Grip socks improve slalom course performance and reduce in-shoe foot displacement of the forefoot in male and female sports players

Charlotte Apps, Laura Dawson, Billy Shering & Petros Siegkas

Published online: 01 Jun 2022.

Submit your article to this journal

Article views: 12

View related articles

View Crossmark data

Routledge
Taylor & Francis Group

SPORTS MEDICINE AND BIOMECHANICS

🔓 OPEN ACCESS | Check for updates

Grip socks improve slalom course performance and reduce in-shoe foot displacement of the forefoot in male and female sports players

Charlotte Apps [ID][a], Laura Dawson [ID][a,b,c], Billy Shering[a,d] and Petros Siegkas [ID][a,d]

aSHAPE Research Group, School of Science and Technology, Nottingham Trent University, Nottingham, UK; bFaculty of Sport, Allied Health & Performance Science, St Mary's University, Twickenham, UK; cSchool of Health and Sports Sciences, University of Suffolk, Ipswich, UK; dSchool of Engineering and Technology, Cyprus University of Technology, Limassol, Cyprus

ABSTRACT

This study assessed whether grip socks reduce in-shoe foot motion and improve change of direction performance in team sports players and compared the effects between males and females. A sledge and pulley system confirmed the static coefficient of friction was increased in the grip socks (1.17) compared to the regular socks (0.60). Performance during a slalom course was faster in the grip socks compared to regular socks (p = .001). Yet, there was no difference in the utilised coefficient of friction between the shoe-floor interface during a side-cut and turn change of direction manoeuvre. Three-dimensional motion capture revealed the grip socks reduced in-shoe foot displacement during the braking phase, with greater effect during the sharper turn manoeuvre. The magnitude of natural foot spreading within the shoe was greater in the calcaneus region than the metatarsals which suggests in-shoe sliding may only occur at the forefoot. Males tended to have increased in-shoe displacement, which is associated with larger foot spreading due to their increased mass. Findings provide guidance for product developers to enhance the support inside the shoe at the forefoot, and change of direction performance.

1. Introduction

Rapid changes of direction, or cutting manoeuvres, are frequent in team sports (e.g., Fox et al., 2014; Matthew & Delextrat, 2009; Morgan et al., 2021). Enhanced capability to change direction quickly enables players to create the space and time needed for a shot, pass, or block that can influence match performance. Faster change of direction ability has discriminated higher division versus lower division players (Sekulic et al., 2017) and identification of youth athletes who develop into elite players (Forsman et al., 2016). Whole-body change of direction angles varies both within and between sports. For example, elite youth football players perform more direction changes that are less than 90 degrees (Morgan et al., 2021), whereas netball players are reported to have increased frequencies of sharper turns and side-cuts (Darnell, 2008; Fox et al., 2014). However, there is limited evidence that any certain type of cutting manoeuvre is more beneficial to performance outcomes than others (Fox et al., 2014), thus interventions to improve change of direction ability should assess both slight and severe cuts.

Athletic footwear technologies can enhance change of direction performance. Outsoles enable this by increasing the coefficient of friction at the shoe-floor interface (e.g., Ismail et al., 2021; Luo & Stefanyshyn, 2011), which is a biomechanical determinant of change of direction performance (Dos' Santos et al., 2017). Players are also able to subjectively perceive increased footwear traction and their increased confidence may trigger technique adaptations to increase the horizontal ground reaction force impulse and

consequently agility (Morio & Herbaut, 2018; Starbuck et al., 2016). Moreover, other footwear components such as the midsole, collar height (Stacoff et al., 1996), laces (Myers et al., 2019) and insoles (Apps et al., 2019) can increase foot stability inside the shoe by limiting foot-shoe motion. Thus, the time for the foot to decelerate in the shoe is reduced and time to change direction may be faster. Socks are the interim contact area between the f7oot and footwear and are a standard piece of sports apparel. Previous research associates different sock materials with an increased risk of blisters and plantar foot discomfort (Bogerd et al., 2012; Van Tiggelen et al., 2009). There is likely an optimal amount of friction between the sock-shoe interface to limit in-shoe motion and enhance agility performance and maintain comfort. Players from a range of team sports report wearing grip socks, which contain materials with increased frictional properties, such as rubber. Grip socks are marketed to reduce in-shoe slipping, and enhance speed and agility. Yet, despite their widespread use, it has not been investigated whether grip socks influence change of direction performance or how they are subjectively perceived.

Previous research on the influence of footwear friction focuses mainly on male participants (Morio et al., 2017). The different anatomy and physiology of females has been reported to result in gender specific biomechanical and neuromuscular responses during cutting manoeuvres, which are related to their increased risk of injury (Beaulieu et al., 2008; Sigward & Powers, 2006). The anatomy of the female foot tends to be relatively slimmer at the instep and shorter from the heel

---

to the outside ball of the foot, which should be considered for shoe design (Wunderlich & Cavanagh, 2001). While certain companies do manufacture female specific footwear for team sports (e.g., Idasports), generally it is not clear if female shoes are based upon a female specific last. Moreover, industry response to the scientific knowledge that females require different sports shoes has lagged behind (Althoff & Hennig, 2014; Kulessa et al., 2017) and anecdotal evidence suggests that female football players often wear male boots. Sex specific adaptations to in-shoe frictional properties have not been investigated. We postulated that the slender instep of the female foot (Wunderlich & Cavanagh, 2001) would result in increased in-shoe motion due to there being more space within the shoe. Grip socks may therefore have an increased performance benefit in female sports players.

Therefore, the primary aim of this study was to assess if grip socks reduce in-shoe foot motion and improve change of direction performance in team sports players. The secondary aim was to compare the response between male and female participants.

2. Materials and methods

Due to the lack of prior investigation, our assessments included mechanical, biomechanical, performance and subjective perception testing. This provided a comprehensive exploratory evaluation of the functional effect of grip socks (Sterzing et al., 2012).

