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Contoured in-shoe foot orthoses increase mid-foot plantar contact area when compared with a flat insert during cycling

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ABSTRACT

Objectives: To determine the effect of contouring of an in-shoe foot orthosis on plantar contact area and surface pressure, as well as perceived comfort and support at the foot-orthosis interface during stationary cycling.
Design: A randomised, repeated measures control study.
Methods: Twelve cyclists performed steady-state seated cycling at a cadence of 90 rpm using a contoured orthosis and a flat insert of similar hardness. Contact area (CA) and plantar mean pressure (PP) were measured using the PEDAR® system, determined for seven discrete plantar regions and represented as the percentage of the total CA and PP respectively (CA% and PP%). Perceived comfort and support were rated using a visual analogue scale (VAS).
Results: The contoured orthosis produced a significantly greater CA% at the medial midfoot ($p = 0.001$) and lateral midfoot ($p = 0.009$) with a standardised mean difference (SMD) of 1.3 and 0.9 respectively. The contoured orthosis also produced a significantly greater PP% at the hallux ($p = 0.003$) compared to the flat insert with a SMD of 1.1. There was a small non-significant effect (SMD < 0.4) for the perceived comfort measures between conditions, but perceived support was significantly greater at the arch ($p = 0.000$) and heel ($p = 0.013$) with the contoured orthoses (SMD of 1.5 and 0.9, respectively).
Conclusion: Contoured orthoses influenced the plantar surface of the foot by increasing contact area as well as a perception of greater support at the midfoot while increasing relative pressure through the hallux when compared to a flat insert during stationary cycling. No difference in perceived comfort was noted.

1. Introduction

In cycling, the majority of the energy imparted to the bike occurs through the single linkage of the foot-shoe–pedal interface.[1–3] As cycling involves highly repetitive loading there is the potential for high reactive forces between the foot and the pedal over a period of cycling.[4–6] These high reactive forces result in high pressures beneath the foot and are proposed to be responsible for frequently reported foot pain and paraesthesia.[7–9] Previous investigations of plantar pressures during steady state seated cycling indicate a consistent pattern where the greatest pressure occurs in the forefoot region directly over the pedal axle, more specifically beneath the head of the first metatarsal phalangeal joint and the hallux.[5,6,10] Additionally with increasing foot load a medial shift in forefoot pressures is demonstrated with an increased reliance on the anteromedial structures as load bearers.[6]

Orthoses are commonly used in cycling shoes. We previously surveyed 52 elite professional road cyclists during a series of road races in Australia and found that 33% currently used orthoses in their cycling shoes.[11] It is commonly thought that a role of foot orthoses is to control motion of the foot,[12–14] but this has been questioned.[15,16] Since cycling has been shown to cause increased forefoot pressures, another possible benefit of using in-shoe foot orthoses is the modulation of forefoot pressure through an increased conformity to the contours of the foot resulting in the distribution of pressure over a larger plantar surface area.[7,17] While there is some research regarding the distribution of plantar pressures using orthoses in walking and running,[18,19] this issue has not been addressed in cycling. The primary aim of this study

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was to evaluate the effect of orthoses on plantar contact area, plantar pressure, perceived comfort and support of the foot plantar surface.

2. Methods

This randomised, repeated measures, control study evaluated the initial effects of a pre-fabricated contoured/shaped orthosis on plantar surface characteristics (pressure, contact) and perception of foot comfort and support in cyclists. A flat insert of the same hardness was used as a control condition.

Twelve participants, eight male and four female were involved in the study. All participants were competitive or recreational road cyclists. The mean age of the participants was 35.1 years (±10.6), mean height was 174.7 cm (±8.7) and mean weight was 70.0 kg (±9.8). Participants were initially screened for a weekly riding distance > 200 km per week (mean of 285.4 ± 82.9 km) and were required to be free of musculoskeletal or neurological disorders affecting the spine or lower extremity at the time of testing. Participants were also required to have been using their current bike, set-up position, cycling shoes and pedals for the previous three months. Prior to participation, each participant provided informed written consent. All procedures were approved by the Australian Institute of Sports Ethics Committee and The University of Queensland Medical Research Ethics Committee.

A commercially available contoured orthosis and a flat non-contoured insert (Vasyli International, Australia) made from ethylene vinyl acetate (EVA) with the same hardness (52° Durometer Shore A, Model # 28246-A, Shore Instrument and Manufacturing Company, Jamaica, NY, USA) were evaluated. Each participant wore their own cycling specific cleated road cycling shoes with a rigid sole for the duration of testing. Any insert present in the cycling shoe was removed prior to testing so that the only insert present in the shoe was either the flat insert or the contoured orthosis being tested.

