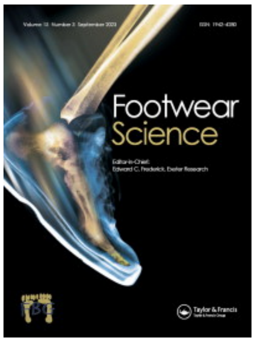

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RESEARCH ARTICLE

Effects of athletic socks with high frictional properties on in-shoe foot sliding and performance in football-specific movements

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ABSTRACT

The purpose of this study was to examine the efficacy of high friction socks on in-shoe foot sliding and running performance of male footballers during change of direction movements. Twelve recreational football players (mean age 20.3 ± 1.1 years) completed a 26 m dynamic agility course at their maximum running speed. 3D kinematic and kinetic data were collected for three maximum speed 45° side-cuts, and 180° turns in two different sock conditions. Comparisons were made between a sock with a high static coefficient of friction (GripSock) and a regular sock (CompressionS). The Gripsock condition significantly increased utilized traction (COFu) and a reduction of GRF angle (GRFα) was identified during the braking phase of the side cut (COFu: + 9.3 ± 10%; GRFα: −3.1 ± 2.9%) but not in the side-cut propulsion, turn braking and turn propulsion phases. Speed perception was raised in the GripSock condition (+18 ± 30%). However, wearing a sock with high frictional properties did not significantly reduce in-shoe foot sliding in any examined direction nor did it significantly reduce running times over a functional traction course. The relationship between in-shoe traction and running performance is complex and likely dependent on the overall interaction of shoe properties and the type of athletic sock.

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Footwear; traction; performance; sliding; perception

Introduction

Athletic performance in a change of direction (COD) tasks is essential for many field-and court-based sports (Bourgeois et al., 2017). Elite performers across different sports tend to be superior in sport-specific COD tests than non-elite players (Shepard et al., 2014), and the number of CODs, especially conducted at moderate (>16 km/h) and high speed (>21 km/h), has been shown to increase with competition level (Granero-Gil et al., 2020). In particular, elite football (soccer) players have been reported to make approximately 500–700 CODs between 0° to 90°, and around 90-100 COD between 90° to 180° per game (Bloomfield et al., 2007).

For COD performance, higher traction between footwear and ground surface can be beneficial by decreasing running times in specific COD tests (Sterzing et al., 2009). In footwear science, traction is expressed as the coefficient of friction (COF), the ratio of shear forces to the vertical force (McClay et al., 1994). More specifically, the mechanically measurable maximum limit of static friction between two surfaces is defined as mechanical COF (COFm), while utilised COF (COFu) is the proportion of the COFm athletes can utilise during movement tasks (Luo & Stefanyshyn, 2011). The greater the COFm the more COFu footballers can apply in tasks like curved sprinting, linear acceleration and 180° turns (Apps et al., 2020; Luo & Stefanyshyn, 2011). This improves different COD test running times from 3% up to 30% (Ismail et al., 2021; Pedroza et al., 2010; Worobets & Wannop, 2015). Indeed, most football players can perceive and adapt to the frictional properties of the footwear, giving them a feeling of more in-game speed and resulting in faster COD test running times (Morio et al., 2017; Sterzing et al., 2009).

During COD tasks the available traction also influences a footballer's body position in relation to the surface. Body position can be described as the ground reaction force angle (GRFα) between the horizontal surface and the resultant ground reaction force (GRF) vector. For example, in curved sprinting, linear acceleration and 180° turns a higher COFm decreases the GRFα, leading to a footballer's body position which is more tilted to the ground compared to a lower COFm condition (Apps et al., 2020; Luo & Stefanyshyn, 2011). Such a lower GRFα has been shown to lead to higher net positive horizontal force during treadmill running, correlating with improved maximum and mean running speed in 100 m sprints (Morin et al., 2011). A lower GRFα (anterior tilt) additionally correlates positively with propulsion impulse during acceleration from standing and flying starts (Kugler & Janshen, 2010).

