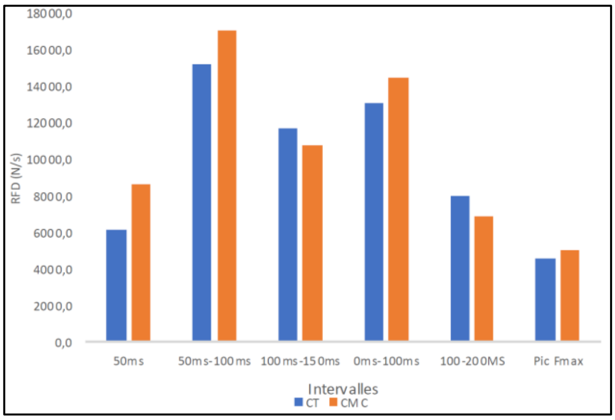

Figure 5. RFD comparison between CMC and CT on the first pedaling pattern

3.5 Subjective Variables

The use of CMC shoes had a mixed impact across the four variables assessed qualitatively. The questionnaire results (Fig.6) indicated an improvement in ratings for pedaling efficiency (increase of +2.35) and the ergonomics of the foot/pedal system (increase of +2.47). However, a significant decrease in ratings was observed for overall acceptability (decrease of -6.1) and comfort (decrease of -8.1).

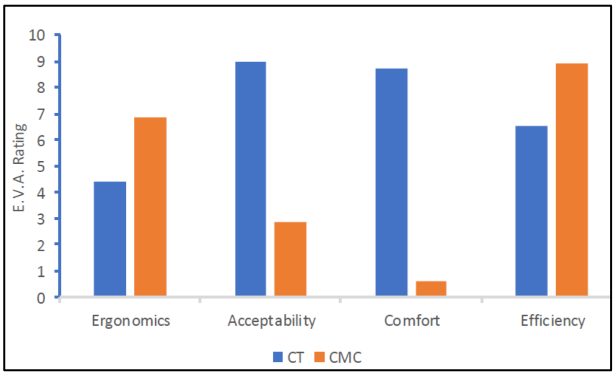

Figure 6. Subjective results of the comparison between CMC and CT

4 Discussion

This study confirms that the use of CMC shoes allows for biomechanical adaptation of the pedaling pattern in accordance with orthopedic recommendations, while remaining within the standards of bikefitting recommendations (Scoz & Oliveira, 2022) as with the increase of the lateral knee oscillations. This biomechanical adaptation could contribute to injury prevention in line with the objectives of the orthopedic intervention performed by the podiatrist in link with the specific pathological issues and the morphological characteristics of each athlete.

However, our findings indicate that CMC shoes had no impact on mechanical variables during supra-maximal efforts. This aligns with previous studies that haven't found significant improvements during sub and supra-maximal cycling performance when using shoes with varying outsole stiffness (Varvat et al., 2021). Our study further confirms this statement, supported by the robustness of our statistical analysis on the mechanical variables assessed. We investigated the entire pedaling pattern rather than focusing solely on isolated peaks of maximum power, force, or velocity.

While indices such as IDP and RFD did not let us differentiate shoe performance, a larger number of standing start analyses would be required to yield statistically meaningful results. Nevertheless, the proposed multidimensional method provides valuables insights for understanding characterizing, and quantifying the efforts produced by sprinters during standing starts, particularly through the incorporation of RFD and IDP. These variables offer actionable data that can be re-invested by coaches to objectively quantify athlete performance on the track. To legitimize our subjective results, each athlete has done a psychometric characterization. This psychometric evaluation was conducted under the supervision of TNP Consultant using the Predictive Index (*PI Behavioral Assessment™ Certified in the European Federation of Psychologists' Associations' (EFPA) Test Review Model*, s. d.) tool. This tool, in future further investigation, will let us understand the behavioral traits that influence responses related to the subjective assessment of each shoe configuration. However, the perceived benefits of CMC shoes, in terms of ergonomics and pedaling efficiency, still require adjustments to improve comfort and overall acceptability. We must take these variables into consideration as they are an integral part of increasing cycling performance (Bouillod, 2017).

5 Conclusions

Thanks to their proper biomechanical considerations and adjustments, CMC shoes could be a viable solution for reducing the risk of injuries in sprinters without degrading or improving the overall performance. Future studies with larger cohorts are warranted to confirm these findings and generalize the result.

Funding: This research received no external funding.

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

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