2. 1 Socks and footwear

Two sock conditions were tested, grip socks (GS) and regular sport socks (RS). The RS (Performance Crew Sports Socks, Adidas) were 1.2 mm thick and material consisted of 60% cotton, 36% polyester, 3% elastane and 1% nylon (Figure 1a). The GS (LUX Sports) were 2.4 mm thick and had rubber pads (7

x 9 mm) on the inside and outside of the sock material (Figure 1b). The haptic sensation of the nodules was immediately detectable which meant it was not possible to blind the participants to the sock condition they were wearing. To control for the influence of different types of shoes, participants were provided with a standardised indoor football shoe (Lunargato II, Nike; Figures 1(c,d)) in each size from UK 6–11. It is assumed that this is a unisex model, despite no smaller size being commercially available. A practical approach was used to ensure the fit of the shoe because the football shoe tended to fit too small based on foot length measurement. Participants tried on their usual sports shoe size, and if they believed the fit was correct the investigator checked there was one finger width between the end of the shoe and the longest toe (Blazer et al., 2018).

2. 2 Mechanical coefficient of friction

To confirm the GS had increased frictional properties compared to the regular sock a sledge and pulley system was used to test the sock-insole interface and obtain the coefficient of friction (Figure 2). The system was fitted on a Shimadzu (Nakagyo-ku, Kyoto, Japan) AG-XD plus (part no. 337–01122-21, 50KN frame) screw driven mechanical testing machine using a 1KN (Class 1) load cell. The sledge was pulled horizontally at a constant velocity (1.5 mm/min) using a steel wire (Ø = 1.2 mm). The wire connected the sledge to the load cell and machine crosshead through a pulley at a 90° angle. The insole was attached to a stationary bottom plate and the sock specimens were attached to the sledge. Mass was added to the sledge (~ 2.5 Kg). The peak force prior to sliding was recorded and used for calculating the static coefficient of friction. Two different sock specimens of each type (i.e. 2x grip sock and 2x regular sock) were tested. Each test was repeated three times. The apparatus was validated using a polyimide film-film interface that was tested using two different methods i.e. the sledge and

Figure 1. The regular sock (a). the grip sock (b). the indoor football shoe (c and d) with markers attached to the shoe midsole: posterior lateral (spl), anterior lateral (sal), anterior medial (sam), posterior medial (spm). Foot marker locations: first metatarsal head (mh1), first metatarsal base (mb1), fifth metatarsal head (mh5), fifth metatarsal base (mb5), lateral calcaneus (lc), and medial calcaneus (mc).
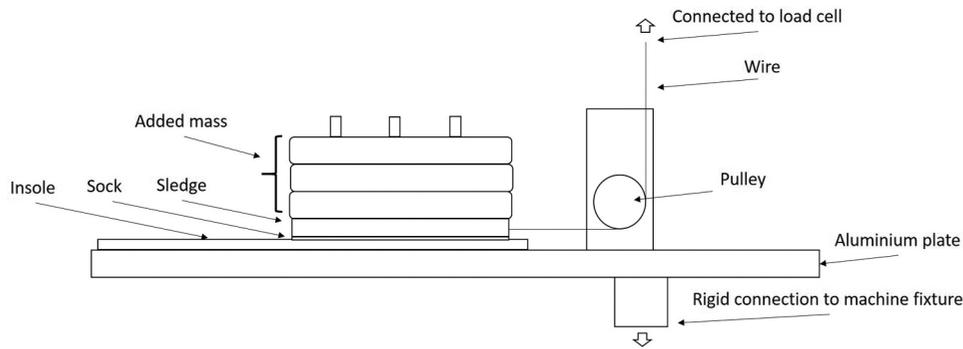
Figure 2. Schematic representation of the apparatus for comparing the coefficient of friction between grip sock and regular sock specimens. The insole was fixated to the aluminium plate. The sock specimen with sledge attachment were pulled along the insole.

pulley setup described above, and also tested by using an inclined plane and a digital inclinometer for measuring the angle of slippage, to ensure agreement and consistency in the resulting coefficient of friction.

2.2 Participants

Twenty recreational team sports players (10 males, 10 females; age 21.7 (SD 2.4); height 170 cm (SD 8.3); body mass 76.8 kg (SD 17.2)) were recruited to participate in this study. All participants had regularly played sport for at least 2 years, playing 3 times a week on average (SD 1.3). Participant inclusion required the absence of serious musculoskeletal injury in the six months preceding testing. The study protocol received ethical approval from the Human Invasive Research Ethics Committee at Nottingham Trent University (application #637), and all participants gave written informed consent prior to testing.

The protocol consisted of two separate measurement sessions: one for biomechanical measurements, and one for agility performance and subjective perception.

2.3 Biomechanics

Participants completed a 10-minute warm-up including dynamic stretches and a familiarisation to the cutting manoeuvres in their own footwear and then several practices in each of the sock condition with the standardised shoe. Following this, participants completed five maximal effort 45° side-cuts and five 180° turns in each sock condition. This allowed us to investigate the influence of the GS in both a fast-paced, slight (45°) and slower, severe (180°) change of direction applicable to team sports (Bloomfield et al., 2007; Darnell, 2008; Robinson et al., 2011). A trial was repeated if the change of direction step was not completed with the dominant foot landing on the force plate or if there was any noticeable targeting. To ensure the correct degree of the side-cut were achieved, cones were placed 1 metre away at 45° from the centre of the force plate. The order of sock type and change of direction angle was mixed between each participant. Timing gates (Brower Timing Systems, Draper, UT, USA) monitored approach speed (Figure 3). Participants were instructed to fasten the
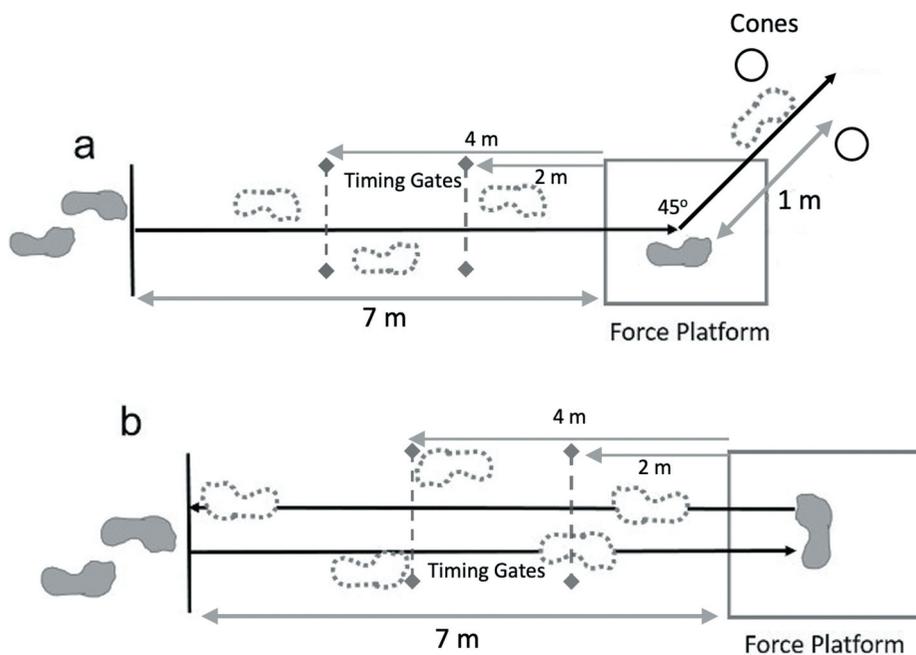

