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Author Information:

Michael P I Nunns (co-author):

Affiliation: Exeter Biomechanics Research Team, College of Life and Environmental Sciences, University of Exeter, EX1 2LU, UK.

Address: Richards Building, St Luke's Campus, Heavitree Road, Exeter, Devon, UK. EX1 2LU

Email: mn227@exeter.ac.uk

Tel: 01392 722157

Sharon J Dixon:

Affiliation: Exeter Biomechanics Research Team, College of Life and Environmental Sciences, University of Exeter, EX1 2LU, UK.

Address: Richards Building, St Luke's Campus, Heavitree Road, Exeter, Devon, UK. EX1 2LU

Email: s.j.dixon@exeter.ac.uk

Tel: 01392 724712

James Clarke:

Affiliation: Sports Engineering Research Group, University of Sheffield, Sheffield, UK

Address: Sports Engineering Research Group, Department of Mechanical Engineering, University of Sheffield, UK. S1 3JD

Email: j.clarke82@hotmail.co.uk

Tel: 0114 222 7829

Matt Carré:

Affiliation: Sports Engineering Research Group, University of Sheffield, Sheffield, UK

Address: Sports Engineering Research Group, Department of Mechanical Engineering, University of Sheffield, UK. S1 3JD

Email: m.j.carre@sheffield.ac.uk

Tel: 0114 222 7829

Exeter Biomechanics Research Team, College of Life and Environmental Sciences, University of Exeter, EX1 2LU, UK

[b]*Sports Engineering Research Group, University of Sheffield, Sheffield, UK*

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TITLE PAGE

Boot-insole effects on comfort and plantar loading at the heel and fifth metatarsal during running and turning in soccer

Michael P I Nunns[a], Sharon J Dixon[a], James Clarke[b], Matt Carré [b]

[a]*Biomechanics Research Team, College of Life and Environmental Sciences, University of Exeter, EX1 2LU, UK*

[b]*Sports Engineering Research Group, University of Sheffield, Sheffield, UK*

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ABSTRACT

Plantar loading may influence comfort, performance and injury risk in soccer boots. This study investigated the effect of cleat configuration and insole cushioning levels on perception of comfort and in-shoe plantar pressures at the heel and fifth metatarsal head region. Nine soccer academy players (age 15.7 ± 1.6 yrs; height 1.80 ± 0.40 m; mass 71.9 ± 6.1 kg) took part in the study. Two boot models (8 and 6 cleats) and two insoles (Poron and Poron/gel) provided four footwear combinations assessed using pressure insoles during running and 180^{O} turning. Mechanical and comfort perception tests differentiated boot and insole conditions. During biomechanical testing, the Poron insole generally provided lower peak pressures than the Poron/gel insole, particularly during the braking step of the turn. The boot model did not independently influence peak pressures at the fifth metatarsal, and had minimal influence on heel loads. Specific boot-insole combinations performed differently ($p<0.05$). The 8-cleat boot and the Poron insole performed best biomechanically and perceptually, but the combined condition did not. Inclusion of kinematic data and improved control of the turning technique are recommended to strengthen future research. The mechanical, perception and biomechanical results highlight the need for a multi-faceted approach in the assessment of footwear.

Keywords

Insoles, plantar pressure, perception, boots.

1. INTRODUCTION

Soccer is a fast-paced activity involving changes of direction, sprinting and jumping actions, therefore soccer boots have evolved to allow a compromise between stability and freedom of movement for the performer (Chomiak, Junge, Peterson & Dvorak, 2000). Modern boots are low-profile, flexible and lightweight, but provide little protection against injury. Any cushioning tends to be through a thin insole issued as standard within the boot, therefore exposing the plantar surface of the foot to potentially damaging loads. The provision of cushioned insoles has been demonstrated to reduce peak pressures in military boots (Windle, Gregory & Dixon, 1999; Hinz, Henningsen, Metthes et al., 2008) and injury rates in military recruits (Schwellnus, Jordaan, & Noakes, 1999), although there is also evidence of no reduction in injury rate with cushioned insoles (Gardner, 1988). The effectiveness of such insoles has been previously assessed using in-shoe plantar pressure analysis, but despite the limited existing cushioning in modern soccer boots, and the importance that players place on boot comfort (Hennig & Sterzing, 2010), the influence of adding cushioning insoles on comfort or plantar loading in soccer boots is yet to be investigated.

