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Physical performance and perception of foot discomfort during a soccer-specific match simulation. A comparison of football boots.

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Football boots are marketed with emphasis on a single key performance characteristic (e.g. speed). Little is known on how design parameters impact players' performance. This study investigated the impact of boot design on performance maintenance and perceived foot comfort during a 90-minute period. Eleven male university football players were tested in two commercially available 'sprint boots' known to generate significantly different plantar pressures (high=Boot H and low=Boot L) in a random order. Players completed a modified Soccer-specific Aerobic Field Test on a 3G pitch. Heart rate, rated perceived exertion and perceived foot discomfort were assessed for each 15-min interval. Power generation using counter movement jump height and Illinois agility sprint test were assessed pre- and post-match simulation. A significantly higher mean heart rate was seen for Boot L in the 60th–75th and 75th–90th minute intervals ($P=0.017$, $P=0.012$ respectively). Perceived exertion did not differ between boots ($P\geq0.302$). Power generation significantly decreased in Boot H between pre- and post-match ($P=0.042$). Both boots increased discomfort with significantly more plantar discomfort felt in the last 30 min in Boot H (75th min: $P=0.037$; 90th min: $P=0.048$). The results imply that a comfortable boot design may improve maintenance of performance during match-play.

Keywords: soccer; footwear; shoes; lightweight; fatigue

Introduction

Technological innovations are frequently introduced by sporting goods companies to distinguish themselves in a progressively dynamic and competitive market (Xerfi 2XDIS04, 2015). Football boots are commonly marketed with an emphasis on highlighting a single performance characteristic (e.g. speed, touch/control or kicking power). Despite the emphasis on football boot design when delivering advertised performance benefits, little research is published on the impact of specific design parameters on performance. An increased understanding of the impact of specific design parameters on performance can support an evidence-based approach by the football boot designers which can subsequently improve footwear for the consumer.

Speed boot designs are marketed to enhance sprint performance. Despite high-speed activities only contributing for a small part the total distance covered, they are essential for success in football. In particular, high-speed activities can create decisive match instances such as obtaining ball possession and scoring goals (Kaplan et al., 2009; Reilly et al., 2000). These activities are usually short (<10 m), last 2-4 s and take up 3-5% of the total match-play time or 10% of the total distance covered in professional male matches (Bloomfield et al., 2007; Osgnach et al., 2010). Thus, they primarily involve rapid accelerations requiring high power generation, rather than the maintenance of maximum speed. Speed generation is, therefore, a fundamental skill for football players.

The key feature of speed boots is their lightweight design, with the associated claim that carrying less mass decreases a player’s energy demands. However, running shoe research has indicated that provided the shoe mass is less than 300 g, then shoe mass does not impact running economy (Franz et al., 2012). Modern football boots typically have a mass of ~250 g and for speed boots this drops to below 200 g, achieved through minimising outsole thickness and removing upper padding and altering the material. For football boots, Sterzing et al. (2009) found no change (P = 0.98) in sprinting/cutting time when a 70 g rubber insole was added to a 200 g boot. However, this study focused on short-term exposure effects with players completing only a 6 m acceleration sprint drill and a short agility side cutting drill. In basketball, no relationship has been found between shoe mass and sprinting, cutting or jumping performance (Mohr et al., 2016; Worobets and Wannop, 2015). Additionally, research has shown that players find it difficult to perceive shoe mass; however when the mass differences are explained, players will perceive their performance to improve with a decrease in footwear mass despite no measured change in performance (Mohr et al., 2016; Slade et al., 2014).

The tight fit of football boots allows players optimal ball control and multidirectional motion (Hennig, 2014; Hennig and Sterzing, 2010; Sterzing et al., 2011). The tighter fit has, however, shown to significantly increase plantar pressures in comparison to running shoes (Santos et al., 2001). Concerns have been raised that low football boot mass is likely to come at the cost of further increasing plantar pressures and hence increased discomfort due to more centralised pressures around the stud locations. Whilst short-term exposure to increased plantar pressure in football boots has shown no correlation with increased discomfort (Okholm Kryger et al., 2016; Wong et al., 2007), exposure to ‘excessive’ plantar pressures for longer periods has been shown to increase foot discomfort (Che et al., 1994; Jordan and Bartlett, 1995). It must, however, be acknowledged that shoe comfort has been shown to be influenced by multiple factors in addition to insole plantar pressures including shoe size, shape, style, mass, flexibility, inside climate (temperature, humidity), cushioning, materials, tread and aesthetics (Goonetilleke and Luximon, 2001).