Whilst most studies have examined traction in the shoe-surface interface, few have focussed on the traction in the *in-shoe* surface between the sock and shoe. According to

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Lafortune (1997) for increased foot stability to improve COD performance, it is desirable to maintain the foot position at the heel and midsole of the shoe. Wearing high frictional insoles has been shown to help maintain in-shoe foot position by reducing in-shoe foot sliding during the braking, but not in the acceleration phase, of 20° side-cuts and 180° turns, resulting in improved running performances by up to 5% (Apps et al., 2020). Apps et al. (2020) attribute such enhancement to observed higher COFu and lower GRFα values, and significantly higher athletes' traction perception (Apps et al., 2020; Ismail et al., 2021). However, for some athletes wearing high-friction insoles might be impractical due to the need for personal orthotics (Werd et al., 2017). As an alternative, various manufacturers offer athletic socks with high outside frictional properties designed to enhance in-shoe friction. Support for such an option is provided by Dai et al. (2006) who, in a 3D finite element simulation, found that by increasing the frictional properties of a sock, the displacement in this interface is reduced. Testing males and females, Apps et al. (2022) stated that socks with enhanced frictional properties improve the performance of recreational team sports athletes with moderate effect. However, Apps et al. (2022) is the only study assessing high frictional socks for COD performance and in-shoe foot displacement. While reporting performance improvement across sexes with no interaction effects, no tests on GRFα were conducted. Combined GRFα, COFu, foot sliding and performance parameters were solely investigated in gender-mixed and mixed recreational team sport athletes using higher frictional insoles (Apps et al., 2020). Therefore, this study is the first to examine the effect of athletic socks with high frictional properties on in-shoe foot sliding (COFu and GRFα), performance and speed perception, specifically during football-specific CODs in male footballers. It was hypothesised that compared to standard athletic socks, socks with high frictional properties during COD tasks would (i) lower GRFα and increase COFu, (ii) reduce in-shoe foot sliding in posterior-anterior, medio-lateral and resultant direction, and (iii) improve performance and speed perception.

Methods

Participants

Twelve recreational football-playing males (age: 20.3 ± 1.1 years, height: 1.77 ± 0.07 m, weight: 74.4 ± 12.4 kg) voluntarily participated in the study. A sample size of twelve was calculated using Gpower (v3.1.9.4, Franz Faul, Universität Kiel, Germany) with a predefined high effect size ($d = 0.8$), power = 0.8, and alpha = 0.05. Previous research had observed high effect sizes for GRFα and running times (Apps et al., 2020). All participants were right-foot dominant, participating in competitive football and with 2 × 90 min weekly training during 12 of the last 24 months, and free of any lower limb injury in the last six months. Participants provided written informed consent before testing and ethical approval was granted by the institution's Faculty of Medicine and Life Sciences research ethics committee.

Study design

The study utilised a single-group repeated measures cross-over design in which the dependent variables (biomechanical and football-specific movement measures) were measured in one session under both experimental (sock) conditions. Both sock conditions and sessions were administered in a randomised order. In biomechanics testing, six participants started with the TURN movement and six with the CUT. Within these six participants, the sock condition order was randomised in groups of three, respectively. In performance testing, six participants first performed the test in the Gripsock and six in the CompressionS. The socks comprised a standard athletic sock (CEP Compression Short Socks 3.0 Men, CompressionS, 89% polyamide, 11% spandex) and a sock with purportedly high frictional properties (CEP Griptech Short Socks Men, GripSock, 63% polyamide, 26% cotton, 11% spandex, Medi GmbH & Co KG, Bayreuth, Germany). Both socks contained high compression properties to reduce in-shoe sock movement. The Gripsock was additionally equipped with 74 rubber pads in the shape of parallelograms (length = 1cm, width = 1cm, area 1cm^2) located on the foot sole, medial- and lateral side of the foot and the heel (Figure 1). The footwear was standardised across participants with a commercially available football-specific "Puma Evoknit Indoor Men's Football Trainer" in different shoe sizes.