The PEDAR® pressure measurement system (Novel, Munich, Germany), with a sampling rate of 50 Hz, was used to record foot plantar pressure and contact area within the shoe for each orthoses condition. The validity of the capacitance sensor used with the PEDAR® system has been previously documented.[20] The capacitance sensor insole, which is attached to the PEDAR® system, consisted of a matrix of 90–100 capacitance transducers and is approximately 2 mm in thickness. All pairs of sensor insoles used in the study were calibrated prior to the start of data collection using a rubber bladder that was pressurised with compressed air over a range beginning with 5 kPa and ending with 600 kPa. The sensor insoles were placed in the shoe directly beneath the sock covered foot.

Participants were asked to rate aspects of the comfort and support provided by each specific (orthotic/insert) condition using a 10 cm visual analogue scale (VAS). We adapted scales for measuring comfort and support from those used by Mundermann et al.[21] that were shown to provide a reliable measure of assessing footwear comfort (Fig. S1 in Supplementary data). For the comfort measures, the left end was labelled 'not comfortable at all' (0 cm) while the right end was labelled 'most comfortable imaginable' (10 cm). For the support conditions, the left end was labelled 'no support at all' (0 cm), the middle was labelled 'perfect support' (5 cm) and the right end was labelled 'too much support' (10 cm). Clear instructions were given and participants were asked to take their time and consider each question individually (Fig. S2 in Supplementary data).

Cycling trials were performed with the participants using their own bicycle set up on a Tacx (Technishe Industrie Tacx BV, Wassenar, Netherlands) stationary magnetic resistance trainer. All participants used clipless pedals and road cycling specific shoes with a rigid sole. Cycling trials performed were seated and steady state. Each participant was required to cycle at a cadence of 90 rpm and was instructed to self select a gear that they could comfortably maintain for 20 min of cycling. A 'comfortable' level of cycling was determined as a rating of perceived exertion (RPE) of 12 as obtained from participants' using Borg's 15 point (6–20) RPE scale.[22] This gear setting was maintained for the duration of testing. RPE was the preferred measure of performance over the alternative of power output regulation for two main reasons. RPE firstly allows participants to use their own bicycle and equipment for testing and secondly, it provides a reliable measure of exercise intensity that is not influenced by varying power profiles that occur between cyclists.[23–25] Cadence and RPE were the primary determinants of participant performance.

The order of testing of the two insert conditions was randomised. For each test condition, the participant cycled for approximately ten minutes with PEDAR® data collected in the latter six minutes of this period. The first few minutes of the testing period were required to allow the participant to achieve the constant cadence of 90 rpm. Once a constant cadence was achieved, PEDAR® data were collected in the final ten seconds of every second minute; thus three sampling periods for each condition were acquired. Immediately after each test condition (three trials) was completed, the participants were asked to rate their perceptions of comfort and support provided by that specific 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 for each cycling stroke into the following nine plantar regions: medial heel, lateral heel, medial midfoot, lateral midfoot, medial forefoot, central forefoot, lateral forefoot, hallux, and toes. These regions were based on a percentage of the total foot length and width and were consistently applied to all strokes selected for analysis. The heel was from 0 to 30% and the midfoot from 30 to 60% of foot length. The forefoot was from 60 to 85% and the toes from 85 to 100% of foot length. The total width of the heel and midfoot regions were divided in half, while the forefoot region was divided into thirds. The medial and lateral heel regions were not included in any further analysis because pressures in the heel region are commonly low due to the nature of pedalling. As force is applied to the pedal primarily by the forefoot region and contoured orthoses tend to add contact through the midfoot region, these were the primary regions of interest in the investigation. Once all the regions for each stroke were defined, the Novel Multimask Evaluation program (Novel, Munich, Germany) was used to calculate the plantar surface contact area (CA) and plantar peak mean pressure (PP) for the seven plantar regions for each contiguous stroke for both types of orthoses. The first three strokes of the recording were ignored then recordings from 15 contiguous strokes were averaged for each condition per participant. The mask was subsequently applied to the PEDAR® data in order to evaluate specific areas of the plantar surface. Both the CA and the PP were determined for each discrete region as well as for the total plantar surface. For each of the seven discrete plantar regions, CA and PP were then further defined as a percentage of the total CA and total PP respectively (CA% and PP%) for the purpose of analysis. Defining each region CA and PP as a percentage of the total allowed for standardising of these two measures between participants irrespective of variation in pedal force, which could not be recorded. While the PEDAR® insole does provide a force measure it only records the force applied perpendicular to the insole. Thus, it does not provide a true measure of the resultant force that is applied to the shoe or pedal. Since all participants were required to use their own bike, shoe and pedal system, the resultant pedal force was not recorded as no current technology allows for measuring of pedal force within the testing procedure utilised in this study.