The connection between improved ability to maintain performance and appropriate foot comfort is widely assumed in the field of sport (Miller et al., 2000; Nigg et al., 1999; Schubert et al., 2011) and football specifically (Sterzing et al., 2009; Sterzing and Hennig, 2008). Yet, the role of neurophysiology through neuromuscular responses and pain inhibition as a factor of performance is still not well understood (Kinchington et al., 2012). Whilst no evidence exist in football, long-term exposure to running shoe related discomfort has, however, been linked to decreased running performance due to increased energy expenditure, accelerated muscular fatigue and altered lower extremity muscle loading (Luo et al., 2009; Nurse et al., 2005; Wakeling et al., 2002). Furthermore, fatigue and disruption to the usual movement patterns may evoke compensatory musculoskeletal mechanisms which compromise performance and increase the risk of injury (Cheung et al., 2003; Weist et al., 2004). No research has yet been performed on the impact of 90 min football match play exposure on foot discomfort or exertion.

Only a single study has assessed the impact of football boot related discomfort on sprint time, with no difference between boots observed ($P = 0.98$; Sterzing et al., 2009). However again, this study only focused on short-term exposure (6 m acceleration sprint and short agility side cutting drills). The extension of these results to the longer-term wear situation of match play remains open to question. Hence, the purpose of this study was to investigate the impact of football boot design on maintenance of performance, progression of exertion and progression of perceived foot comfort during a 90-minute period. Two commercially available speed boots were chosen based on previously collected data that demonstrated significantly different plantar pressures in the medial and lateral forefoot and heel region (one demonstrating significantly higher pressures in all areas; Okholm Kryger et al., 2016). Performance (countermovement jump height and speed generation), measures of maintenance of intensity level (heart rate and Borg's rated perceived exertion; RPE) and perceived foot comfort were assessed throughout a 90-min match simulation drill completed in both boots. It was hypothesised that players would be able to better maintain performance with higher evidence of maintenance of intensity level and foot discomfort in the football boot previously demonstrating lower peak plantar pressures in the forefoot region.

Methods

Participants

Eleven skilled male university football players (age 20.6±2.2 years, stature 1.78±0.05 m, mass 70.1±4.7 kg, UK shoe size 8–10) volunteered for this study. Players had 7.3±2.9 years of experience playing club level football. None of the players had suffered from match-preventive lower limb injuries in the six months prior to testing or suffered from pathologies causing altered perception of mechanical stimuli. The investigation received ethical clearance from the institutional ethics committee and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots

Two commercially available ‘sprint design’ football boot models were tested (Boot L and Boot H). Both were firm ground stud models to match the artificial turf pitch used for testing but with distinct differences in stud shape, upper material and boot mass. Boot L had a synthetic upper, a mass of 160 g (size UK8), four heel studs, five studs on the forefoot of which one was placed centrally and one stud under the hallux and 4^{th}/5^{th} toe. Boot H had a leather upper, had a mass of 180 g (size UK8), four bladed heel studs, three bladed studs under the forefoot, three bladed studs below hallux and one bladed stud at the base of the 4^{th} and 5^{th} toe (Figure 1). Boot H had demonstrated significantly higher plantar pressures in the heel and 1^{st} and 5^{th} metatarsal (MT) regions during sprinting, side cutting and cross cutting movements (1^{st} MT peak plantar pressure Boot L = 370±77 kPa, Boot H = 406±138 kPa, $P<0.05$; 5th MT peak plantar pressure Boot L = 270±112 kPa, Boot H = 350±151 kPa, $P<0.05$; Okholm Kryger et al., 2016). All boots were dyed black using shoe dye recommended for football boots to minimise the impact of the upper design affecting the players' perception of the boots. During each test players were given the same brand of new football socks to wear. Football boot size fit (length) and tying of lace was checked by the assessor before each test session.

