# Footwear insoles with higher frictional properties enhance performance by reducing in-shoe sliding during rapid changes of direction

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## Insole friction reduces in-shoe foot sliding enhancing cutting performance

Keywords: footwear, friction, performance, cutting

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# Footwear insoles with higher frictional properties reduce in-shoe sliding and enhance change of direction performance

## Abstract

A novel 3D motion capture analysis assessed the efficacy of insoles in maintaining the foot position on the midsole platform inside the shoe during rapid change of direction manoeuvres used in teams sports. An insole (TI) with increased static (35%) and dynamic (49%) coefficient of friction compared to a regular insole (SI) were tested. Change of direction performance was faster ($p < .001$) and perceived to be faster ($p < .001$) in TI compared to SI. Participants utilised greater coefficient of friction in TI compared to SI during a complete turn, but not during a 20 degree side-cut. In-shoe foot sliding reduced across the forefoot and midfoot during the braking phase of the turn and in the rearfoot during the side-cut in TI. Greater in-shoe foot sliding occurred in the turn than the side-cut across all foot regions. Results provide guidance for athletic footwear design to help limit in-shoe foot sliding and improve change of direction performance.

Keywords: footwear, friction, performance, cutting

## Introduction

Changing direction rapidly is advantageous for team sports players because it enables them to out manoeuvre their opponents and have time to make a pass or a shot that can influence the outcome of the game. Whole body changes of direction are among the most frequent movements in team sports, but different sports necessitate varied severity of cutting angles. Bloomfield and colleagues (2007) assessed the physical demands of elite soccer players during a match. Results showed players completed 727 ± 203 turns per match. The majority (609 ± 193) were rapid directional changes less than 90º, often after sprinting and followed by further high intensity running. In contrast, it was reported the most frequent change of direction angle among competitive netball players was 135º and that 180º turns are performed during every minute of match play (Darnell, 2008).

The foot experiences large horizontal shear forces during cutting movements (McClay et al., 1994), placing considerable demands on footwear traction to provide a stable base of support to maximise performance. By counteracting these shear forces, the frictional properties of sports shoes prevent sliding reducing the time needed to change direction. Additionally, the player can increase the horizontal angle of the ground reaction force, which increases acceleration in the desired direction of motion. This has been observed in linear acceleration on a treadmill (Morin, Edouard, & Samozino., 2011), as well as, linear acceleration overground and curved sprinting (Luo & Stefanyshyn, 2011). Thus, the player's change of direction performance is faster. Yet, too much friction may also increase the risk of injuring the ankle and knee ligaments by the foot being fixated (Torg, Quedenfeld, & Landau, 1974) or obtaining blisters (Knapik, Reynolds, & Barson, 1998; Mailler-Savage & Adams 2006). On the other hand, reduced friction increases the chance of obtaining an injury through slipping. Regardless of the optimal amount of friction, sports players can perceive differences in the level of grip provided by athletic footwear and surfaces, which triggers adaptations to improve their performance (Morio, Bourrelly, Sissler, & Gueguen, 2017; Starbuck et al., 2016). Additionally, traction and/or stability have been rated amongst the most important footwear properties in football players (Hennig & Sterzing, 2010) and basketball players (Brauner, Zwinzscher, & Sterzing, 2012).

The coefficient of friction (COF), the ratio of the shear forces to the vertical force, has distinguished athletic footwear or surfaces with different mechanical friction properties during change of direction tasks. On hard surfaces, participants utilise increased COF when performing frontal cutting steps, curved sprints, or accelerations in footwear outsoles that have increased mechanical COF (Luo & Stefanyshyn, 2011; Morio et al., 2017). However, once the mechanically available COF increases beyond a threshold level, no further gains in performance are observed (Luo & Stefanyshyn, 2011). This is attributed to participants reaching their physiological limit in the magnitude of shear forces they can apply. The optimal friction for a given athlete is a complex interaction of the goals of the movement, mechanical friction, subjective perception. No one single metric is able to capture it all, therefore a variety of testing procedures is required to obtain a comprehensive overview of effects (Sterzing, Lam, & Cheung, 2012). For example, Müller and colleagues (2010) found a soft ground soccer boot with higher mechanical friction on artificial turf reduced in-vivo COF during a 180$^{o}$ cut and resulted in slower times compared to three other soccer boots with less mechanical friction. This was attributed to the longer soft ground studs not penetrating the artificial turf and fewer being in contact with the ground during push-off.