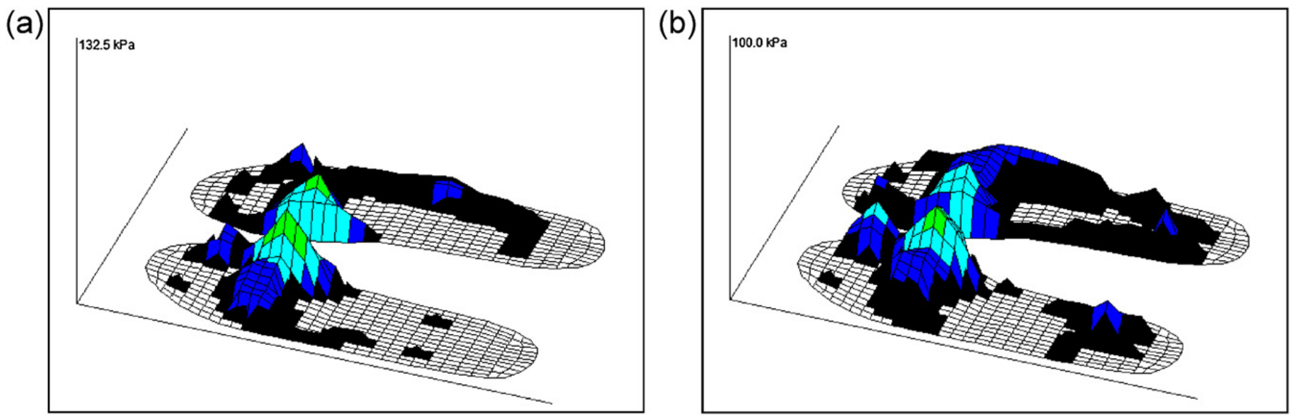

Fig. 1. Example of plantar profile of a single participant demonstrating CA (cm^2) and peak PP (kPa) using (a) flat insert and (b) contoured orthosis.

Two separate two factor repeated measures ANOVA were used to evaluate the effect of orthoses (contoured versus flat) and mask region (hallux; remaining toes; medial, mid and lateral forefoot; medial and lateral midfoot) CA% and PP%. Post hoc tests of simple effects for contoured versus flat inserts were used to further evaluate interaction effects at each of the seven separate plantar regions using paired *t*-tests. Two separate two factor repeated measures ANOVA were also used to evaluate the effect of orthoses (contoured versus flat) on the perceived comfort and support aspects. Post hoc tests of simple effects for contoured versus flat inserts were used to further evaluate interaction effects at each of the four perceived comfort and two perceived support measures using paired *t*-tests. For all comparisons the alpha was set at 0.05. The mean data, differences between the means and 95% confidence intervals are presented. Standardised mean differences (=mean difference/between subject standard deviation) were calculated and presented to provide an estimate of the degree to which the effect was meaningful.[26] SMD of greater than 1.2 were defined as large differences, 0.6 to 1.2 were moderate and less than 0.6 were defined as small.[26]

3. Results

For all participants, the PP occurred predominantly in the anterior one-third or forefoot region of the insole with a moderate degree of involvement noted in the midfoot and lesser at the heel (Fig. 1).

For the CA data, expressed as a percentage of total contact area, repeated measures ANOVA results indicated a statistically significant interaction effect between plantar region and orthosis condition ($F = 7.290$, $p < 0.001$). Follow up tests of simple effects of orthosis condition at each specific plantar region demonstrated that there was a significant increase in CA% at both the medial midfoot ($p = 0.001$) and the lateral midfoot ($p = 0.009$), with standardised mean differences of 1.3 and 0.9 respectively with the contoured orthosis (Table 1). For the PP data, expressed as a percent of total mean pressure, repeated measures ANOVA indicated a statistically significant interaction effect between plantar region and orthosis condition ($F = 2.755$, $p = 0.019$). Follow up tests of simple effects of orthosis condition at each specific plantar region demonstrated an increase in PP% at the hallux ($p = 0.003$), with a standardised mean difference of 1.1 with the contoured orthosis (Table 1).