Running shoe comfort has been shown to vary with insole design (Chen, Nigg & de Koning, 1994), and literature has demonstrated experimentally (Bus, Ulbrecht & Cavanagh, 2004) and with mathematical modelling (Goske, Erdemir, Petre, Budhabhatti & Cavanagh, 2006) that altering the material, shape and thicknesses of insoles can result in different pressure distribution patterns. Therefore the correct choice of soccer boot insole may have the potential to reduce peak loads under key areas of the foot. This may subsequently reduce injury susceptibility and improve comfort. It is suggested that the effectiveness of such devices to reduce peak plantar loads should be investigated in order to help inform their selection.

Overuse injuries such as Achilles tendon pathology, lower back pain and stress fracture of the foot are prevalent in soccer (Paavola et al., 2002). The loads occurring at heel impact have been previously linked with overuse injuries (Schwellnus et al., 1990). In addition, the reported high incidence of fifth metatarsal fracture in soccer (Knapp et al., 1998; Jaquot et al., 2005; Shuen et al., 2009) may be associated with repeated loading of the forefoot, leading to a temporary weakening of this structure and thus susceptibility to fracture in the absence of sufficient rest. The number of cleats is likely to directly influence peak pressures, with more cleats providing increased points of contact with the ground and thus a greater dissipation of ground reaction forces. If the sole of the boot is not sufficiently stiff to dissipate the force acting through the cleats, then the cleat may serve to channel vertical ground reaction force onto the area of the foot immediately above it. Thus, when performing soccer-specific activities such as running and turning, the flexible sole of the soccer boot may lead to areas of high pressure immediately above the cleats. Research by Eils et al. (2004) demonstrated that the heel region is commonly loaded in soccer specific movements, while Santos et al. (2001) highlighted the increased lateral forefoot loading when wearing soccer boots compared to running shoes. High plantar loading, leading to discomfort, pain and potentially injury is likely to be influenced by movement type and cleat location (Coyles & Lake, 1999; Lake, 2000; Queen et al., 2008), thus it is important to identify whether specific cleat configurations influence loading at the heel and 5th metatarsal regions during dynamic movements such as running and turning.

Comfort is an important consideration in footwear selection, with players citing this as a high priority in boot design (Hennig & Sterzing, 2010). The interaction between the foot and the supporting surface may contribute to pain and discomfort in footwear, particularly where high plantar pressure occurs (Witana et al., 2009). In soccer boots, this may be where excessive localised pressures occur as the studs/cleats penetrate the playing surface. Therefore, by understanding the interaction between the plantar surface of the foot and the surface of the shoe, the level of comfort a shoe-surface combination provides may be inferred. Changes in peak plantar pressures have been found to correlate with changes in the perception of running shoe comfort (Chen et al., 1994; Jorda, Payton & Bartlett, 1997), however only Brizuela et al. (1998) have investigated links between plantar pressure values and the perception of comfort in soccer boots. Brizuela et al. (1998) concluded that high comfort perception related to lower peak plantar pressures when performing in boots of varying cleat numbers and locations.

Although conclusions can be made from biomechanical and mechanical test data, the perception of the end user is critical in judging whether or not a soccer boot insole is adequately improving the comfort of the boot. Clarke (2011) identified fit, construction/material properties, stud/cleat design, and protection as the four key dimensions that influence soccer boot comfort. Of these, Clarke (2011) stresses that 'stud pressure' is a dominating factor influencing the perception of comfort during dynamic play due to its likelihood to cause pain, and its relationship with performance – if the studs do not penetrate the surface with sufficient ease to provide grip the player will not only experience discomfort (pressure) but associate this with poor stud performance. In line with this, it is expected that lower plantar pressures will be accompanied by perception of increased general comfort.