The static frictional properties (COFm) of both socks were measured via a wooden block covered with the sock and additionally weighted with 11 kg dragged across the insole (which was extracted from the footwear). The 11 kg on the wooden block (contact area of 30cm^2, 6 × 5 × 2 cm length, width, depth) created a pressure (force per area) approximately equivalent to the participants' mean weight generated pressure distributed on the insole area (202cm^2). Realistic weight in COFm testing ensures correct COFm material responses compared to the expected human–weight scenario of the testing (Dixon et al. 2015). The static COFm was defined as the ratio between the shear force necessary to start the movement and the normal force (Dixon et al., 2015). The peak shear force required to start dragging the block was measured with a commercially available spring gauge (Spring Scale Lightline 10 N, Pesola Präzisionswaagen AG, Switzerland) and averaged over three trials. Reliability of this COFm measurement was previously ensured by 30 test repetitions in each sock condition with results of .455 ± 002 (CompressionS) and .556±.006 (GripSock).

Figure 1. Experimental socks; GripSock (left) with frictional enhancing dots, CompressionS (right).

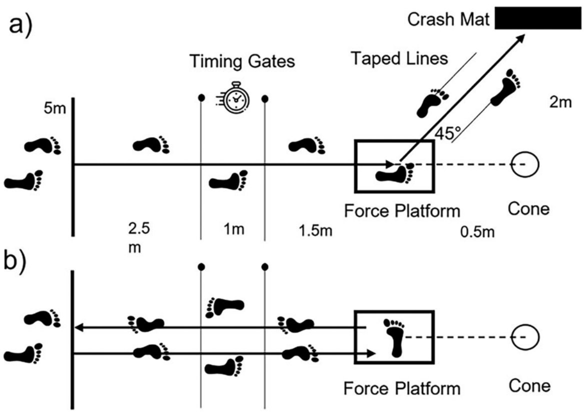

Figure 2. Biomechanical (3D motion capture) setup for (a) 45° CUT and (b) 180° TURN.

Figure 3. Lateral, medial shoe and foot marker.

Procedures

Participants attended one appointment incorporating biomechanical testing (3D motion capture) in the biomechanics laboratory and a football-specific movement test in the indoor sports hall of the University of Chester. Participants completed either a self-directed or a researcher-led 10-minute warm-up and fastened their shoelaces to their preferred tightness before testing. The position of the laces was then marked on the top shoe eyelets to ensure consistent support of the shoe upper across trials.

The 3D motion capture session recorded the participants completing five 4 × 45° sidecuts (CUT) and five 180° turns (TURN) with maximum approach speed in both sock conditions (Figure 2) on a Mondotrack WS surface (Mondo, Alba, Italy). The trials were interspersed with a one-minute passive recovery and a five-minute break to change the sock condition. Participants had three familiarisation trials before each movement task. Trials with incomplete foot placement on the force plate or noticeable targeting were rejected and repeated.

Eight Qualisys cameras from the Oqus 7+ Series with 300 Hz sampling rate, 12 MP, operated with Qualisys Track Manager (Qualisys, Gothenburg, Sweden) were positioned within an approximate distance of 3 m to the force plate. Maximum accepted camera residuals of 0.5 mm for each of all eight cameras ensured submillimetre foot sliding measurement accuracy. Ground reaction force data were obtained using a Kistler force plate (Wintherhur, Suisse, Type 9281CA) size 0.4 × 0.6 m sampling at 1200 Hz. Seven reflective spherical markers were attached to the shoe; four at the medial and lateral border of the anterior and posterior shoe (12.5 mm Ø), three on the sock (8 mm Ø), centrally in pre-cut 25 mm circular holes in the shoe upper (Figure 3). This optimal hole size (recommended by Bishop et al., 2015) ensured sufficient maintenance of initial shoe properties while preventing any marker deflection of the shoe upper during foot sliding. The football-specific movement session was conducted indoors on a Uni-Turf Embossed PVC Vinyl surface (Sports Surfaces UK Ltd, Altrincham, UK) over a 26 m long functional traction course (Sterzing et al., 2009), consisting of eleven cutting and turn movements (Figure 4).