**** Figure 1 near here ****

Experimental design

The study involved a randomised crossover experimental design. Participants completed two sessions, one for each boot in a randomized order, separated by at least 7 days. Participants performed the test together to increase motivation and competitiveness throughout the test. Each session was 3 h in duration and was performed at the same time of the day. All tests were performed on the same outdoor third generation artificial turf pitch (LigaTurf RS+ 265, Polytan, Burgheim, Germany). In brief, the pitch had a Polytan EL 25 shockpad, the carpet fibres were 65 mm monofilament polyethylene and infill comprised of sand and rubber crumb. The surface was FIFA Two Star accredited two months prior to testing (Fédération Internationale de Football Association, 2015). Pitch testing using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015) demonstrated shock absorption of 70±4%, vertical deformation of 11±2 mm and rotational resistance of 45±1 Nm. Tests were only performed under dry conditions to minimise the impact of varying surface conditions on the outcome.

Experimental procedures

Prior to each test session, players completed a questionnaire comprising three sections designed to confirm whether or not they were fit to complete the test on that day. Firstly, readiness to complete the test was assessed though the Hooper's index (Haddad et al., 2013), secondly muscle soreness in the main lower limb muscle groups was assessed using the muscle map suggested by Thompson et al. (1999), and thirdly overall perceived foot comfort was assessed using a novel 7-point Likert scale ranging from 1 = unbearable discomfort to 7 = extremely comfortable together with foot comfort maps to identify and score the location of any discomforts felt (Figure 2). Any player that rated any measure on the Hooper's index below "neither good nor bad", or rated muscle soreness ≥3 on the muscle map, or rated overall perceived foot comfort below "neither comfortable nor uncomfortable", or marked any discomfort locations on the foot map was excluded from testing on that day.

**** Figure 2 near here ****

Each session commenced with a standardised warm up (Figure 3). This was followed by each player completing two repetitions of the Illinois agility speed test (Getchell, 1979), which has been validated for test-retest assessment of speed (Hachana et al., 2013, 2014; Lockie et al., 2013; Stewart et al., 2014). A visual and verbal demonstration of the drill was performed prior to the first test in each session. Sprint times were recorded using a GoPro HERO4 Black camera (240 Hz, 1280x720 pixels, maximum barrel distortion = 2.1%) placed on the start/finish line. Time was measured in accordance to the chest passing the start and finish lines. The best performance of the two trials was used for statistical analyses. The players were offered a minimum of 3 minutes recovery between sprints. Directly after, three repetitions of maximal countermovement jump height (with hands on hips) were completed. The countermovement jump height protocol has previously been validated for test-retest assessment of lower limb power generation (Bosco and Komi, 1979; Markovic et al., 2004; Slinde et al., 2008). Jump height was assessed using the Quattro Jump (Type 9290AD; Kistler Group, Winterthur, Switzerland), a portable uniaxial force platform (500 Hz) and associated software (Quattro Jump V1.1.1.4; Kistler Group, Winterthur, Switzerland) which calculates jump height using double integration of the force signal using Simpson’s rule of integration (Cheney and Kincaid, 2003). The platform was positioned on a hard level surface next to the football pitch and the players completed the jumps with boots off, i.e. in socks. Players performed the jumps in sock to assess the players’ power generation rather than the impact of the football boot. The researcher visually observed all jumps and jumps were repeated if the player landed at a different location to take-off or altered landing technique. The best performance of the three trials was used for statistical analyses.

Players then completed the match simulation drill. This comprised of two 45 min match simulation halves separated by a 15 min break and followed the official instructions for the Soccer-specific Aerobic Field Test (SAFT90; Lovell et al., 2008) but with a modified length of 22 m (original was 20 m) to obtain appropriate match-related heart rate (Figure 4). Previous studies using the SAFT90 have failed to achieve match related heart rates or RPE (e.g. Nédélec et al., 2013) and, based on this, pilot work demonstrated that match related heart rates similar to those reported in the literature (Edwards and Clark, 2006; Los Arcos et al., 2016; Lovell et al., 2008) could be achieved by extending the length of the SAFT90 drill from 20 m to 22 m. Heart rate was measured continuously during the SAFT90 using a Polar Team Pro system (Polar Electronic, Kempele, Finland) and assessed using mean and maximum heart rate for each 15 min

SAFT90 interval. Whilst maintenance of intensity level assessment via mean heart rate measures is well accepted in endurance sports, this method is debateable in team sports since the overall load often comprises of anaerobic and mental elements that do not include a significant cardiorespiratory component (Borresen and Lambert, 2009; Buchheit et al., 2013). Therefore, both maximum heart rate and RPE were used as additional measures.

