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Original research

Foot orthoses do not affect crank power output during maximal exercise on a cycle-ergometer

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ABSTRACT

Objectives: To investigate the effects of custom-made foot orthoses on the torque- and power-cadence relationships and perceived comfort during maximal cycling exercises in a population of competitive road cyclists.
Design: Randomised, repeated measures, participant-blinded controlled study.
Methods: Twenty-four competitive road cyclists (22 males, 2 females; aged 18–53 years) with mobile feet performed the torque–velocity test with custom-made and sham foot orthoses. For both conditions, the maximal power, optimal cadence, optimal torque, maximal torque, and maximal cadence were extracted from the individual torque- and power-cadence relationships. Comfort was assessed on a 150 mm visual analogue scale. Paired-samples *t*-tests were used for comparison of means between conditions.
Results: No differences were observed between the custom-made and sham foot orthoses for any of the key variables extracted: maximal power (1022 ± 180 vs. 1020 ± 172 W; $p = 0.794$), optimal cadence (118 ± 10 vs. 119 ± 9 rpm; $p = 0.682$), optimal torque (82 ± 10 vs. 82 ± 11 Nm; $p = 0.559$), maximal torque (157 ± 23 vs. 159 ± 20 Nm; $p = 0.665$) and maximal cadence (220 ± 22 vs. 221 ± 20 rpm; $p = 0.935$). There was no difference in comfort between custom-made and sham foot orthoses (106 ± 30.5 vs. 116 ± 25.0 mm; $p = 0.995$).
Conclusions: Compared to the sham foot orthoses, the custom-made foot orthoses did not significantly affect the torque and power generating capacities or comfort during a maximal exercise performed on a stationary cycle ergometer.

1. Introduction

In most competitive disciplines of cycling (e.g. road racing, track racing and BMX), an athlete's ability to produce high levels of crank torque and power over a wide range of cadences are considered as key factors of sprint performance.[1] Additionally, sprint performance is generally considered a major determinant of success for road cyclists.[1,2] The use of foot orthoses have been suggested to improve a road cyclist's ability to transmit power to the cranks.[3,4] As foot orthoses can provide additional support to the midfoot of cyclists,[5] it has been proposed that orthoses can limit in-shoe foot motion and maintain the alignment of the foot and the lower limb during the pedalling motion.[3] The effect of foot orthoses on the biomechanics of the pedalling movement has been advocated to potentially improve force/power transmission between the foot and the pedal[3,4] while also improving the level of comfort perceived by cyclists.[3]

Only one study has previously investigated the effect of foot orthoses on maximal power output during cycling.[6] The study found that there was no significant difference between the use of foot orthoses and control insoles on maximal and mean power output while performing a Wingate Anaerobic Test.[6] However, it is not possible to draw a definitive conclusion about the effect of foot orthoses on power output during cycling from the aforementioned study[6]: (i) as the ergometer used has not been validated for accurate power measurements,[7] and (ii) between-sessions variations in cadence and fatigue status can have a substantial impact on power production during a Wingate Anaerobic Test.[8] Consequently, it seemed necessary to develop a study protocol allowing an evaluation of the isolated effect of foot orthoses on power output and comfort during cycling.[9] To achieve this goal, it appeared possible to evaluate whether foot orthoses affect the ability of road cyclists to transmit force/power to the pedals in fatigue-free conditions, while cycling over a typical range of cadences. It was hypothesised

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Table 1
Participant characteristics (N = 24; males = 22; females = 2).

	Age (years)	Height (m)	Weight (kg)	BMI (kg/m^2)	FPI – 6 (left foot)	FPI – 6 (right foot)	FMM (left foot)	FMM (right foot)
Males (n = 22)								
Mean	34.4	1.81	76.6	23.5	5.1	5.5	1.96	1.97
Standard deviation	9.2	0.07	9.6	2.6	3.0	2.7	0.28	0.36
Range	18–53	1.64–1.94	59.7–98.4	18.8–29.8	1–10	0–10	1.54–2.66	1.13–2.50
Females (n = 2)								
Mean	22.1	1.66	65.7	23.9	7.5	7.5	1.97	2.07
Standard deviation	3.5	0.06	9.1	1.7	2.1	0.7	0.45	0.00
Range	19.6–24.5	1.62–1.70	59.3–72.1	22.7–25.1	6–9	7–8	1.65–2.29	2.07–2.07

Abbreviations: BMI, body mass index; FPI, foot posture index; FMM, foot mobility magnitude.

that foot orthoses would increase force/power transmission to the pedals during maximal cycling exercises, and that the foot orthoses were more likely to provide a benefit to road cyclists with greater foot mobility.

Therefore, the aim of this study was to compare the torque- and power-cadence relationships and derived variables obtained from a torque–velocity (T–V) test completed on a stationary cycle ergometer with custom-made and sham foot orthoses in a population of competitive road cyclists with mobile feet.