Figure 3. Change of direction tasks for biomechanical measurements. (a) 45° side-cut through cones; (b) 180° complete turn.

shoes to their preferred tightness before the first trial, the laces were then marked through the top eyelets. To ensure the support provided by the upper remained consistent across sock conditions participants were required to ensure the marks were just visible through the top eyelets for all trials. To limit the influence of fatigue, there was a 1-minute rest between trials.

A force plate (0.4 m x 0.6 m, Kistler, Winterhur, Switzerland), sampling at 1000 Hz recorded ground reaction forces during the change of direction step. Eight Miqus motion capture cameras (Qualisys, Gothenburg, Sweden) were used to measure the displacement of the markers placed on the foot relative to the markers placed on the shoe during foot ground contact. The cameras were placed around the force plate, approximately 1 m from the centre, sampling at 200 Hz. The capture volume was calibrated across the length and width of the force plate, and 0.5 m above the surface. Calibration was accepted when the residual camera errors were <0.3 mm, allowing sub-millimetre accuracy. Four reflective markers were attached to the shoe midsole at the anterior and posterior of the lateral and medial border (Figure 1). Holes were cut on the shoe-upper and sock on the dominant foot for the attachment of six reflective markers (12 mm Ø) directly onto the foot (Figure 1). To limit interference from movement of the shoe upper, holes were 25 mm in diameter (Bishop et al., 2015). The marker locations enabled assessment of regional foot displacement which varies between cutting manoeuvres (Apps et al., 2019).

Marker data was digitised in Qualisys Track Manager (Qualisys, Gothenburg, Sweden) and exported to Visual 3D (C-Motion, Rockville, MD, USA) for further analysis. A fourth order bi-directional Butterworth filter with 20 Hz and 50 Hz frequency cut-off frequency were applied to the marker co-ordinate and analogue force plate channels, respectively.

The initial touchdown and toe-off events of the change of direction step were determined by a 10 N threshold of the vertical ground reaction force and estimated ground contact time. The utilised coefficient of friction (uCOF) between the shoe-floor was calculated as the ratio of the resultant horizontal forces to vertical force (Morio et al., 2017). The mean uCOF during the braking phase and propulsive phase were computed, according to Apps et al., (2019), to avoid artefacts by dividing by low vertical forces (Luo & Stefanyshyn, 2011). The braking phase was defined from two frames after initial touchdown and ended at 50% of ground contact time. The propulsive phase started at the end of the braking phase and ended two frames prior to toe-off. The resultant horizontal impulse was computed to indicate changes in the magnitude of the shear forces between sock conditions and sex.

To calculate in-shoe foot displacement, the three-dimensional distance between the following lateral foot markers and shoe landmarks were computed:

- The fifth-metatarsal head and the midpoint between the anterior-lateral and anterior-medial shoe markers.
- The fifth metatarsal base and the midpoint of the anterior and posterior shoe markers.
- The lateral calcaneus and the midpoint between the posterior-lateral and posterior-medial shoe markers.

These shoe landmark locations were selected due to their closer proximity of the foot markers, thus limiting changes to foot-shoe displacement due to inter-segmental foot motion. Each foot-shoe distance at the start of the braking phase was subtracted to set the initial value to zero. In-shoe foot motion between the lateral foot markers and shoe were determined by the range of displacement during the braking and propulsive phase. This was to correspond with the uCOF and determine during which phases of the change of direction GS may influence performance. To give indication of the level of in-shoe foot motion, which is caused by natural foot spreading (Morio et al., 2009) the range of displacement in the three-dimensional distance between the markers on the metatarsal heads, metatarsal bases and medial and lateral calcaneus were computed.

2.4 Slalom performance and subjective perception

All participants completed a 26 m slalom course, previously used to evaluate actual and perceived performance with varying footwear and surfaces (Sterzing et al., 2009). The slalom incorporates 12 accelerations with 10 cutting movements and 1 complete turn. Prior to testing there was a 10-minute warm up including: 2 sub-maximal familiarisation trials in participants' own footwear and an additional sub-maximal and maximal familiarisation trial in each sock condition. Following this, three maximal effort trials in GS and RS were recorded. After each trial, the sock condition was alternated during a mandatory 3-minute recovery period to limit the influence of fatigue.

A pair of timing gates (Brower Timing Systems, Draper, UT, USA) were placed where the course both started and finished to evaluate performance. After each maximal trial subjective perception of speed and in-shoe grip was measured using 150 mm visual analogue scales (VAS), anchored with the terms "very slow" to "very fast" and "very low" to "very high", respectively (Apps et al., 2019). Following a further submaximal trial in each sock condition, subjective perception of comfort and stability were measured using VAS, with the terms "very uncomfortable" to "very comfortable" and "very unstable" to "very stable". This method of assessing perception of footwear comfort has been proven reliable in previous research (Mills et al., 2010).