For the comfort and support perception data, repeated measures ANOVA indicated a statistically significant interaction effect between plantar region and orthosis condition ($F = 5.241$, $p = 0.001$). Follow up tests of simple effects of orthosis condition for each comfort and support aspect demonstrated that there was a significant increase in the perceived/reported support VAS at both the arch ($p < 0.001$) and the heel ($p = 0.013$) with SMDs of 1.5 and 0.9 respectively with the contoured orthosis (Table 2). No significant differences were noted in the perceived/reported comfort

Table 1
Mean and standard deviation (SD) of contact area (CA) and plantar mean pressure (PP) at each region, expressed as a percent of total pressure and contact area, respectively, for the flat and contoured orthoses with the mean differences (95% confidence intervals) and standardised mean differences (SMD).

	Flat	Contoured	Difference	SMD
CA region (%)				
Hallux	10.3 (3.8)	9.8 (3.7)	−0.5 (−1.4 to 0.4)	0.3
2nd–5th toes	7.8 (5.4)	7.0 (4.1)	−0.8 (−2.2 to 0.7)	0.3
Med forefoot	20.4 (6.6)	18.9 (8.4)	−1.5 (−4.6 to 1.6)	0.3
Mid forefoot	15.3 (3.6)	13.0 (5.0)	−2.2 (−5.2 to 0.8)	0.5
Lat forefoot	15.4 (6.3)	14.2 (5.2)	−1.2 (−2.5 to 0.1)	0.6
Med midfoot	3.1 (2.2)	8.8 (4.1)	5.7 (3.0 to 8.4)*	1.3
Lat midfoot	13.8 (7.5)	18.4 (8.4)	4.6 (1.4 to 7.8)*	0.9
PP region (%)				
Hallux	115.0 (29.8)	136.4 (32.2)	21.4 (9.1 to 33.6)*	1.1
2nd–5th toes	83.4 (34.4)	85.4 (35.4)	2.0 (−8.4 to 12.4)	0.1
Med forefoot	148.4 (35.2)	147.2 (29.8)	−1.2 (−13.8 to 11.3)	0.1
Mid forefoot	115.4 (37.4)	106.7 (25.2)	−8.7 (−28.5 to 11.1)	0.3
Lat forefoot	88.3 (29.1)	89.6 (30.1)	1.2 (−3.1 to 5.6)	0.2
Med midfoot	69.9 (37.0)	64.9 (33.4)	14.9 (−3.2 to 33.0)	0.5
Lat midfoot	65.6 (26.7)	66.6 (23.4)	1.1 (−16.2 to 18.3)	0.04

* Confidence intervals not containing 0 are statistically significant ($p < 0.05$).

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Table 2
Mean and standard deviation (SD) of comfort and support measures at each region for the flat and contoured orthoses with the mean differences (95% confidence intervals) and standardised mean differences (SMD).

	Flat	Contoured	Difference	SMD
Comfort (mm)				
Overall	6.0 (1.3)	6.2 (1.8)	0.2 (−1.1 to 1.5)	0.1
Forefoot	5.5 (1.8)	6.3 (1.7)	0.8 (−0.6 to 2.2)	0.4
Arch	5.2 (1.5)	5.4 (2.2)	0.3 (−1.5 to 2.0)	0.1
Heel	5.9 (1.6)	6.3 (2.1)	0.5 (−1.2 to 2.1)	0.2
Support (mm)				
Arch	3.1 (1.5)	6.4 (1.6)	3.2 (1.8 to 4.6)*	1.5
Heel	3.7 (1.3)	5.0 (1.2)	1.3 (0.3 to 2.3)*	0.9

* Confidence intervals not containing 0 are statistically significant ($p < 0.05$).

measures. There was a large spread of scores indicating either more or less comfort in individual reports of change of comfort perception.