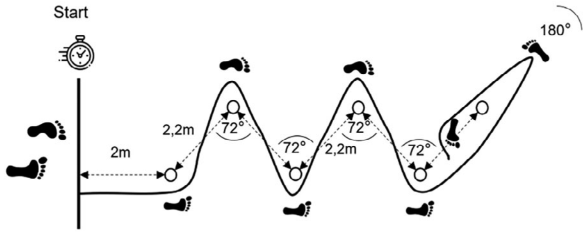

Figure 4. Football-specific movement course.

Participants had three familiarisation trials before completing the course three times with maximum effort in each sock condition, interspersed with three minutes of passive recovery breaks and one five-minute break to change sock condition. Running times to complete the course measured with a pair of timing gates (Brower Timing System LLC, Draper Utah, USA). Participants rated their perceived running speed after each run by setting a pen mark on 150 mm visual analogue scales (VAS) anchored with the terms "very slow" to "very fast" after each trial (Apps et al., 2020). Mean running times and VAS scores were used for analysis.

Data analysis

Kinetic and kinematic data were processed using Visual 3D (C-Motion, Rockville, MD, USA). GRF data determined foot-ground contact after exceeding a recommended 10 N threshold (Tirosh & Sparrow, 2003). The residual analysis identified an optimal fourth-order zero-lag Butterworth filter with a 26 Hz frequency cut-off for kinetics and a 15 Hz cut-off for kinematics (Winter, 2009). Braking and propulsion phases' average GRFα values were calculated with trigonometry from the horizontal and resultant GRF vector and during ground contact after removing the first and the two last frames to avoid artefacts by dividing by low forces (Apps et al., 2020). Running phase-specific average COFu values were computed by dividing the resultant horizontal GRF by the vertical GRF. Three successful trials were used for analysis. Exclusion criteria were shoe sliding, marker tracking interruptions during stance or incorrect cutting movement completed.

Foot sliding distance data was obtained during the foot flat period (FFP) to limit the influence of soft tissue artefacts and inter-segmental foot motion (Apps et al., 2020). The FFP was defined as the movement phase where participants have stable on-ground shoe positioning but foot movement within the shoe remains possible. It is initiated by the global minimum of the sum of the vertical position of all four shoe markers. The FFP ended with a peak in the vertical acceleration of the proximal shoe sole segment, defined by the medial and lateral rearfoot shoe markers, as in both movements the heel is lifting off first after full shoe contact with the force plate. FFP was split into a braking and propulsive phase. The braking phase was initiated with the FFP and ended with the start of the propulsion phase. The CUT propulsion phase started at the local minimum resultant GRF value after the first peak in the typical 45° CUT GRF pattern (Cong et al., 2014). The propulsion phase of the TURN started at the local minimum between the first and second peaks in the typical resultant GRF pattern.

Foot sliding distance was calculated by subtracting each foot marker's position values from the midpoint of the posterior shoe marker's position (values at the start of each phase were subtracted so that initial sliding distances were zero; Apps et al., 2020). The maximum distance across the three successful trials in each cut was averaged for each participant and extracted for analysis. Medio-lateral (ML), posterior-anterior (PA) and resultant (calculated as resultant $= \sqrt{|ML|^2 + |PA|^2}$) foot sliding distances of the foot markers were calculated. ML and PA sliding distances were computed in relation to the sole segment defined by the four shoe markers. As one participant's midfoot marker constantly fell off during testing the midfoot displacement distance calculation was restricted to 11 participants.