2.6 Statistics

For each participant, parameter mean values were computed across trials for each sock condition. Statistical analysis was performed in SPSS software (SPSS v26, SPSS Inc., Chicago, IL, USA). Normality of parameters were checked with the Shapiro-Wilk test and visually checked with box-plots (Ghasemi & Zahediasl, 2012) to identify deviations from normality and detect outliers. Parameters met parametric test assumptions. Two-way mixed ANOVA tests assessed the main effect within participants (socks: regular vs grip) and between participant groups (sex: male vs female) for biomechanics, performance and subjective perception results. The alpha level was set at 0.05, there was no adjustment for the large number of comparisons due to the nature of this research being explorative. To indicate

the relevance of findings, effect sizes (η^2) were calculated for the main effects. A strong effect size was defined by $\eta^2 > 0.5$, moderate between 0.5 and 0.3 and low < 0.3 (Field, 2015). Significant interactions were followed up with paired t-tests to indicate sock specific effects in males and females. Paired t-tests confirmed there was no difference approach speed between sock conditions during side-cuts (p = .630) or turns (p = .872) and was subsequently not considered as a covariate for foot-displacement and foot-spreading results.

2. Results

Mechanical coefficient of friction

The coefficient of friction obtained by the mechanical tests appeared consistent (Table 1). The GS-insole interface resulted in nearly double the coefficient of friction to that of the RS-insole interface.

Biomechanics

The was only one significant interaction across biomechanical results, indicating the GS had similar effect across both sexes.

Ground reaction forces

There were no significant differences between sock conditions in the horizontal ground reaction force impulse, uCOF or contact time for either change of direction tasks (Table 2). There was a significant main effect of sex in the horizontal ground reaction force impulse, whereby males had increased impulses during both manoeuvres in the braking phase and propulsive phase. The uCOF results revealed no significant difference between males and females.

In-shoe foot displacement

During the braking phase for both change of direction manoeuvres, the GS significantly reduced in-shoe foot displacement across foot locations compared to RS, except at the fifth metatarsal head in the side-cut (Table 3). Females had significantly reduced in-shoe foot displacement compared to males during the braking phase at the fifth metatarsal base across manoeuvres, and in the lateral calcaneus in the turn.

During the propulsive phase, there were fewer significant results. There was significantly reduced in-shoe displacement at the lateral calcaneus in GS compared to RS in the side-cut and the turn. In the turn at the lateral calcaneus there was significantly reduced in-shoe displacement in females compared to males.

Foot spreading

The foot spreading results are reported in Table 4. In two participants (1 male and 1 female) there were missing data for the calcaneus spreading during turns due to the medial calcaneus marker being obscured by shoe. There appeared to be a greater effect of sex, than sock condition, with males tending to have increased foot spreading. Yet there were fewer significant results than the in-shoe foot displacement results.

During the braking phase there was reduced foot spreading at the calcaneus in females compared to males during the side-cut and turn. In the turn there was also significantly reduced foot spreading in females compared to males at the metatarsal bases during the braking and propulsive phase. The only significantly difference between sock conditions was the reduced calcaneus spreading in GS compared to RS during the braking phase of the turns.

In the side-cut during the propulsive phase there was a significant interaction in the calcaneus. Follow-up paired t-tests results revealed significantly reduced spreading in GS compared to RS in females (p = .042) and a tendency to increase in males (p = .075).

Slalom performance and subjective perception

Regardless of sex, there was a significant main effect for sock condition (p = .001), with faster times in GS compared to RS (Table 5). There was no significant main effect of sex, with similar times achieved between males and females (p = .429). There was no significant interaction effect on the type of sock worn between males and females in the time to complete the slalom course (p = .711).

There were significant interactions of the subjective scores for speed, in-shoe grip and stability, but not comfort. Figure 4 illustrates this was due to females rating RS relatively lower and GS relatively higher than males. Follow-up paired tests revealed females perceived their speed to be significantly faster in GS (p = .003), but no effect in males (p = .121). In-shoe grip and stability were significantly increased in GS compared to RS in both males (grip: p = .011; stability: p < .001) and females (grip: p = .001; stability: p < .001). Comfort perception was significantly increased in GS compared to RS, but there was no effect between sexes.

3. Discussion

In relation to the primary aim of this study, the commercially available grip socks (GS) tested did improve change of direction performance during a slalom course compared to a regular sock (RS). On average, female and male participants completed the course in 12.74 and 12.57 seconds in GS compared to 13.29 and 12.89 seconds in RS respectively, which was a moderate effect (Table 5). However, there was no difference in the approach speeds, contact time and horizontal ground reaction forces during the side-cut and turn tasks. Participants may have adapted to the different friction at the sock-shoe interface during a single change of direction, but any technique alterations were not sufficient to maintain performance over multiple cuts. Alternatively, slight biomechanical modifications that were not detected in our cutting results may accumulate over the multiple changes of directions in the slalom course.

Table 1. Calculated coefficient of friction for grip (gs) and regular socks (rs). Two specimens of each type were tested.

Sock type	Specimen	COF (SD)	Average COF
RS	1	0.55 (0.023)	0.6
	2	0.65 (0.045)	
GS	1	1.2 (0.041)	1.17
	2	1.13 (0.109)	

Table 2. Mean (sd) ground reaction force parameters during the side-cut and turn as a function of sock condition and sex.

		Females		Males		
	Cut	RS	GS	RS	GS	Effect Size
Contact time (s)	Side-cut	.209 (.025)	.209 (.031)	.214 (.030)	.224 (.034)	
	Turn	.474 (.088)	0.479 (.098)	.539 (.070)	.546 (.079)	
Horizontal GRF impulse braking phase (N.s)	Side-cut	57.0 (7.7)	56.0 (8.9)	65.6 (4.7)	66.8 (8.8)	[#].34
	Turn	115.5 (16.5)	121.1 (13.3)	152.7 (22.7)	146.9 (26.5)	[#].42
Horizontal GRF impulse propulsive phase (N.s)	Side-cut	33.60 (3.8)	34.7 (5.6)	43.0 (7.0)	41.4 (6.2)	[#].43
	Turn	93.8 (15.2)	93.4 (10.6)	130.3 (22.0)	127.9 (27.1)	[#].50
uCOF braking phase	Side-cut	.415 (.041)	.406 (.037)	.395 (.058)	.383 (.046)	
	Turn	.578 (.063)	.591 (.067)	.590 (.062)	.577 (.063)	
uCOF propulsive phase	Side-cut	.527 (.038)	.538 (.034)	.510 (.032)	.500 (.054)	
	Turn	.588 (.057)	.605 (.064)	.615 (.048)	.603 (.047)	

GRF = ground reaction force. uCOF = utilised coefficient of friction. RS = regular sock, GS = Grip sock. Significant results ($p < .05$): * = main effect of SOCK, [#] = main effect of SEX, [$] interaction.