4. Discussion

When compared to the flat insert, the contoured foot orthosis influenced the plantar surface of the foot during seated, steady state cycling. The contoured orthosis significantly increased plantar surface contact area through the midfoot with a large increase noted in the medial midfoot and a moderate increase noted in the lateral midfoot. This finding supports the hypothesis that a contoured orthosis/insert should provide greater plantar contact area through increased conformity to the contours of the foot.[17] For pressure distribution, the contoured orthosis produced a moderate significant increase in mean plantar pressure at the hallux but not at the first metatarsal phalangeal joint, which differs to the pattern documented in previous reports.[5,6,10] The increase in mean plantar pressure noted at the hallux may be a result of increased passive tension through the flexor hallucis longus due to the shaped arch region of the contoured orthosis.[27] It is unknown if this increase in hallux pressure is detrimental or beneficial in contributing to any performance gains. Regarding the foot, it would be tempting to speculate that the increased contact area through the midfoot (particularly at medial forefoot with the largest effect size (SMD 1.3 for contact and 1.5 for support in arch)) would override any potential increase in risk of injury due to pressure at the hallux.

For the contoured orthosis, perception of support showed a large significant increase at the arch of the foot and a moderate significant increase at the heel. With a significant increase noted in the contact area through the midfoot region, the perceived increase in arch support would appear to be a function of increased plantar surface contact area. The change in perceived heel support was an interesting finding due to the nature of cycling, since as previously discussed there is limited pressure beneath the heel at the shoe–pedal interface.

Recent reviews of literature into the mechanisms of actions of foot orthoses and inserts have raised questions as to the ability of these devices to change skeletal alignment and have proffered a concept that the perceived orthotic comfort level is a key factor in determining the efficacy of orthoses/inserts.[16,28,29] In this investigation, there was no difference noted in any aspect of perceived comfort between the contoured orthosis and flat insert as may be expected from previous walking and running research.[18,30] This finding could have been due to the similar hardness of the orthosis and insert. The response in perceived comfort ratings to different hardness of EVA material of orthoses in cycling shoes requires evaluation. Notwithstanding the issue of hardness, the lack of a sufficiently strenuous bout of exercise may have also contributed to this observation since the testing period examined was relatively short and of a comfortable exertion level. It would be of interest to evaluate longer periods of cycling time with increased training intensity in future studies as current research indicates that foot pain and paraesthesia typically occur after a more extensive period of riding time.[7–9]

The results of this study provide some initial evidence supporting the role of orthoses in cycling to initially influence plantar surface contact and pressure profile, however there were limitations. For example, cadence was standardised across all participants, but while gearing (i.e. resistance) was kept constant for each individual, it varied between participants. Additionally, resultant pedal force was not recorded as no current technology can provide a measure of pedal force within the testing procedure parameters for this study where participants were required to use their own bike, shoe and pedal system. Ideally, pedal force would be recorded to allow for control over potential force variations that may result between participants and even between conditions. Lastly the contoured orthosis was not molded to the participants' foot as may well be the case clinically, nor did we measure foot posture in fitting the orthoses.

5. Conclusion

The use of a contoured orthosis versus a flat insert influences the plantar surface of the foot during steady state seated cycling. The contoured orthosis significantly increased contact area beneath the medial and lateral midfoot providing greater plantar contact area through increased conformity to the contours of the foot. Furthermore, it significantly increased plantar mean pressure beneath the hallux. The contoured orthosis provided greater perceived support through both the arch and the heel while not influencing perceived comfort.

6. Practical implications

- A contoured orthosis in a cycling shoe increases plantar contact area in the midfoot whereas plantar pressure increases beneath the big toe.
- Perceived support through the arch and heel increased with no change in comfort level while the contoured orthosis was in the cycling shoe.
- Shifting contact and support to the arch moves forward to the big toe the usual peak pressures under the joint of the big toe, which may help reduce any pressure related issues at that joint in cyclists.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jsams.2012.04.006.

References

1. Gregor RJ, Wheeler JB. Biomechanical factors associated with shoe/pedal interfaces. Implications for injury. *Sports Med* 1994;**17**(2):117–131.
2. Ruby P, Hull ML. Response of intersegmental knee loads to foot/pedal platform degrees of freedom in cycling. *J Biomech* 1993;**26**(11):1327–1340.