Statistical analysis

Descriptive (mean ± SD) statistics were calculated for all dependent variables. The normality of the sample distributions was assessed with the Shapiro-Wilk test and where satisfied, a one-tailed paired *t*-test was applied to test hypotheses (i) (with a Bonferroni adjusted alpha = .0125) and (iii). GRF and COF for the CUT braking phase violated normality, football-specific performance times contained outliers and perception data was ordinal. A one-tailed non-parametric Wilcoxon-signed-rank-test was applied to these variables and results were presented with median and mean absolute deviation (MAD) (Brace et al., 2006). Additionally, Cohen's *d* effect sizes were computed, and thresholds of 0.2 (small effect), 0.5 (medium effect) or 0.8 (large effect) were applied (Cohen, 1988). For Wilcoxon-signed-rank tests, the effect size was presented as biserial *r* with thresholds of 0.1, 0.3 and 0.5 (Cohen, 1988). For hypothesis (ii) a repeated measure multivariate ANOVA (rMANOVA) was employed to assess within-participants foot sliding differences across all three-foot markers during each task and phase between the two sock conditions. RMANOVA effect size thresholds were partial eta-squared estimates of 0.01, 0.06 and 0.14 (Cohen, 1988). Alpha was set at ≤ 0.05. All statistical analyses were conducted with SPSS Statistics Version 1.0.0.1447 (IBM Corp, Armonk, USA).

Results

The initial static frictional properties of the two socks were found to be different ($p < .001$), with the GripSocks' mean static COFm (0.56±.01) being 22% higher than that of the CompressionS (0.46±.00). Uniform approaching speed ensured comparability between GripSock and CompressionS (Table 1).

Table 1. Phase times and approaching speed.

	CUT		TURN	
	CompressionS	GripSock	CompressionS	GripSock
Ground contact (s)	0.24 (0.03)	0.25 (0.04)	0.57 (0.17)	0.57 (0.15)
Foot flat period (s)	0.14 (0.03)	0.13 (0.04)	0.46 (0.16)	0.44 (0.16)
Braking phase (s)	0.02 (0.01)	0.02 (0.01)	0.20 (0.06)	0.19 (0.07)
Propulsion phase (s)	0.12 (0.03)	0.11 (0.04)	0.27 (0.11)	0.26 (0.09)
Approaching speed (m/s)	4.0 (.55)	4.0 (.50)	3.7 (.33)	3.6 (.53)

Table 2. 45° side-Cut and 180° turn mean (SD) kinetic results with effect size (ES).

Task, phase	Condition	GRFα (°)	ES	COFu	ES
CUT, braking	GripSock	61.4 (1.6)*	0.62	0.55 (0.03)*	−0.62
	CompressionS	63.4 (2.2)*		0.51 (0.04)*	
CUT, propulsion	GripSock	59.4 (3.3)	0.23	0.60 (0.02)	−0.18
	CompressionS	59.8 (3.5)		0.59 (0.09)	
TURN, braking	GripSock	55.6 (3.3)	0.30	0.69 (0.08)	−0.33
	CompressionS	56.1 (3.1)		0.68 (0.08)	
TURN, propulsion	GripSock	56.4 (4.2)	0.58	0.68 (0.10)	−0.60
	CompressionS	57.5 (5.2)		.65 (.12)	

*Denotes significance $p < 0.05$.
Cut braking values = median and absolute median deviation and ES is represented as biserial r. Turn propulsion ES is presented as Cohen's d.

In the CUT braking phase, the GripSock reduced the GRFα ($t = 78$, $p = .001$, $r = .62$) and increased the COFu ($t = 78$, $p = .001$, $r = -.62$) with a large effect size. On the other hand, no significant differences were found for the CUT propulsion phase (Table 2). No significant GRFα reduction or COFu increase with the GripSock in either the TURN braking (GRFα: d = .30, COFu: d = −.33) or TURN propulsion phases (GRFα: d = .58, COFu: d = −.60) were evident (Table 2).

RMANOVA did not reveal any significant in-shoe foot sliding effects during the CUT or TURN in any of the three examined directions despite reporting high effect sizes in the directions ML for CUT braking ($\eta p^2 = .16$), PA for CUT propulsion ($\eta p^2 = .20$) and PA for TURN propulsion ($\eta p^2 = .24$) phases (Table 3).