**** Figure 4 near here ****

Before, during and after the match simulation drill each player was asked to complete a questionnaire assessing the player's perceived levels of exertion and foot comfort. The match simulation drill was paused every 15^{th} minute for <2 min to allow players to fill in the questionnaire (Figure 2). This method has previously been performed (e.g. Azidin et al., 2015; Nédélec et al., 2013; Small et al., 2009). Perceived exertion was assessed using RPE rating; players were asked to report an RPE score (Borg, 1970) which has been shown to be a reliable tool to assess perceived exertion in football (Impellizzeri et al., 2004). To assess the perceived foot comfort the same novel 7-point Likert scale and foot comfort maps as used in the pre-test questionnaire were used (Figure 2). The use of a novel Likert scale was rationalised as any score placed between the two defined extrema using visual analogue scales like previously validated for foot comfort scales (Mills et al., 2010; Mündermann et al., 2002) can be challenging to quantify. Using a similar population and test setup, test-retest reliability of the novel scale demonstrated intraclass correlation coefficients ($ICC_{2,1}$) scores of 0.311-0.746 and standard error of measurement (SEM) <±1 and the count of discomforts per foot region $ICC_{2,1}$ scores of 0.704-0.709 and SEM ≤±4. Finally, immediately following the SAFT90 and final questionnaire, each player completed a further two repetitions of the Illinois agility speed test (Getchell, 1979) and three maximal countermovement jumps following the same protocols as at the start.

Statistical analysis

Repeated measures analyses of variance (boot*time) were performed to analyse the effect of boot design and time on heart rate, RPE, overall foot comfort, countermovement jump height and Illinois agility speed test outcomes variables. Where Mauchly's test for sphericity was violated a Greenhouse-Geisser correction was performed. Effect size was assessed using partial eta squared (η_p^2). For a significant main effect of time, polynomial contrasts were performed. To determine the timepoints following an interaction effect, dependent t-tests were performed at each level of time; corrections for multiple comparisons were not performed as the post hoc t-tests were only used to indicate the source of the interaction effects. To assess the potential differing effects of the two boots on the occurrence of discomfort using a foot map, a Chi^2 analysis was performed in addition to relative risks (RR) with confidence interval (CI) calculations following Morris and Gardner (1988). An RR greater than one suggests a greater occurrence of discomfort within Boot H, with an RR lower than one suggesting the opposite. Statistical analysis was carried out using Excel (Microsoft, Redmond, WA) and SPSS software (Version 23.0; SPSS Inc., Chicago, IL) with significance set at $P \leq 0.05$ throughout.

Results

Maintenance of performance

There was a main effect of mean heart rate for both boot and time (boot $F_{(1,10)}=5.0$, $P=0.049$, $\eta_p^2=0.001$; time $F_{(2.4,23.6)}=5.4$, $P=0.009$, $\eta_p^2=0.207$, Greenhouse-Geisser corrected) demonstrating a higher heart rate in Boot L and a significant negative linear trend over time (polynomial contrast; P=0.015; Figure 5A). Following Greenhouse-Geisser correction a close to significant interaction (boot*time) was reported ($F_{(1.9,19.1)}$=3.4, P=0.056, η_p^2=0.073, Greenhouse-Geisser corrected). The post-hoc assessment demonstrated higher mean heart rates for Boot L for 60-75th min (160±9 bpm versus 152±4 bpm, P=0.017; Figure 5A) and 75-90th min (159±7 bpm versus 151±6 bpm, P=0.012; Figure 5A). However, for maximum heart rate there was no main effect of boot ($F_{(1,10)}$=0.008, P=0.928, η_p^2=0.283) or time ($F_{(2.0,19.9)}$=2.6, P=0.098, η_p^2=0.343; Greenhouse-Geisser corrected; Figure 5B). Despite the observation of a difference in mean heart rate between boots, no main effect of boot condition was observed for RPE ($F_{(1,10)}$=0.007, P=0.933, η_p^2=0.001). A main effect of time was, however, observed for RPE ($F_{(5,50)}$=38.1, P<0.001, η_p^2=0.792) demonstrating a positive linear trend with time (polynomial contrast; P<0.001; Figure 5C).