The region of the 5th metatarsal has been found to be particularly susceptible to excessive stud pressure. Clarke (2011) surveyed 1000 active soccer players, with 22% reporting regularly experiencing excessive stud pressure in this region (described as the lateral toe region) with their own soccer boots and 24% feeling that this region required the most cushioning in the boot. Soccer boots have been found to increase forefoot peak pressures by around 35%, in comparison with running-specific footwear (Santos et al., 2001). Santos et al. (2001) identified the lateral forefoot as a distinct region of increased pressure when wearing soccer boots, caused by the channelling of ground reaction forces through the studs.

The aim of this study was to investigate the influence of two types of insole on plantar pressure at the heel and fifth metatarsal regions when placed within two soccer boot models with different cleat formation, during steady state running and turning. A semantic differential approach was used to investigate the relationship between players' perception of soccer boot comfort and plantar pressures measured at the foot, for the combinations of soccer boot and insole. Mechanical testing was also conducted in order to relate the soccer players' feedback perceptions to physical measurements. It was hypothesised that: (a) an insole with greatest mechanical cushioning would result in lower pressures at the heel and fifth metatarsal; (b) peak pressure would be lower in the boot with the higher number of cleats and (c) lower pressures would be accompanied by perception of decreased stud pressure and increased comfort.

2. METHODS

Following approval from the University of Exeter Sport & Health Sciences Ethics Committee, nine injury-free youth team players (age 15.7 ± 1.6 yrs; height 1.80 ± 0.04 m; mass 71.9 ± 6.1 kg) from the Blackburn Rovers Football Club Academy volunteered to participate in the study. Two football boot models; A and B (Figure 1) and two insole prototypes, P and G, provided four footwear combinations for comparison: AP, AG, BP and BG. Insole P was constructed of a 3mm layer of Poron, while insole G consisted of a 1.5 mm layer of Poron, and a 1.5mm layer of gel.

Boot A had an eight cleat configuration, while Boot B had six cleats. The six cleats under the forefoot of Boot A covered an area encompassing the hallux and metatarsal regions. In Boot B, the four forefoot cleats covered a relatively small area, and the cleats were positioned distal to the hallux and posterior to the fifth metatarsal (Figure 1). Both boots were equipped with 12.9 mm long aluminium cleats in the forefoot and 15.4 mm long aluminium cleats in the heel. The cleat tip diameter was 7.6 mm in all cases.

Boot outsole stiffness was assessed by measuring the peak force required to bend the outsole of each boot 45° with the experimental setup shown in Figure 2. The insole was removed from the boot and a solid plate was inserted into the forefoot of the boot and clamped to allow bending at the estimated location of human metatarso-phalangeal (MTP) joint. An actuator, driven vertically at approximately 0.3 $m.s^{-1}$, applied a vertical force that was recorded by a load cell. This is a bespoke method of examining outsole stiffness, adapted from Oleson et al. (2005).

The impact attenuation properties of the insoles were assessed by an impact-testing device (ASTM, 2001. Test method: F1976-99, Standard Test Method for Cushioning Properties of Athletic Shoes Using an Impact Test. ASTM International, West Conchohocken PA, USA). A 45 mm diameter, 8.5 kg mass was dropped with an impact velocity of 92 $cm.s^{-1}$ as in Stiles & Dixon (2007). The missile was positioned to strike the heel section of the boot, with the insole placed inside as for normal use.