The GripSock (median = 12.03 s, MAD = 0.98) did not significantly ($t = 23.5$, $p = .11$, $r = .25$) reduce the running time compared to the CompressionS (median = 12.10s, MAD = 0.82). Wearing the GripSock (median = 99.5, MAD = 5.2), however, yielded significantly ($t = 54$, $p = .03$, $r = -.38$) higher speed perception ratings than when wearing the CompressionS (median = 88.0, MAD = 11.3) with a medium effect size (Figure 5).

Discussion

This study assessed the effect of socks with high frictional properties on in-shoe foot sliding, a football-specific movement performance and an associated perception of speed. The findings allow partial acceptance of the first hypothesis in that, compared to a standard compression sock, the GripSock generated lower GRFα and higher COFu but only in the CUT braking phase. Hypotheses (ii) and (iii) were rejected as the GripSock did not reduce in-shoe foot sliding in any direction, and whilst the footballers' perceptions of

Table 3. Mean ML, PA, resultant foot displacement (SD) in mm. Negative values indicate movement opposite to the predefined direction.

Task, phase	Condition	medio-lateral			posterior-anterior			resultant		
		Rearfoot	Midfoot	Forefoot	Rearfoot	Midfoot	Forefoot	Rearfoot	Midfoot	Forefoot
CUT, braking	GripSock	-.18 (.36)	.35 (.67)	.66 (.56)	.42 (.26)	.33 (.30)	.38 (.36)	1.3 (.56)	1.0 (.49)	1.0 (.65)
	CompressionS	.07 (.67)	.31 (.58)	.41 (.29)	.48 (.28)	.42 (.41)	.57 (.45)	1.1 (.67)	.98 (.64)	.91 (.69)
	ES (η_p^2)		.16			.08			.07	
CUT, propulsion	GripSock	-1.8 (1.1)	1.9 (1.0)	2.4 (1.1)	-.73 (.79)	-.44 (.46)	-1.1 (.54)	4.4 (1.2)	2.3 (.81)	2.9 (.84)
	CompressionS	-2.0 (1.3)	2.1 (1.3)	2.8 (1.0)	-.67 (1.1)	-.43 (.61)	-1.5 (.0)	4.5 (1.2)	2.7 (.80)	3.6 (1.1)
	ES (η_p^2)		.04			.20			.11	
TURN, braking	GripSock	-.40 (1.4)	2.5 (1.4)	2.7 (1.4)	.48 (.64)	.51 (.64)	.69 (1.3)	2.3 (1.3)	3.1 (.82)	3.1 (.85)
	CompressionS	-.66 (2.0)	2.3 (1.9)	2.5 (1.3)	.55 (.92)	.53 (1.1)	.50 (1.7)	2.9 (1.3)	3.2 (1.4)	3.6 (1.5)
	ES (η_p^2)		.02			.02			.08	
TURN, propulsion	GripSock	-.58 (.40)	.50 (.68)	.89 (.50)	.00 (.21)	.08 (.33)	.01 (.37)	1.4 (.56)	1.3 (.53)	1.3 (.51)
	CompressionS	-.43 (.78)	.58 (.63)	.82 (.63)	.24 (.25)	.20 (.23)	.10 (.30)	1.5 (.52)	1.5 (1.0)	1.9 (1.5)
	ES (η_p^2)		.05			.24			.08	