3. Wheeler JB, Gregor RJ, Broker JP. The effect of clipless float design on shoe/pedal interface kinetics and overuse knee injuries during cycling. *J Appl Biomech* 1995;**11**(2):119–141.
4. Sanderson DJ, Black AH, Montgomery J. The effect of varus and valgus wedges on coronal plane knee motion during steady state cycling. *Clin J Sport Med* 1994;**4**(2):120–124.
5. Sanderson DJ, Cavanagh PR. An investigation of the in-shoe pressure distribution during cycling in conventional cycling shoes or running shoes. In: *Biomechanics XB*. Champaign, IL: Human Kinetics; 1987.
6. Sanderson DJ, Hennig EM, Black AH. The influence of cadence and power output on force application and in-shoe pressure distribution during cycling by competitive and recreational cyclists. *J Sports Sci* 2000;**18**(3):173–181.
7. Sanner WH, O'Halloran WD. The biomechanics, etiology, and treatment of cycling injuries. *J Am Podiatr Med Assoc* 2000;**90**(7):354–376.
8. Mellion MB. Common cycling injuries: management and prevention. *Sports Med* 1991;**11**(1):52–70.
9. Dickson TB. Preventing overuse cycling injuries. *Phys Sportsmed* 1985;**13**(10). pp. 116–119, 123.
10. Hennig EM, Sanderson DJ. In-shoe pressure distributions for cycling with two types of footwear at different mechanical loads. *J Appl Biomech* 1995;**11**(1):68–80.
11. Bousie J, Vicenzino B, McPoil T. Do contoured in-shoe foot orthoses reduce foot plantar pressures by increasing plantar contact area during cycling? *J Sci Med Sport* 2006;**9**(1):4.
12. Bates BT, Osternig LR, Mason B, et al. Foot orthotic devices to modify selected aspects of lower extremity mechanics. *Am J Sports Med* 1979;**7**(6):338–342.
13. Baitch SP, Blake RL, Fineagan PL, et al. Biomechanical analysis of running with 25 degrees inverted orthotic devices. *J Am Podiatr Med Assoc* 1991;**81**(12):647–652.
14. Novick A, Kelley DL. Position and movement changes of the foot with orthotic intervention during the loading responses of gait. *J Orthop Sports Phys Ther* 1990;**11**(7):301–312.
15. Stacoff A, Reinschmidt C, Nigg BM, et al. Effects of foot orthoses on skeletal motion during running. *Clin Biomech* 2000;**15**(1):54–64.
16. Mills K, Blanch P, Chapman AR, et al. Foot orthoses and gait: a systematic review and meta-analysis of literature pertaining to potential mechanisms. *Br J Sports Med* 2010;**44**(14):1035–1046.
17. Jarboe NE, Quesada PM. The effects of shoe stiffness on forefoot pressure. *Foot Ankle Int* 2003;**24**(10):784–788.
18. Chen H, Nigg BM, de Koning J. Relationship between plantar pressure distribution under the foot and insole comfort. *Clin Biomech* 1994;**9**(6):335–341.
19. Chen H, Nigg BM, Hulliger M, et al. Influence of sensory input on plantar pressure distribution. *Clin Biomech* 1995;**10**(5):271–274.
20. McPoil TG, Cornwall MW, Yamada W. A comparison of two in-shoe plantar pressure measurement systems. *Lower Extremity* 1995;**2**(2):95–103.
21. Mundermann A, Nigg BM, Stefanyshyn DJ, et al. Development of a reliable method to assess footwear comfort during running. *Gait Posture* 2002;**16**(1):38–45.
22. Borg GA. Perceived exertion. *Exerc Sport Sci Rev* 1974;**2**:131–153.
23. Feriche B, Chicharro JL, Vaquero AF, et al. The use of a fixed value of RPE during a ramp protocol. Comparison of the ventilator threshold. *J Sports Med Phys Fitness* 1998;**38**(1):35–38.
24. Perz-Landaluce J, Fernandez-Garcia B, Rodriguez-Alonso M, et al. Physiological differences and rating of perceived exertion (RPE) in professional, amateur and young cyclists. *J Sports Med Phys Fitness* 2002;**42**(4):389–395.
25. Skinner JS, Hutsler R, Bergsteinova V, et al. The validity and reliability of a rating scale of perceived exertion. *Med Sci Sports* 1973;**5**(2):94–96.
26. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; **41**(1):3–13.
27. Howard PD. Differential diagnosis of calf pain and weakness: flexor hallucis longus strain. *J Orthop Sports Phys Ther* 2000;**30**(2):78–84.
28. Mundermann A, Stefanyshyn DJ, Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Med Sci Sports Exerc* 2001;**33**(11):1939–1945.
29. Mundermann A, Nigg BM, Humble RN, et al. Foot orthotics affect lower extremity kinematics and kinetics during running. *Clin Biomech* 2003;**18**(3): 254–262.
30. Mills K, Blanch P, Vicenzino B. Influence of contouring and hardness of foot orthoses on rating of perceived comfort. *Med Sci Sports Exerc* 2011;**43**(8):1507–1512.

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