Biomechanical testing took place on a natural turf surface. The SERG impact hammer method (Clarke & Carré, 2010) was performed on the day of data collection. The SERG impact hammer has a pre-calibrated accelerometer contained within a hemispherical hammer profile. As the hammer hits the ground the voltage signal from the accelerometer is sampled and transformed to calculate the force and displacement throughout the loading and unloading phase of the impact. The peak force (N) is a measure of the maximum deceleration of the hammer during impact. Higher impact decelerations suggest a harder surface. Clarke and Carré (2010) used the SERG impact hammer test method to assess the hardness of a third generation (3G) artificial soccer surface and a natural soccer surface (with gravimetric moisture content of 30.7 ± 1.8%). The findings by Clarke and Carré (2010) show that peak forces of approximately 1000 N would be considered a firm surface (3G artificial) and peak forces of approximately 600 N would be considered a soft playable natural surface. In the present study, for comparison purposes, identical impact hammer tests were carried out on the test surface and two extreme natural surface samples (taken from Norton Playing Fields, Sheffield) with contrasting mean gravimetric moisture contents, 12.2 ± 1.84% and 30.4 ± 1.73% respectively. The samples were watered to give extreme examples of playable natural soccer surfaces and were considered to be hard ground (HG) and soft ground (SG) surfaces respectively. Ten drops were performed over the area of each surface. This process was replicated on the day of testing for the present study test surface. Representative force-displacement curves (with two examples from the test surface) for each surface condition are shown in Figure 3 (the force-displacement curve that gave the median peak force result). The mean peak force value was found to be 747.8 ± 17.4 N, indicating that the test surface can be considered a surface in a soft to firm condition.

Figure 4 outlines the data collection set-up. Performers began jogging approximately 5-7 m before data collection commenced in order to reach and maintain a steady speed (3.8 $m.s^{-1}$ ± 5%, monitored with photocells). They continued at this steady speed for 15 m, before accelerating for 5 m, performing an 180° turn, accelerating back for 5 m, turning 180° again and sprinting away. Three trials were performed for each condition, providing nine running strides and six turning steps (three pre-steps and three push-off steps) for each participant per footwear combination. Footwear conditions were tested in a random order.

Steady running steps for the left and right foot were grouped to provide a mean of 18 steady running steps per participant. Turning steps were identified as either the braking (or pre-) step (Figure 5a) or the acceleration (or push-off) step (Figure 5b), regardless of whether it was a left or right footstep in each case. This provided 6 of each turning step type per participant for analysis.

A semantic differential questionnaire was used to compare players' responses to the combinations of soccer boot and insole (Figure 6). The questionnaire used a seven-point scale on which participants placed a cross on a position on the scale that best represented their perception. A seven point scale was used, as one with fewer than 10 points increases the spectrum of results by reducing central tendency biases in participants Osgood, Suci & Tannenbaum (1957). The seven point range provided the participants with a scale in which they could differentiate their strength of a feeling towards an adjective. Care was taken to ensure all the participants understood the relevance and definition of each semantic differential. The players' ratings on each semantic differential scale were tabulated and averaged. Non-parametric Kruskal-Wallis H tests, with a significance level of 0.05, were conducted to identify significant differences in perception between footwear conditions.

Pressure insoles (RSScan International, Belgium), sampling at 500 Hz, were placed within the football boot to record in-shoe pressures during the trials. Mask analysis was used to identify peak pressures at the medial heel (HM), lateral heel (HL) and 5th metatarsal (M5) for each type of footstep (Figure 1). Standing trials were recorded immediately before and after dynamic testing of each condition to ensure that pressure insole data were not being influenced by sensor creep. For each footstep type (steady running, braking step and acceleration step), a two-way ANOVA with repeated measures was performed to examine effects for boot, insole, and boot*insole. Where effects for boot*insole were identified, post-hoc Tukey's HSD tests were performed to identify differences. An alpha level of 0.05 was used throughout.

3. RESULTS

Figure 7 displays the results of mechanical testing of the forefoot bending stiffness of each boot. The construction of each soccer boot meant the forefoot segment and the heel segment were not parallel when unloaded. The unloaded angle between these boot segments was approximately 10º for Boot A and 15º for Boot B. The mean peak force required to bend each boot outsole 45º from the initial position was 42.4 N ± 2.7 for Boot A and 59.6 N ± 4.5 for Boot B, suggesting that boot B was stiffer than boot A. Table 1 displays the results of mechanical drop testing for the four conditions, with perception values for comfort and stud pressure included. Drop test results indicate that for both boot types, the Poron insole provided better impact attenuation then the Poron/gel condition.