**** Figure 5 near here ****

Maintenance of performance was assessed through countermovement jump height and Illinois Agility Sprint completion time. There was a main effect of jump height for both boot and time (boot $F_{(3.6,10.0)}$=7.3, P=0.022, η_p^2=0.472; time $F_{(15.5,5.0)}$=5.6, P=0.040, η_p^2=0.357; Table 1) demonstrating a higher jump height in Boot L and a significant negative trend over time. A non-significant interaction (boot*time) was also reported ($F_{(3.3,5.0)}$=2.2, P=0.052, η_p^2=0.183). The Illinois Agility Sprint tests demonstrated no significant effect of boot or time on completion time (boot $F_{(1,10)}$=0.3, P=0.570, η_p^2=0.033; time $F_{(1,10)}$=0.3, P=0.570, η_p^2=0.33; Table 1).

**** Table 1 near here ****

Foot comfort

A potential main effect for overall comfort between the two boots was reported ($F_{(1,10)}$=3.6, P=0.087, η_p^2=0.265) with tendencies of higher discomforts in Boot H compared to Boot L. A main effect was, however, observed for time ($F_{(6,60)}$=18.4, P<0.001, η_p^2=0.648; Figure 6A). The polynomial contrast suggested a negative linear trend of discomfort increasing with time (P=0.021). Analysis of the interaction effect (overall comfort*time) suggests this increase in discomfort is similar between boots ($F_{(2.6,26.1)}$=2.2, P=0.115, η_p^2=0.183). From the foot map, the overall count of discomforts demonstrated no significant difference between Boot L and Boot H (P≥0.371 with RR CIs including a RR of one; Figure 6B; Table 2).

Of the five foot regions assessed, the plantar and dorsal regions had the highest rates of reported discomfort (Figure 6C). For plantar discomfort a relative risk greater than one, with confidence intervals supporting this and significant p-values (indicating higher presence of discomfort in Boot H), were observed at timepoints 15, 75 and 90 min (Figure 6D; Table 2). For dorsal discomforts no significance was observed apart from pre-testing, which is likely due to no reported discomforts in Boot H (i.e. cell count of zero in Chi^2 tabulation).

**** Table 2 near here ****

**** Figure 6 near here ****

Discussion

The purpose of this study was to assess changes in performance and perceived foot comfort throughout a match simulation session for two commercially available speed category football boot designs. Despite the use of a consistent and controlled match simulation drill, differences between boots were observed in jump power generation changes, foot comfort measures and mean heart rate. Specifically, players experienced significantly lower mean heart rates in the last 30 minutes of the match simulation when wearing Boot H compared to Boot L, despite players experiencing similar levels of exertion seen by consistent RPE scores. This may indicate that maintenance of intensity level was higher and better tolerated in Boot L over the duration of the match simulation drill. Also, there was a decrease in jump height between pre- and post-session jumps when wearing Boot H, whilst no decrease was seen when wearing Boot L. This suggests that players were better able to maintain their power generation in Boot L throughout the 90-min match simulation drill. Yet, no effect of boots or time was observed on sprint times between using the Illinoi Agility test. However, pilot test-retest reliability of the setup demonstrated ICC scores ranging from 0.206 to 0.451 and corresponding smallest real different scores of 1.1 to 3.7 s, indicating a poor setup or test sensitivity to detect changes in performance.

Although there were no significant differences in overall perceived foot comfort, there was a tendency ($P = 0.087$) towards a greater discomfort in Boot H, which may have been impacted by the relatively small sample size used. Yet, a significantly higher count of plantar discomforts for Boot H during the last 30 min of the match simulation drill was also observed. This is the same period where a lower mean heart rate was observed and further directly followed by a decrease in jump performance. In combination, the results suggest an association between an increase in foot discomfort, a decreased ability to maintain intensity level and a decrease in power generation throughout a 90-min match simulation drill when wearing Boot H. Based on these results, future research is needed to investigate whether this relationship is caused by the increased plantar pressures, by using boot designs with higher design similarities to minimise the impact of additional design variations.