To investigate the mechanism of how GS affect change of direction ability we assessed the mechanical coefficient of friction, and in-vivo measurements of in-shoe displacement using motion capture and ground reaction forces. Mechanical measurements revealed GS nearly doubled the coefficient of friction, compared to RS (Table 1). The embedded polymer components, within the GS fabric, appeared to be slightly protruding which may result in partial enveloping by the insole hence increasing the effective interface resistance to slippage. Due to this, a variation to the ASTM D1894 standard test was used that had a lower velocity and increased weight, which were intended to reveal any relevant enveloping mechanisms due to the different stiffness of the GS nodules, whilst reducing inertial effects. The increased mechanical coefficient of friction in GS corresponded with a reduction of in-shoe foot displacement during the braking phase of the change of directions manoeuvres (Table 3). However, as mentioned the reduced in-shoe foot motion in the GS did not improve performance during the side-cut or turn. We speculate reduced in-shoe movement and better foot stability in the GS resulted in improved slalom course performance, but further research is warranted to substantiate this claim. In the side-cuts, the absolute difference in in-shoe foot displacement between socks at the lateral calcaneus and fifth metatarsal base was less than 1 mm in males. The small effect size and accuracy of the motion capture system up to 0.3 mm suggest this is not a meaningful difference. In the sharper turn manoeuvre, GS reduced in-shoe foot displacement to a greater extent; between 1.3–2.8 mm across sexes and foot locations (Table 3). This is related to the increased horizontal shear forces and uCOF in the turn compared to side-cut (Table 2). These results are similar to Apps et al., (2019), who reported an insole with increased mechanical friction was associated with reductions of in-shoe foot displacement in a complete turn during braking, but not a side-cut. During the initial braking phase of a cut, uCOF is increased and dependent of the movement dynamics upon landing (C. Y. M. Morio et al., 2015). Landing with a forefoot strike during cuts increases ankle work (Donnelly et al., 2017), shear forces and potentially subsequent in-shoe motion at the forefoot. We did not assess foot strike pattern in this study and future research is warranted to assess the effect on in-shoe motion.

Our secondary aim was to compare the response between male and female participants. Given females tend to have narrower feet we speculated females may have increased in-shoe foot displacement in the shoe last designed for male feet, and therefore GS may have greater effect to their agility performance. However, there was no difference to performance between males and females, shown by the lack of significant interaction result on the slalom course. Thus, performance advantage of wearing grip socks seems to work equally for both sexes.

Table 3. Mean (sd) range of in-shoe foot displacement (mm) of the fifth metatarsal head, fifth metatarsal base and lateral calcaneus during the braking and propulsive phases of the side-cut and turn as a function of sock condition and sex.

		Females		Males		
Cut, phase	Foot location	RS	GS	RS	GS	Effect Size
Side-cut, braking	Metatarsal head 5	5.2 (3.1)	5.2 (2.2)	4.8 (1.9)	4.7 (1.9)	
	Metatarsal base 5	4.8 (2.3)	3.7 (1.3)	6.4 (2.3)	5.6 (1.6)	*.25, [#].22
	Lateral calcaneus	4.7 (2.7)	2.8 (1.1)	5.5 (1.7)	5.1 (1.8)	*.27
Turn, braking	Metatarsal head 5	9.9 (3.0)	8.6 (2.4)	12.2 (4.8)	10.8 (2.2)	*.27
	Metatarsal base 5	8.9 (2.6)	6.4 (2.2)	11.4 (2.3)	9.2 (1.4)	*.71, [#].33
	Lateral calcaneus	6.6 (3.6)	3.8 (1.3)	8.4 (1.8)	6.2 (2.0)	*.55, [#].24
Side-cut, propulsive	Metatarsal head 5	4.4 (1.8)	5.5 (2.2)	4.3 (1.6)	4.3 (2.5)	
	Metatarsal base 5	3.1 (1.6)	3.4 (1.6)	3.6 (2.0)	3.8 (1.9)	
	Lateral calcaneus	4.1 (1.6)	2.5 (1.1)	3.8 (1.1)	3.6 (1.4)	*.22
Turn, propulsive	Metatarsal head 5	5.9 (1.3)	6.1 (1.8)	6.3 (2.2)	6.7 (2.5)	
	Metatarsal base 5	4.9 (2.3)	4.8 (1.6)	5.5 (1.6)	5.2 (1.3)	
	Lateral calcaneus	3.1 (1.2)	2.2 (1.0)	4.0 (1.6)	3.4 (0.7)	*.34, [#].24

Significant results ($p < .05$): * = main effect of SOCK, [#] = main effect of SEX, [$] interaction. RS = regular sock, GS = Grip sock.
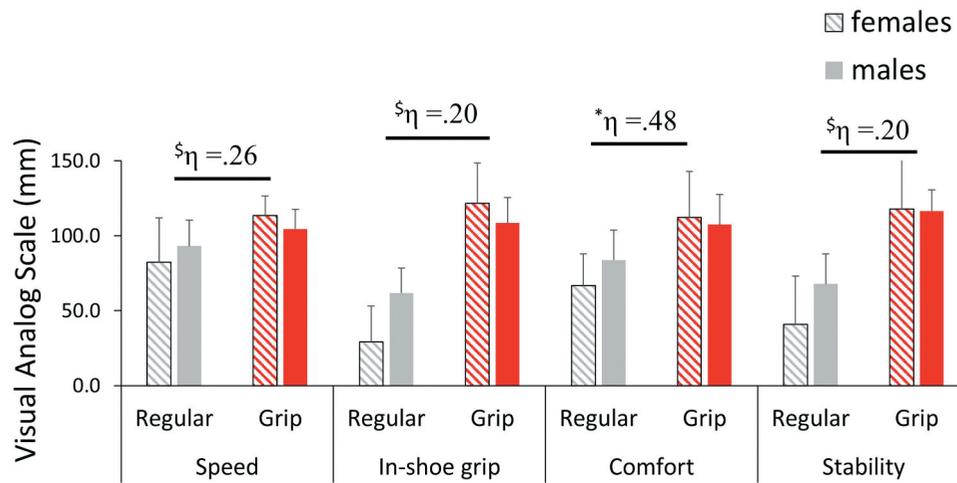
Figure 4. Mean (sd) subjective perception scores across sock conditions and sexes. Significant results indicated: * = main effect of sock, # = main effect of sex, $ interaction.