2. Methods

This was a randomised, repeated measures, laboratory-based, participant-blinded controlled study. Volunteers from Victoria, Australia responded to poster advertising at local road cycling races and on social media. Ethics approval was obtained by La Trobe University Human Ethics Committee (FHEC14/025) conforming to the Declaration of Helsinki, and all participants provided written informed consent.

Participants were eligible to participate if they were aged 18 years or older, typically rode more than 100 km per week (including a ride longer than 50 km), and held a current Cycling Australia Gold Race license.[10] Additionally, participants were required to have a foot classified as mobile using the foot mobility magnitude (FMM).[11] A foot was considered mobile if the FMM was greater or equal to one standard deviation from the population mean, in the direction of a more mobile foot (>2.02 and >1.94 for a male right and left foot respectively, >1.89 and >1.84 for a female right and left foot, respectively).[11] The FMM is determined by measuring the change in dorsal arch height and midfoot width at 50% of the total foot length between non-weight bearing and weight bearing.[11]

Participants were excluded from the study if they had a medical condition or injury that would affect their ability to cycle, were unable to speak English, or had a history of using foot orthoses/in-shoe wedges/shims during cycling.

At the initial assessment, participant characteristics and anthropometric measures, including the modified Foot Posture Index (FPI-6),[12] were documented (Table 1). The FPI-6 determines foot posture by using six criterion-based observations, which are each scored on a 5-point scale (range −2 to +2); with the resulting aggregate score being able to range from −12 (highly supinated) to +12 (highly pronated).

The two orthotic conditions analysed in this study were (Supplementary material):

i. Custom-made foot orthoses
ii. Sham foot orthoses (control)

All feet were cast using the neutral suspension technique as described by Root et al.[13] The custom-made foot orthoses were a modified Root style device balanced to the neutral calcaneal stance position.[14] The orthotic shell was made from 4 mm polypropylene as this material is rigid[15] and low bulk. The custom-made foot orthoses were manufactured by a commercial orthotic laboratory (Footwork Podiatric Laboratory Pty Ltd., Melbourne, Australia), using computer-aided technology whereby each orthotic shell was directly milled from a polypropylene block.

Following this, the sham orthoses were moulded against milled positive casts. The shell of the sham orthoses were made from 1 mm polyethylene, which has been shown to collapse under minimal force and provide minimal mechanical effects on the foot.[15] Both orthotic conditions had the same full-length top cover applied (2 mm ethylene vinyl acetate, density 0.12 g/cm^3 hardness 25 shore A). A single custom-made and sham foot orthosis (Men's US size 9 shoe) weighed 74 and 29 g, respectively.

Upon orthotic issue, participants were advised that they were receiving two different pairs of foot orthoses. The participants were instructed to wear each pair of orthoses for an equal amount of time, and for a minimum of 2 h while cycling during the two-week familiarisation period. During this period, all participants were instructed to perform brief (5 s) maximal sprints as part of their rides. They were asked to perform the sprints while having their hands on the handlebar drops and remaining seated in order to familiarise them with the testing procedure used for the torque–velocity (T–V) test so that valid and reliable measurements could be obtained during the laboratory testing session.[16] Participants completed a diary to indicate they had met the familiarisation requirements. Participants used their own cycling shoes (cleated) and pedals during the familiarisation period and laboratory testing. All shoes were assessed using a footwear assessment tool.[17]

An electro-magnetically braked cycle ergometer (Dynafit Pro Velotron, RacerMate Inc., Seattle, WA, USA), fitted with 170 mm scientific SRM cranks (Schoberer Rad Messtechnik International, JÜlich, Germany) was used for the T–V test. The SRM PowerMeter cranks were calibrated prior to and following data collection using a static protocol.[18] At the beginning of the testing session, the ergometer geometry was individually adjusted to match the dimensions of each participant's personal bicycle. Then, participants completed a standardised warm-up and rested for 5 min before completing the T–V test. For each orthotic condition, the T–V test consisted of three maximal sprints of 5 s each, as described thereafter: one sprint started at 0 rpm against 3 W/kg braking resistance, one sprint started at 50–60 rpm against 2 W/kg braking resistance, and one sprint started at 90–100 rpm against no braking resistance. The braking resistances were adjusted using the Velotron Wingate software (v1.0, RacerMate Inc., Seattle, WA, USA). For each sprint, participants were given postural cues (such as "lock your elbows, tighten your core") and were instructed to maximally accelerate on verbal command. To avoid sequencing effects, each orthotic condition was matched to the three abovementioned sprints (6 orthotic-sprint conditions in total) and these 6 sprints were performed in random order. The sprints were interspaced by a 6-min recovery period, allowing all sprints to be performed in a fatigue-free state.[19] The analogue torque signal generated by the strain gauges of the SRM was sampled at a frequency of 250 Hz using Torxtar^{TM} data logging system. Left top dead centre crank position