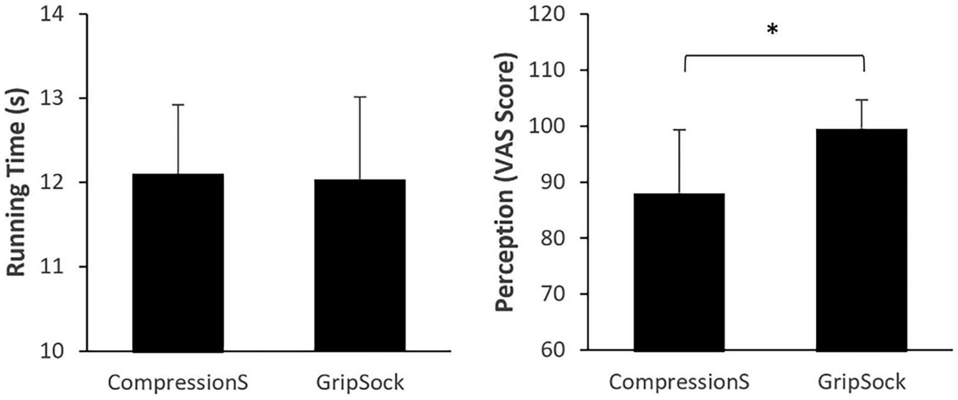

Figure 5. Performance testing running time (s) and speed perception score (150 mm visual analogue scale) presented as median with median absolute deviation bars. *denotes significant difference, $p < .05$.

speed were more favourable when wearing it, the measure of movement performance was not improved. This is the first study examining foot sliding, GRFα and COFu effects by wearing socks with high frictional properties specifically on male recreational football players, providing a basis for future investigations.

The higher CUT braking COFu values observed in the GripSock condition, which suggest more sock-insole traction, likely enabled the lower CUT braking GRFα and a more horizontally oriented GRF. Previous studies have reported this relationship in curved sprinting and linear acceleration by increasing the outsole COFm (Luo & Stefanyshyn, 2011) and in the braking and propulsion phases of 180° turn by using insoles with higher frictional properties (Apps et al., 2020). In propulsion tasks, a smaller GRFα improves both net horizontal force (Morin et al., 2011) and propulsion impulse (Kugler & Janshen, 2010). Dos'Santos et al. (2017) also suggest that a higher vertical GRF results in slower COD performances. Both the lower GRFα and higher COFu in the CUT braking phase indicate a shift of forces in the horizontal direction. However, the mean CUT braking time of 0.02 (±.01) s is very short. This is due to our definition of the braking and FFP phases based on the resultant GRF values (Cong et al., 2014) which may underestimate the whole braking period. For the CUT propulsion, TURN braking and propulsion the GripSock did not enable improvements, which is in alignment with previous non-significant findings using GripSocks in CODs (Apps et al., 2022). Stacoff et al. (1996) reported that in-shoe traction also depends on other shoe properties like shoe upper, midsole positioning, shoe cushioning or outside wrap. Indeed, when wearing modified shoes without a midsole and minimal outside wrap, increasing the sock-insole interface COFm leads to significantly improved GRFα and COFu in the TURN braking phase (Apps et al., 2020). In this study's phases with no significant results, the shoe properties likely added sufficient traction to the foot, leading to COFu values higher than the COFm. However, in the only phase with COFu < COFm, the CUT braking, the GripSock improved the GRFα. This indicates that a sock with higher frictional properties could increase the foot's traction as long as COFu < COFm, additionally leading to beneficial adaptions in the GRFα. In phases where COFm > COFu this effect is reversed and no benefits can be gained by using the GripSock.