The semantic profile plot, Figure 8, reveals that the players were able to perceive differences between the general comfort of the boot/insole combinations. Condition AP was deemed to be both the most comfortable, and have the lowest perceived stud pressure, while condition BG was the least comfortable and had the highest perceived stud pressure. However, statistically the only significant difference was found between the BG and AP comfort rankings.

Mean peak pressures with standard deviations for each condition are presented for steady running (Figure 9), the braking step of the turn (Figure 10) and the acceleration step of the turn (Figure 11).

Table 2 provides the peak pressures for each condition and foot region, with significant differences highlighted. During steady running, there was an effect ($p<0.05$) for insole at the medial heel (HM) region, with higher pressures found wearing insole G; and for boot at the lateral heel (HL) region, with higher pressures in boot B. During the braking step of the turn, there was an effect ($p<0.05$) for insole at all regions, with insole G resulting in higher peak pressures. At the HL region, there was also an effect ($p<0.05$) for insole*boot during the braking step, with the combination of boot B and insole G resulting in significantly higher peak pressures than any other condition. Insole G resulted in lower peak pressure ($p<0.05$) at the M5 region during the propulsive step, while there was also a more complex boot*insole interaction at the HM during this step: condition AP resulted in higher peak pressures than condition BP ($p<0.05$); however condition BG resulted in higher peak pressures than conditions AG and BP ($p<0.05$).

4. DISCUSSION

This study investigated the influence of two types of cleat configuration and two types of insole on peak pressures at the heel and 5th metatarsal and on perceptions of comfort during three types of soccer-specific movement step. The observed differences in plantar pressure in response to certain changes in footwear cushioning/stiffness is consistent with some observations in running shoe studies which have utilised pressure insoles (Dixon, 2008; Wiegerinck et al., 2009). Mechanical drop testing showed that insole P, constructed from Poron, provided the best impact attenuation mechanically and thus would be expected to provide better cushioning than insole G, constructed from a Poron/gel combination. Plantar pressure analysis revealed that where differences were observed, insole P performed better than insole G. Hypothesis (a) is not fully accepted, as differences were not consistently observed at all regions, for all movements. The influence of insole was seen most prominently during the braking step of the turn, where insole P outperformed insole G at all three regions. It is possible that the strength of the gel construction insole is under shear loading (Curryer & Lemaire, 2000), rather than normal loading. Pressure insoles detect normal loading, therefore this speculation could not be assessed in the present study. While further investigation of the influence of shear loads on plantar discomfort and the ability of insoles to reduce this is warranted, the present results indicate that a Poron insole offers better protection overall against high plantar pressures when worn in a soccer boot.

The eight-cleat boot (Boot A) was expected to distribute force more evenly than the six-cleat boot (Boot B), resulting in lower peak pressures at the investigated regions. While each boot had two heel cleats, the cleat configuration at the forefoot varied. Boot A included two more cleats, covering a larger area of the mid/forefoot, thus greater expectation of an effect for boot might be expected at the M5 than the heel. Contrary to this expectation, boot type had no influence on M5 pressures in any movement. At the heel, the model of boot alone influenced peak pressure at the HL during steady running, while a mixed effect was seen at this region in the braking step of the turn. These results suggest that hypothesis (b) should therefore be rejected. One possible explanation for the observed result is that Boot B had a stiffer outsole than Boot A. This added stiffness may have offset the lower number of contact points with the ground by better dissipating the force channelled above each cleat. Mechanical principles suggest that, if the outsole stiffnesses of the two boots were similar, the model with more cleats would provide lower peak pressures. The implication of the present results however, is that variation in other components of boot construction will combine to influence overall performance. As shown by the significant mixed effects, certain boot-insole combinations may produce optimal conditions for certain movements. This highlights the importance of dynamic, sport-specific movements when testing footwear conditions, in agreement with a number of previous studies (Eils et al., 2004; Ford et al., 2006; Muller et al., 2010).