Results further confound this theory because males actually had increased in-shoe displacement during the braking phase at the fifth metatarsal base in both cuts, and the lateral calcaneus in the turn during the braking and propulsive phase (Table 3). The movement dynamics of the male participants resulted in an increased horizontal force impulse (Table 2), which may be associated with their increased mass. Yet there was similar utilised coefficient of friction (uCOF) between the sexes, suggesting males must have also applied an increased normal force. Having an increased horizontal force requires a sufficient increase in normal force so that the uCOF does not exceed the mechanically available friction and result in slippage. Although we did not measure the in-shoe forces, the similar ratio of horizontal to vertical ground reaction force between the shoe-floor interface suggests the higher momentum in males is not associated with the increased in-shoe foot displacement. Female participants were able to perceive the influence of the grip socks on their speed, whereas the males did not (Figure 4). This may give females a psychological advantage whilst wearing grip socks, but this did not result in an increased uCOF or performance during the side-cut and turn task. Thus, a sex effect of GS on performance is not supported by our findings.

Natural foot motion causes the foot to expand, even when restricted by footwear (Morio et al., 2009). Previous research investigating in-shoe motion has not accounted for foot spreading contributing to foot-shoe displacement results. Therefore, we estimated foot spreading by calculating the displacement of the foot markers on the metatarsal heads, metatarsal bases and the calcaneus. The male foot tended to expand to a greater extent than the female foot (Table 4). This suggests the increased in-shoe foot displacement results in males are in fact caused by larger foot spreading, particularly at the metatarsal base and lateral calcaneus during braking for the turn where both results were significantly greater in males (Tables 3 and 4). A normalisation method to account for foot size when calculating in-shoe foot displacement should be considered in the future work to limit this issue. Interestingly, some foot spreading results were greater than the in-shoe foot displacement which would suggest there might not be any foot sliding. Particularly, the calcaneus foot spreading results were all greater than the lateral calcaneus in-shoe displacement. The heel fat pad deforms to cushion impacts upon landing, and although the extent during cutting manoeuvres is unknown, it was reported to deform 35% in shod running (Aerts & De

Table 4. Mean (sd) range of foot spreading (mm) of the metatarsal heads, metatarsal bases and calcaneus during the braking and propulsive phases of the side-cut and turn as a function of sock condition and sex.

Cut, phase	Foot location	Females		Males		Effect Size
		Regular	Grip	Regular	Grip	
Side-cut, braking	Metatarsal heads	3.6 (1.6)	4.1 (1.5)	5.2 (2.6)	5.5 (2.0)	
	Metatarsal bases	3.3 (1.4)	3.5 (1.2)	4.8 (1.7)	6.1 (3.2)	
	Calcaneus	5.7 (2.4)	4.2 (1.1)	6.6 (2.2)	7.1 (3.0)	#.22
Turn, braking	Metatarsal heads	5.1 (1.4)	5.8 (1.2)	7.5 (3.1)	6.7 (2.8)	
	Metatarsal bases	5.0 (2.6)	4.1 (1.7)	8.1 (3.1)	8.3 (4.9)	#.28
	Calcaneus	8.3 (2.1)	5.7 (1.7)	13.0 (1.9)	9.5 (2.9)	*.64, #.64
Side-cut, Propulsive	Metatarsal heads	4.2 (1.9)	5.1 (2.3)	5.1 (3.2)	5.9 (3.5)	
	Metatarsal bases	4.0 (1.4)	3.6 (1.4)	5.5 (2.9)	5.6 (4.1)	
	Calcaneus	7.2 (2.7)	6.1 (1.8)	6.5 (1.5)	8.4 (2.3)	$.38
Turn, propulsive	Metatarsal heads	4.7 (1.9)	5.4 (1.2)	5.4 (3.2)	6.0 (3.1)	
	Metatarsal bases	3.9 (1.7)	3.5 (0.8)	5.4 (2.4)	4.9 (1.7)	#.20
	Calcaneus	5.5 (1.1)	5.6 (1.2)	7.6 (3.0)	6.9 (2.7)	

Significant results (p < .05): * = main effect of SOCK, # = main effect of SEX, $ interaction

Table 5. Mean (sd) slalom course performance times (seconds).

Females		Males		
Regular	Grip	Regular	Grip	Effect Size
13.29 (1.10)	12.74 (.81)	12.89 (0.99)	12.57 (0.89)	*.49

Significant results (p < .05): * = main effect of SOCK, # = main effect of SEX, $
interaction

Clercq, 1993). When taking foot spreading results into account, only the forefoot in the turn manoeuvre has greater in-shoe foot displacement results. Thus, agility performance gains due to in-shoe movement may only occur in the forefoot region where there is less support from the shoe upper during sharp changes of direction.

The grip socks were perceived to increase comfort, stability and in-shoe grip (Figure 4). This suggests that the increased frictional properties of GS did not increase the plantar pressures and shear forces that are associated with foot discomfort and blisters (Castro et al., 2013; Knapik et al., 1996). It is acknowledged that the lack of blinding to the sock condition because of the rubber nodules on GS would very likely have affected the subjective perception scores (Matthias et al., 2021) and potentially the performance in the slalom course. However, players can feel the haptic sensation of socks in the real-world sporting environment and artificially removing this would reduce the external validity of this research. Moreover, the perception of stability and in-shoe grip may have important implications for reducing sports injuries. Shinohara and Gribble (2013), assessed the effects of five-toed socks with rubber grip on the foot sole on static postural control in healthy young adults. They reported an improvement of static postural control, highlighting that one of the contributing factors was the increased traction due to the GS increasing proprioception. Whether this has an applied effect during dynamic change of directions in team sports is unknown and warrants investigation.