As a result of increased COFm, wearing a higher friction insole inside modified shoes also reduces resultant in-shoe foot displacement (Apps et al., 2020). However, Apps et al. (2020) reported large mean resultant foot sliding values (up to 18.4 mm) and displacement differences up to 6.0 mm. Studies using commercially available shoes and changing in-shoe COFm by wearing socks with higher traction properties report less in-shoe foot displacement. For example, male team sport athletes in Apps et al. (2022) slid up to 12.2 mm with a maximum difference of 2.8 mm. In the current study, our recreational footballers' highest displacement is 4.5 mm with a maximum delta between sock conditions of 0.7 mm. Apps et al. (2022) probably reported larger foot sliding values because they calculated foot displacements including the initial and final shoe touchdown where the foot was not flat on the ground. Likely a lot of in-shoe displacement occurs in these phases. Additionally, lower displacement values could be explained by foot markers being attached to the sock instead of directly on the foot after cutting holes in the sock. It is indicated that the sock and foot move differently within CODs with both the CompressionS and GripSock moving less than the foot itself. Whilst some research has reported increasing shoe-surface COFm enhances performance in sprinting and linear acceleration (Worobets & Wannop, 2015; Luo & Stefanyshy, 2011) and CODs, there was no significant improvement with the GripSock in the current study. Mean performance times (12.03±.98 s and 12.10±.82 s) in the functional traction course were similar to that reported by Müller et al. (2010) for amateur to sub-elite footballers (9.324 s to 12.590 s), faster than males in Apps et al. (2022) (12.57±.89 s and 12.89±.99 s) and much faster than a group of 6 male and 5 female athletes in Apps et al. (2020) (15.5 ± 1.0 s and 16.3 ± 1.3 s), all of them using the same running course. Contrarily, Apps et al. (2020) reported their higher frictional insole condition significantly improved performance when wearing their specially designed shoe. By removing certain shoe properties this modified shoe allowed more in-shoe foot sliding which the higher frictional insole then was able to significantly reduce, compared to a standard insole, while running times were still much slower than comparable studies in the literature. In effect, the general shoe properties are arguably more important to performance and in-shoe traction than sock-insole frictional properties alone. When wearing commercially available shoes, Apps et al. (2022) observed better running performance while also reporting a significant beneficial performance effect of wearing socks with higher frictional properties, in contrast to the current findings. One explanation could be the variety of shoe properties in the different commercially available shoes used in both studies. Additionally, performance times suggest that recreational footballers examined in this study could be more familiar with COD tasks than the general team sport athletes in Apps et al. (2022), enabling them to perform closer to their maximum COD performance, but that more in-shoe traction did not cause significant further performance improvement.

Although performance did not improve wearing the GripSock in the current study, the footballers did perceive higher performance speeds. Movement perception is based on visual, tactile and proprioceptive senses (Proske & Gandevia, 2012) and athletes' universal movement patterns are constantly updated by proprioceptive and visual feedback and they can adapt to given circumstances (Tuthill & Azim, 2018). In our case, footballers were able to visually identify the GripSock during testing, and, moreover, during the familiarisation, they might have been able to sense differences in traction between sock conditions via proprioception. Both may lead to movement pattern adaptations, enabling them to approach the movements that differ between conditions, yielding improved traction (COFu and GRFa) and a perception of higher running speed that was not matched by actual overall performance.

It is acknowledged that the sensitivity of the 3D method with camera residuals <0.5 mm to analyse in-shoe foot displacement should be considered carefully when absolute displacements are very low (<1mm) and likely include higher partitions of noise. These minimal sliding values could result from markers being placed on the sock instead of the foot. Apps et al. (2022) reported higher displacements with measurements directly on the foot. While cutting holes in the socks possibly influenced sock properties, their results likely reflected differences between the in-shoe foot and sock movement. Future research should examine this in-shoe foot and sock sliding interaction. Additionally, owing to the observed low displacement values and performance differences, future studies should aim to recruit larger, more heterogenous samples in order to examine the stated hypotheses more thoroughly. Indeed, as only the lateral side of the forefoot was tracked in the current study to calculate in-shoe sliding, there is scope to further investigate complete in-shoe foot movement. By exclusively analysing foot sliding during the FFP, the effects of the initial ground contact are neglected. Moreover, some measurement error is likely as the soft-tissue artefacts and spread of the foot metatarsals on landing are not accounted for.

In conclusion, this study has demonstrated that a sock with higher frictional properties than a regular athletic sock improved some traction parameters (COFu and GRFα) during the braking phase of a CUT movement. These biomechanical adaptations were possibly reflected in the footballers' traction perceptions as they perceived higher running speeds when wearing the sock with higher frictional properties. However, contrary to recent research no movement performance improvement was observed as a consequence. It appears that the relationship between in-shoe traction and running performance is likely to be more complex and dependent on the overall interaction of shoe properties such as insole, sock, shoe upper, midsole positioning, shoe cushioning and outside wrap. Moreover, the level of movement skill and adaptation to sock-shoe frictional properties could play a role in any performance benefits offered by the socks. Further investigation is required to understand better in-shoe foot behaviour and its impact on sport-specific movements in different sports and skill levels.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, GS, upon reasonable request.

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