Hypothesis (c) is partially accepted because there was a significant difference in players' perception of condition AP (most comfortable) and BG (least comfortable), while boot A and insole P performed better than their alternatives. A significant difference in 'General Comfort' was found between the AP and BG conditions, with AP providing the best comfort overall and BG the worst. Within each boot the Poron insole was perceived to give higher comfort and lower stud/cleat pressure. Recent research provides evidence that the kinematics of the shank and foot change in response to differences in cleat configuration (Muller et al., 2010). Such changes could have affected the pressure distribution in the present study, particularly if resulting in a greater proportion of shear forces being applied to the foot, which are undetectable by the pressure insoles. Future research should add kinematic analysis to the approach presented here, in order to better understand these relationships.

For the turning movement, there was evidence of distinct loading patterns of the foot during the braking and acceleration steps. The braking step caused a greater concentration of pressure on the HL region than the M5 and HM regions. The acceleration step caused a greater concentration of pressure on the HM compared to the HL, both of which were much higher than at the M5 region. The technique of the braking step is likely to involve initial contact with the lateral aspect of the heel (Smith, Dyson & Janaway, 2004) and thus the cleat in this location may have initially penetrated the surface and accepted most of the load at this phase of the turn. During acceleration, the participant's low body position and abducted hip (Figure 5(b)) lends itself to pressure being exerted on the medial aspect of the foot. This pattern of pressure distribution corresponds with the observations of Wong et al. (2007), who concluded that plantar pressures were highest in the medial aspect of the foot in turning and cutting movements. However, these authors did not investigate the 180 degree turn specifically and only considered the dominant turning leg. It is interesting that boot*insole effects were seen at the regions that accepted the greatest load during these steps. For both movements, condition BG performed poorly, but condition AP also performed poorly during the acceleration step where the HM is highly loaded. The explanation for this is unclear, but the result indicates the need to test boot-insole combinations for a variety of movements, as the scores for comfort perception and peak pressures for other movements were favourable for this condition.

Previously, perception of comfort has been positively correlated with plantar pressure distribution in walking (Jordan & Bartlett, 1995) and walking and running on a treadmill (Chen et al., 1994). In the light of inconsistent findings here, it is possible that the relationship between perception and plantar pressure distribution is not as straight forward when a turning component is included in the testing protocol. The observed inconsistency between the results of mechanical and biomechanical testing, as observed for the turning movements in particular, has been demonstrated previously (Nigg & Yeadon, 1987; Stiles & Dixon, 2006), further emphasising the need for the testing of materials in sport-specific situations, rather than relying solely on mechanical test results.

The high standard deviations in the turning data were indicative of the difficulty in standardising the turning protocol. The technique was demonstrated to participants and practice trials performed, however there was some variation in the way performers executed the movement, potentially affecting recorded pressure values through different proportions of shear force. The integration of a force plate could improve the study through quantification of shear loads. Average running speed was monitored, but participants were told to simply ‘accelerate hard’ when they reached the relevant point. As a result, the velocity at the point of turn is likely to have varied, thus effecting pressure results. Further standardisation of the turning manoeuvre is therefore required to strengthen procedures in any future testing.

5. CONCLUSION

The measurement of peak plantar pressures at three regions of the foot while wearing four boot-insole combinations during running and turning has revealed differences in the performance of boots, insoles and specific boot-insole combinations at different regions of the foot and during different movements. The location of these differences was dependent on whether running or turning was being assessed, highlighting the importance of sports-movement-specific testing. Mechanical testing provided some indication of biomechanical performance, as did player perceptions of comfort, however there were inconsistencies between results obtained from these different forms of analysis. The combination of biomechanical, perception and mechanical assessment used in this study present a unique insight into the various factors determining the effectiveness of different boot-insole combinations. Given previous disagreement between mechanical and biomechanical data when assessing cushioning properties, and the similarity between mechanical and perception data presented here, a protocol combining perception and biomechanical analysis seems the most appropriate approach for improving the provision of insoles for players in future.

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TABLES

Table 5.1. Mechanical drop test data showing ‘Peak g’ for each footwear condition and the perception of ‘General Comfort’ and ‘Stud Pressure’. The mean (SD) of twenty impacts is shown.