This study had limitations which should be considered when interpreting findings. Firstly, the high impact upon landings during the change of directions causes marker artefacts due to oscillations relative to the skin. The filter applied and analysis was from 2 frames after initial touchdown to limit this effect. Despite there being less influence of wobbling mass on the foot, this artefact cannot be avoided with 3D motion capture (Kessler et al., 2019). Secondly, the GS were thicker than the RS (2.4 vs 1.2 mm), which may have affected the subjective rating, such as comfort and stability. The thicker GS would likely have reduced the space inside the shoe, but we do not believe this confounds the in-shoe foot displacement results because the cotton material was very compliant and deforms easily. Thirdly, although the sample size between sock conditions (n = 20) was similar to past studies, the sample size for the sex comparison (n = 10) was smaller. Lastly, it is acknowledged there were numerous statistical tests conducted in this study due to its explorative approach. This increased the risk of type 1 errors in the findings.

In conclusion, the grip socks tested improved agility performance across male and female participants and can be recommended to team sports players to enhance their change of direction ability. This is attributed to the increased mechanical coefficient of friction of GS reducing in-shoe foot displacement of the forefoot during the deceleration of the sharper turn manoeuvre and not shoe-floor ground reaction forces. The in-shoe motion results calculated in this study and past research are obscured by the natural foot spreading during cutting manoeuvres. The calcaneus foot spreading was greater than the relative in-shoe displacement, suggesting the commercial indoor football shoe provides adequate support to prevent in-shoe movement in the rearfoot. Future work should follow-up findings of perceived in-shoe grip, stability and comfort enhancement in grip socks by assessing balance and injury risk benefits.

Disclosure statement

Funding

ORCID

Charlotte Apps 🔟 http://orcid.org/0000-0002-7354-0003
Laura Dawson 🔟 http://orcid.org/0000-0003-4884-7748
Petros Siegkas 🔟 http://orcid.org/0000-0001-9528-2247

References

Aerts, P., & De Clercq, D. (1993). Deformation characteristics of the heel region of the shod foot during a simulated heel strike: The effect of varying midsole hardness. Journal of Sports Sciences, 11(5), 449–461. https://doi.org/10.1080/02640419308730011

Althoff, K., & Hennig, E. M. (2014). Criteria for gender-specific soccer shoe development. Footwear Science, 6(2), 89–96. https://doi.org/10.1080/19424280.2014.890671

Apps, C., Rodrigues, P., Isherwood, J., & Lake, M. (2020). Footwear insoles with higher frictional properties enhance performance by reducing in-shoe sliding during rapid changes of direction. Journal of Sports Sciences, 38(2), 206–213. https://doi.org/10.1080/02640414.2019.1690618

Beaulieu, M. L., Lamontagne, M., & Xu, L. (2008). Gender differences in time-frequency EMG analysis of unanticipated cutting maneuvers. Medicine and Science in Sports and Exercise, 40(10), 1795–1804. https://doi.org/10.1249/MSS.0b013e31817b8e9e

Bishop, C., Arnold, J. B., Fraysse, F., & Thewlis, D. (2015). A method to investigate the effect of shoe-hole size on surface marker movement when describing in-shoe joint kinematics using a multi-segment foot model. Gait & Posture, 41(1), 295–299. https://doi.org/10.1016/j.gaitpost.2014.09.002

Blazer, M. M., Jamrog, L. B., & Schnack, L. L. (2018). Does the shoe fit? Considerations for proper shoe fitting. Orthopaedic Nursing, 37(3), 169–174.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA premier league soccer. Journal of Sports Science & Medicine, 6(1), 63. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3778701/

Bogerd, C. P., Niedermann, R., Brühwiler, P. A., & Rossi, R. M. (2012). The effect of two sock fabrics on perception and physiological parameters associated with blister incidence: A field study. Annals of Occupational Hygiene, 56(4), 481–488. https://doi.org/10.1093/annhyg/mer127

Castro, M., Abreu, S., Sousa, H., Machado, L., Santos, R., & Vilas-Boas, J. P. (2013). Ground reaction forces and plantar pressure distribution during occasional loaded gait. Applied Ergonomics, 44(3), 503–509. https://doi.org/10.1016/j.apergo.2012.10.016

Darnell, E. (2008). *Injury risk during netball competition: an observational investigation* (Doctoral dissertation, University of Wales Institute Cardiff).

Donnelly, C. J., Chinnasee, C., Weir, G., Sasimontonkul, S., & Alderson, J. (2017). Joint dynamics of rear-and fore-foot unplanned sidestepping. *Journal of Science and Medicine in Sport*, 20(1), 32–37. https://doi.org/10.1016/j.jsams.2016.06.002

Dos' Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Mechanical determinants of faster change of direction speed performance in male athletes. *Journal of Strength and Conditioning Research*, 31(3), 696–705. https://doi.org/10.1519/JSC.0000000000001535

Field, A. (2015). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage.

Forsman, H., Blomqvist, M., Davids, K., Liukkonen, J., & Konttinen, N. (2016). Identifying technical, physiological, tactical and psychological characteristics that contribute to career progression in soccer. *International Journal of Sports Science & Coaching*, 11(4), 505–513. https://doi.org/10.1177/1747954116655051

Fox, A., Spittle, M., Otago, L., & Saunders, N. (2014). Offensive agility techniques performed during international netball competition. *International Journal of Sports Science & Coaching*, 9(3), 543–552. https://doi.org/10.1260/1747-9541.9.3.543

Ghasemi, A., & Zahediasl, S. (2012). Normality tests for statistical analysis: A guide for non-statisticians. *Journal of Endocrinology and Metabolism*, 10(2), 486–489. https://doi.org/10.5812/ijem.3505

Ismail, S. I., Nunome, H., & Tamura, Y. (2021). Does visual representation of futsal shoes outsole tread groove design resemblance its mechanical traction, dynamic human traction performance, and perceived traction during change of direction and straight sprint tasks? *Footwear Science*, 13(1), 79–89. https://doi.org/10.1080/19424280.2020.1825534

