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Original research

Hardness and posting of foot orthoses modify plantar contact area, plantar pressure, and perceived comfort when cycling

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ABSTRACT

Objectives: To evaluate the effects of hardness and posting of orthoses on plantar profile and perceived comfort and support during cycling.
Design: A repeated measures study with randomised order of orthoses, hardness, and posting conditions.
Methods: Twenty-three cyclists cycled at a cadence of 90 rpm and a perceived exertion rating of twelve. Contoured soft and hard orthoses with or without a medial forefoot or lateral forefoot post were evaluated. Plantar contact area, mean pressure and peak pressure were measured for nine plantar regions using the pedar®-X system and represented as a percentage of the total (CA%, MP%, and PP% respectively). Perceived comfort and support was rated on a visual analogue scale.
Results: The softer orthosis significantly increased CA% ($p = 0.014$) across the midfoot and heel with a decrease in the toe region and forefoot. MP% ($p = 0.034$) and PP% ($p = 0.012$) were significantly increased at the mid and lateral forefoot with reductions in MP% at the midfoot and in PP% at the hallux and toes. Forefoot posting significantly increased CA% ($p = 0.018$) at the toes and forefoot and decreased it at the heel. PP% was significantly altered ($p = 0.013$) based on posting position. Lateral forefoot posting significantly decreased heel comfort ($p = 0.036$).
Conclusion: When cycling, a soft, contoured orthosis increased contact across the midfoot and heel, modulating forefoot and midfoot plantar pressures but not altering comfort or support. Forefoot postings significantly modified contact areas and plantar pressures and reduced comfort at the heel.

1. Background

In cycling, the majority of the energy imparted to the bike is provided by the lower limb. With the foot-shoe-pedal interface being the single propulsive link enabling power transmission, there is potential for high reactive and repetitive forces at this site.[1,2] Previous investigations have demonstrated that plantar pressure patterns are consistent when cycling. The greatest pressures occur beneath the head of the first metatarsal phalangeal joint and the hallux which are situated directly over the pedal axle.[3,4] This dominance of the disto-medial structures of the forefoot is evident in both elite and recreational cyclists, indicating an intrinsic relationship between the foot, shoe, and pedal as opposed to a training effect.[3,4] Such repetitive high forefoot plantar pressures are believed to contribute to the foot pain and paraesthesia, frequently reported by cyclists.[5,6]

Previous studies have reported a prevalence of foot and ankle injuries among cyclists between 6% and 16%.[7,8] To alleviate foot problems Gregor and Conconi[9] proposed using orthoses in cycling shoes. They hypothesised that an orthosis would decrease forefoot pressures by more effectively distributing pressure over a larger plantar surface area through increased conformity to the contours of the foot. In a previous study we showed that when compared to a flat insert of the same hardness, a contoured orthosis provided greater contact with the plantar surface of the foot and altered plantar pressures during cycling.[10] However, clinically prescribed orthoses can range from pre-fabricated to individually customized devices with varying material properties (hardness or density). Since the greatest area of loading in cycling is the forefoot, added cushioning as well as moulding to increase surface are in the heel and midfoot would appear to be important to decrease forefoot plantar pressures. Previous research has reported that softer

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orthoses can provide more even plantar pressure distributions.[11] In addition, individual moulding and posting of orthoses influence lower extremity biomechanics, with differing isolated effects.[12–14] When combined, however, the effects of moulding appear dominant, being further enhanced by the posting.[13] Further, it is proposed that perceived comfort level is a key factor in determining the efficacy of orthoses.[11,15,16] While there appears consensus that perceived comfort is influenced by orthosis design, the specific design component that best determines comfort is still a point of contention, with some studies proposing hardness as the dominant factor[11,16,17] while others noting moulding to be the defining feature of comfort.[15,18] How these orthoses features impact on the lower limb in cycling remains, as yet, to be evaluated.

The primary aim of this study was to evaluate the effects of prefabricated contoured orthoses of varying hardness, as well as the impact of forefoot posting, on plantar surface characteristics (contact and pressure) and the perception of foot comfort and support in cyclists. We hypothesised that (a) a softer orthosis would provide increased plantar contact area creating a more symmetrical distribution of plantar pressure and be perceived as more comfortable; (b) the addition of a posting would not significantly alter plantar contact area but would increase pressure beneath the posting region and thus be perceived as less comfortable.

2. Methodology

Twenty-three participants, fourteen male and nine female, completed the study (age = 35.2 (±7.9) years, height = 175.4 (±7.7) cm, and mass = 71.2 (±10.9) kg). All participants were competitive or recreational road cyclists with an average weekly training/riding distance of 275.0 km (±95.7). Participants were required to have been using the bike, cycling shoes, pedals, and set-up position used during the testing period for a minimum of three months prior. At the time of testing, participants were required to be free of musculoskeletal or neurological disorders affecting the spine or the lower extremity, otherwise, they were excluded from the study. All procedures were approved by the Australian Institute of Sport Ethics Committee and The University of Queensland Medical Research Ethics Committee and carried out in accordance with the guidelines of the Code of the World Medical Association (Declaration of Helsinki). Informed consent was provided by all participants prior to involvement in the study.