Condition	‘Peak g’	‘General Comfort’	‘Stud Pressure’
AG	20.15 (0.50)	1.33 (1.12)	-0.56 (1.88)
AP	19.14 (0.37)	1.78 (1.1)	-1.11 (1.45)
BG	19.32 (0.56)	-0.22 (1.86)	0.11 (1.53)
BP	18.68 (0.51)	0.44 (1.74)	-0.67 (1.5)

AG = boot A (8 cleats) with insole G (Gel/Poron); AP = boot A with insole P (Poron only); BG = boot B (6 cleats) with insole G; BP = boot B with insole P.

Table 5.2. Mean (SD) peak pressures (in N/cm^2) for each footwear condition, at each region defined for plantar pressure analysis. One-way ANOVA with repeated measures was performed to compare differences between footwear conditions for each region (*P*=0.05). The results of post-hoc Tukey's tests are displayed where significant differences were identified by ANOVA (*P*=0.05).

Movement & Foot	Region	Footwear Condition				*P* value	Tukey's HSD
		AP	AG	BP	BG		
Left foot during steady running	M5	42.20 (5.04)	43.05 (3.57)	48.32 (3.90)	49.79 (5.67)	.120	n/a
	HM	24.14 (4.26)	29.67 (9.48)	28.44 (9.24)	28.66 (10.53)	.577	n/a
	HL	33.25 (7.98)	33.14 (3.54	40.17 (4.56)	42.43 (8.16)	.018*	BP>AP, BP>AG, BG>AP, BG>AG, BG>BP
Right foot during steady running	M5	41.62 (5.40)	44.21 (3.15)	42.33 (9.18)	46.45 (12.93)	.754	n/a
	HM	34.55 (11.19)	34.75 (9.00)	32.63 (12.48)	36.84 (15.36)	.666	n/a
	HL	36.12 (6.63)	35.57 (6.54)	41.41 (8.76)	45.00 (12.09)	.090	n/a
Braking step of the 180° turn	M5	47.21 (13.11)	41.91 (6.60)	54.15 (16.08)	66.01 (17.34)	.043*	BP>AG, BG>BP, BG>AP, BG>AG
	HM	51.15 (14.79)	50.82 (15.96)	37.48 (12.06)	59.92 (17.88)	.286	n/a
	HL	58.45 (10.98)	54.73 (8.40)	53.82 (10.26)	79.78 (9.36)	.008*	BG>AP, BG>AG, BG>BP
Acceleration step of the 180° turn	M5	29.44 (6.75)	36.45 (7.38)	35.91 (8.12)	42.02 (12.09)	.336	n/a
	HM	79.71 (15.18)	68.22 (13.50)	66.45 (17.61)	79.05 (14.40)	.029*	AP>BP, BG>AG, BG>BP
	HL	59.65 (6.18)	59.94 (9.57)	65.82 (11.19)	72.01 (8.49)	.088	n/a

AG = boot A (8 cleats) with insole G (Gel/Poron); AP = boot A with insole P (Poron only); BG = boot B (6 cleats) with insole G; BP = boot B with insole P. M5 = region of fifth metatarsal head; HM = medial heel region; HL = lateral heel region.

Figure legend

Figure 1. The approximate location of cleats relative to analysed regions of the foot in Boot A (left) and Boot B (right).

Figure 2. Experimental setup for testing of boot outsole bending flexibility.

Figure 3: Representative force-displacement curves, obtained on the surfaces using the SERG impact hammer with hemispherical profile. (HG – Hard ground, SG – Soft Ground)

Figure 4. Schematic of trial.

Figure 5. Pre- or braking step (a) and push-off or acceleration step (b) of the 180 degree turn.

Figure 6. The semantic differential questionnaire used in the study.

Figure 7. Force-flexion angle plots for both boot conditions.

Figure 8. The semantic profile plot showing the semantic differential pairs and the mean perceived ratings on the semantic differential scales.

Figure 9. Mean peak pressures and standard deviations for each location and condition during steady running.

Figure 10. Mean peak pressures and standard deviations for the braking step of the turn

Figure 11. Mean peak pressures and standard deviations for the acceleration step of the turn.