The progressive drop in mean heart rate between each 15-minute interval of the modified SAFT90 match simulation drill may appear surprising due to the controlled movements and distances covered. Previous application of the SAFT90 protocol has presented similar tendencies (Nédélec et al., 2013) as have other match simulation drills with controlled running distances per time interval (e.g. Bendiksen et al., 2013; Funnell et al., 2017; Russell et al., 2011). Russell et al. (2011) visually presented the decrease in both maximum and minimum heart rate throughout a match simulation drill, and suggested this to indicate that players were less able to generate high intensity movements towards the end of the drill, likely to be the result of exertion. A decrease in performance of high intensity movements towards the end of games has also been reported for real match-play (Mohr et al., 2005). Thus, despite the decrease in mean heart rate, it can be argued that players performed the match-simulation drill at the desired high level of effort and that players did, as supported by the increase in RPE scores, experience increased levels of exertion as the modified SAFT90 match simulation drill progressed.

The foot comfort results also demonstrated a significant increase in discomfort throughout the duration of the match simulation. This highlights the need to complete both short- and long- term wear trials as the two can give quite different results and both are relevant to the football boot industry. The initial try-on perception of foot comfort is important when players buy products in the store, whilst assessing foot ‘comfort throughout match-play’ may be an indicator of performance and injury risk (Kinchington et al., 2010a, 2012). The results indicated a continual increase in foot discomfort throughout the 90 minutes, indicating comfort assessments should be performed for the full 90 minutes to obtain an understanding of foot 'comfort throughout match-play'.

Limitations

The methodological setup of the study included some limitations. No power calculation was performed prior to the study due to its novelty and hence no appropriate data set available. However, sample size was similar to that used in many studies (Lovell et al., 2013; Nédélec et al., 2013; Russell et al., 2011). With p-values close to significant for ANOVA (boot*time) and overall foot comfort, it is likely that a higher sample size would have demonstrated significant differences. Close to significant results (p=0.056) were, therefore, post hoc assessed. It is recommended that future studies use the results presented herein to inform the power calculation for sample size. The SAFT90 is not a true representation of match play and although mimicking movements and intensities (Lovell et al., 2008), e.g. elements of ball interaction are lacking. For players to complete the questionnaire, short breaks of up to 2 minutes were required, which will have decreased the ecological validity of the match play simulation effect.

Conclusion

Differences between football boots were seen in heart rate, foot comfort and ability to maintain jump power over the match simulation drill. The boot (Boot H) with the greater count of foot discomforts over the latter stages of the drill also demonstrated higher levels of discomfort and reduced performance. These results may indicate the importance of football boot design to obtaining optimal foot comfort and highlighting the importance of assessing foot comfort over different wear timescales. More research is needed to understand the underlying cause(s) behind the measured trends in foot discomfort and to assess the impact of foot discomfort on exertion and performance including assessment of plantar pressures.

Disclosure statement. No potential conflict of interest was reported by the authors.

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Figure text.

Figure 1. Soleplate image of Boot L (left) and Boot H (right).

Figure 2. Likert scales used for assessment of overall perceived foot comfort (left) and foot comfort map (right).

Figure 3. Schematic of the test session design.

A = complete questionnaire, B = agility sprint and counter movement jump assessments.

Figure 4. Diagram of the modified 22m SAFT90 field course adapted from original SAFT90 by Lovell et al. (2008)

Stippled line = alternating utility movement; Dense line = forwards running; Triangle = cone

Figure 5A-C. Mean heart rate (A), maximum heart rate (B) and rating of perceived exertion (C) for each of the 15 min match simulation intervals.

bpm = beats per minute; RPE = rating of perceived exertion; α = $p \leq 0.05$ for boot conditions; β = $p \leq 0.01$ for boot conditions; γ = $p \leq 0.001$ for boot conditions, T_x = significance level demonstrated higher than x = timepoint order, e.g. 1 = 0-15 and 6 = 75-90; B = significance level assessed between boots.

Figure 6A-E. Likert scale rated overall perceived foot comfort (A), count of discomfort on the foot map over time (B) and for each foot region (C) and count of plantar (D) and dorsal (E) discomforts over time.

PB = post break; Pre = when trying on football boot prior to warm up; Likert score of 1 = Unbearable discomfort; Likert score of 7 = Extremely comfortable.