In this repeated measures study, two commercially available ethylene vinyl acetate (EVA) contoured orthoses (Vasyli International, Australia) of exactly the same shape but differing hardness were evaluated. The soft orthosis (green) had a hardness of 52^0 Durometer Shore A (Model #28246-A, Shore Instrument and Manufacturing Company, Jamaica, NY, USA), while the hard orthosis (red) had a hardness of 75^0 Durometer Shore A. Both orthoses were tested alone as well as with the individual addition of either a medial forefoot or lateral forefoot posting (Vasyli International, Australia). In this instance, the posting (or wedging) was the addition of material to the orthosis to tilt the device from the horizontal. A total of six different orthosis conditions were evaluated, those being the soft or hard orthosis with or without a medial forefoot or lateral forefoot post. Any insert in the cycling shoe was removed so that the only inclusion present in both the left and right shoe while testing was one of the six orthosis conditions. The order of testing of the different combinations of hardness and postings was randomised.

The pedar®-X pressure measurement system (Novel, Munich, Germany) was used to record the plantar measurements of contact area, mean pressure and peak pressure beneath the left foot for each orthosis condition. The pedar®-X pressure measurement system utilises sensor insoles approximately 2 mm in thickness, each consisting of a matrix of 99 capacitance transducers attached to the pedar®-X system. The set-up utilised the system in a mobile capacity recording measurements via the built-in Bluetooth® technology. Validity of the pedar®-X system capacitance sensor has been previously documented.[19] Prior to data collection, each sensor insole was calibrated as per the manufacturer's instructions. The sensor insoles were placed in both the left and right shoe above the orthosis condition being tested and directly beneath the sock covered foot.

Participants were required to rate comfort and support provided by each of the six specific orthosis conditions on a 10 cm visual analogue scale (VAS) adapted from scales that provide a reliable measure of assessment of footwear comfort.[15] The comfort VAS was anchored with 'not comfortable at all' (0) and 'most comfortable imaginable' (10). The support VAS was anchored with 'no support at all' (0) and 'too much support' (10), with an additional median descriptor of 'perfect support' (5). As well as rating overall plantar surface comfort, participants rated three specific plantar regions for comfort (forefoot, arch, heel) and two specific plantar regions for support (arch, heel).

Prior to testing, the arch height ratio (AHR) was calculated for the left and right feet by dividing the dorsal arch height, measured at 50% of total foot length, by the truncated or ball length.[20] The AHR values were compared to the normative data previously published to classify the foot type of each cyclist as normal.[20]

Testing involved participants cycling on their own road bicycle with clipless pedals wearing their own rigid-soled cycling shoes set up on a Tacx (Technishe Industrie Tacx BV, Wassenar, The Netherlands) stationary magnetic resistance trainer. Cycling trials were performed seated and steady-state at a cadence of 90 revolutions per minute (rpm). Participants were instructed to complete a brief warm up and during this period self-select a gear that would allow them to maintain a comfortable pace for the 60–90-min testing period. A rating of perceived exertion (RPE) of 12 based on Borg's 15 point (6–20) RPE scale was used to define the participants 'comfortable' cycling pace.[21,22] RPE was preferred to power output as a performance measure for two reasons. First, it provides a reliable measure of cycling intensity that is independent of the varying power profiles that can exist between individual cyclists.[23–25] Second, it allows participants to use their own bicycle, equipment, and set-up as the testing parameters for this study required that they were using familiar equipment. Cadence and RPE were the primary determinants of participant performance.

The testing period involved six relatively short intervals (approximately five-minutes duration) of cycling during which pedar®-X data were collected, interspersed with rest intervals. For each test condition, once a consistent cadence of 90 rpm was achieved, pedar®-X data were collected at a sampling rate of 50 Hz in the first 20 s of every second minute with three sampling periods for each condition. Immediately following the completion of each test condition (three trials), the participants were asked to rate their perceptions of comfort and support provided by that specific orthosis condition. All data were collected in a single testing session.

The Novel Percent Mask program (Novel, Munich, Germany) was used to divide the plantar surface of the foot into nine separate regions based on a percentage of the total foot length and width. The nine plantar regions defined were the hallux, toes, medial forefoot, mid forefoot, lateral forefoot, medial midfoot, lateral midfoot, medial heel and lateral heel. The heel was defined as being the region from 0 to 30%, the midfoot was from 30 to 60%, the forefoot was from 60 to 85% and the hallux and toes were from 85 to 100% of total foot length. The medial and lateral midfoot and heel regions were determined by halving the total width, while the three forefoot regions were each a third of the total forefoot width. The hallux