Kessler, S. E., Rainbow, M. J., Lichtwark, G. A., Cresswell, A. G., D'Andrea, S. E., Konow, N., & Kelly, L. A. (2019). A direct comparison of biplanar video radiography and optical motion capture for foot and ankle kinematics. *Frontiers in Bioengineering and Biotechnology*, 7, 199. https://doi.org/10.3389/fbioe.2019.00199https://www.frontiersin.org/articles/10.3389/fbioe.2019.00199/full

Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs: A review of physiological, biomechanical and medical aspects. *Applied Ergonomics*, 27(3), 207–216. https://doi.org/10.1016/0003-6870(96)00013-0

Kulessa, D. J., Gollhofer, A., & Gehring, D. (2017). The influence of football shoe characteristics on athletic performance and injury risk–a review. *Footwear Science*, 9(1), 49–63. https://doi.org/10.1080/19424280.2017.1284273

Luo, G., & Stefanyshyn, D. (2011). Identification of critical traction values for maximum athletic performance. *Footwear Science*, 3(3), 127–138. https://doi.org/10.1080/19424280.2011.639807

Matthew, D., & Delextrat, A. (2009). Heart rate, blood lactate concentration, and time–motion analysis of female basketball players during competition. *Journal of Sports Sciences*, 27(8), 813–821. https://doi.org/10.1080/02640410902926420

Matthias, E. C., Banwell, H. A., & Arnold, J. B. (2021). Methods for assessing footwear comfort: A systematic review. *Footwear Science*, 13(3), 255–274. https://doi.org/10.1080/19424280.2021.1961879

Mills, K., Blanch, P., & Vicenzino, B. (2010). Identifying clinically meaningful tools for measuring comfort perception of footwear. *Medicine and Science in Sports and Exercise*, 42(10), 1966–1971. https://doi.org/10.1249/MSS.0b013e3181dbacc8

Morgan, O. J., Drust, B., Ade, J. D., & Robinson, M. A. (2021). Change of direction frequency off the ball: New perspectives in elite youth soccer. *Science and Medicine in Football*, 1–10. just-accepted. https://doi.org/10.1080/24733938.2021.1986635

Morio, C., Lake, M. J., Gueguen, N., Rao, G., & Baly, L. (2009). The influence of footwear on foot motion during walking and running. *Journal of Biomechanics*, 42(13), 2081–2088. https://doi.org/10.1016/j.jbiomech.2009.06.015

Morio, C. Y. M., Sissler, L., & Guéguen, N. (2015). Static vs. dynamic friction coefficients, which one to use in sports footwear research? *Footwear Science*, 7(sup1), S63–S64. https://doi.org/10.1080/19424280.2015.1038609

Morio, C., Bourrelly, A., Sissler, L., & Gueguen, N. (2017). Perceiving slipperiness and grip: A meaningful relationship of the shoe-ground interface. *Gait & Posture*, 51, 58–63. https://doi.org/10.1016/j.gaitpost.2016.09.029

Morio, C. Y., & Herbaut, A. (2018). Neuromechanical adaptations to slippery sport shoes. *Human Movement Science*, 59, 212–222. https://doi.org/10.1016/j.humov.2018.04.016

Myers, C. A., Allen, W., Laz, P. J., Lawler-Schwartz, J., & Conrad, B. P. (2019). Motorized self-lacing technology reduces foot-shoe motion in basketball shoes during dynamic cutting tasks. *Footwear Science*, 11(sup1), S189–S191. https://doi.org/10.1080/19424280.2019.1606326

Robinson, G., O'Donoghue, P., & Wooster, B. (2011). Path changes in the movement of English premier league soccer players. *The Journal of Sports Medicine and Physical Fitness*, 51(2), 220–226. https://europepmc.org/article/med/21681155No DOI is visible on the paper

Sekulic, D., Pehar, M., Krolo, A., Spasic, M., Uljevic, O., Calleja-González, J., & Sattler, T. (2017). Evaluation of basketball-specific agility: Applicability of preplanned and nonplanned agility performances for differentiating playing positions and playing levels. *The Journal of Strength & Conditioning Research*, 31(8), 2278–2288. https://doi.org/10.1519/JSC.0000000000001646

Shinohara, J., & Gribble, P. (2013). Effects of five-toed socks with multiple rubber bits on the foot sole on static postural control in healthy young adults. *The Journal of Physical Fitness and Sports Medicine*, 2(1), 135–141. https://doi.org/10.7600/jpfsm.2.135

Sigward, S. M., & Powers, C. M. (2006). The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clinical Biomechanics*, 21(1), 41–48. https://doi.org/10.1016/j.clinbiomech.2005.08.001

Stacoff, A., Steger, J., Stuessi, E. D. G. A. R., & Reinschmidt, C. (1996). Lateral stability in sideward cutting movements. *Medicine and Science in Sports and Exercise*, 28(3), 350–358. https://doi.org/10.1097/00005768-199603000-00010

Starbuck, C., Damm, L., Clarke, J., Carré, M., Capel-Davis, J., Miller, S., & Dixon, S. (2016). The influence of tennis court surfaces on player perceptions and biomechanical response. *Journal of Sports Sciences*, 34(17), 1627–1636. https://doi.org/10.1080/02640414.2015.1127988

Sterzing, T., Müller, C., Hennig, E. M., & Milani, T. L. (2009). Actual and perceived running performance in soccer shoes: A series of eight studies. *Footwear Science*, 1(1), 5–17. https://doi.org/10.1080/19424280902915350

Sterzing, T., Lam, W. K., & Cheung, J. T. M. (2012). Athletic footwear research by industry and academia. In R. S. Goonetilleke (Ed.), *The science of footwear* (pp. 605–622). CRC Press, Taylor & Francis Group.

Van Tiggelen, D., Wickes, S., Coorevits, P., Dumalin, M., & Witvrouw, E. (2009). Sock systems to prevent foot blisters and the impact on overuse injuries of the knee joint. *Military Medicine*, 174(2), 183–189. https://doi.org/10.7205/MILMED-D-01-8508

Wunderlich, R. E., & Cavanagh, P. R. (2001). Gender differences in adult foot shape: Implications for shoe design. *Medicine and Science in Sports and Exercise*, 33(4), 605–611. https://doi.org/10.1097/00005768-200104000-00015