Previous research has primarily focused on the effect of friction at the shoe-surface interface rather than the foot-shoe interface.  However in order to improve performance during cutting, the footwear must maintain the foot position on top of the midsole/cleat plate platform (Lafortune, 1997).  Footwear components, including upper materials, sidewall wraps, midsole geometries, midsole materials and insoles have been designed to resist the internal shear forces between the foot-shoe interfaces. Stacoff and colleagues (1996) investigated in-shoe heel rotation during side-cuts of five shoes with varied midsole thickness, torsional stiffness and construction features. Holes were cut into the heel-counter to monitor foot motion relative to the shoe. Specific designs or materials reduced in-shoe heel sliding better than others. Rotational in-shoe sliding was linked with ankle injury risk but monitoring the translational sliding will likely effect performance of change of direction tasks. Quantifying in-shoe shear is another option to assess the influence of in-shoe footwear friction, but it is difficult to avoid artefacts of placing shear sensors inside the midsole of the shoe. Cong and colleagues (2014) assessed in-shoe plantar shear by mounting tri-axial force transducers into the midsole of a basketball shoe. Both the 180º lateral shuffle and 45º cut produced greatest shear pressures under the first metatarsal head, but peak stresses occurred during the braking and propulsive phases, respectively.

While the effects of midsole modifications, upper material choices, and torsional stiffness have been evaluated in maintaining the foot over the sole platform, the frictional properties of the insoles has not. Therefore, the aim of this study is to investigate if insoles with higher mechanical friction enhance actual and perceived change of direction performance by increasing the COF and reducing in-shoe foot sliding. It was hypothesised that during changes of direction increased insole friction would:

1. Increase the performance time and perception of speed
2. Increase the COF and horizontal angle of the ground reaction force
3. Better maintain the foot position on the midsole platform by reducing in-shoe foot sliding across the insole surface

## Materials and Methods

### *Insoles and footwear*

Two insole conditions were tested. The standard insole (SI) was made of EVA (35 Asker C) with cloth based top cover (SI). The developed training insole (TI) was also made of EVA (35 Asker C) and had the same thickness and geometry as SI, except they had a knobby surface and no top cloth cover (Figure 1). To confirm TI did provide increased friction compared to SI, which was a pre-requisite for the study, the COF was measured mechanically using a modified version of the ASTM D1894 test. A 3.2 Kg sled covered with a standard athletic sock was dragged 55 mm over the insole surfaces at a speed of 500 mm/min (Instron E3000, Norwood, MA, US). The resistance to movement was recorded and the peak force, static coefficient of friction and average dynamic coefficient of friction were calculated.

To maximize the influence of insole friction on maintaining the foot position, during testing protocols participants were fitted with flexible shoes that were developed without a midsole and minimal outsole wrap (Figure 1). To ensure support provided by the upper was constant across trials, laces were fastened consistently to participants preferred tightness by marking the lace through the top eyelet.

**Figure 1 near here**

### *Participants*

Seventeen recreational team sports players (11 ♂, 6 ♀ with a mean age of 25 (SD 4), mean height of 175 cm (SD 5) and mean weight of 72 kg (SD 10)) volunteered to participate in this study. All participants had regularly played sport for at least 2 years and were right foot dominant (preferred kicking leg). Participants reported they had not suffered any serious musculoskeletal injury for at least 6 months at the time of testing. Ethical approval for this project was attained from the University research ethics committee and participants gave their written informed consent prior to testing.

There were two separate testing protocols: one to obtain biomechanical measurements, the other for agility performance and subjective perception measurements. A few participants were not available to complete both protocols and so exact participant numbers are given in the following sections.

### *Biomechanics*

Fifteen participants (11 ♂, 4 ♀) completed 5 successful side-cuts (20º) and 5 complete turns (180º) in each insole condition (see figure 2). This enabled the biomechanical effects of TI to be investigated in a slight change of direction at a rapid pace and severe change of direction task, applicable to the varied frequencies in different sports (Bloomfield et al., 2007; Darnell, 2008). Prior to testing participants completed a 10 minute warm-up that included a familiarisation to the tasks. Trials were successful when participants performed the change of direction step with their dominant foot on the force platform and there was no noticeable targeting. The 20º side-cuts required participants to run within 90 ± 5% of their maximum speed. Pilot work indicated running at maximum pace in the test footwear conditions may put participants at risk of slipping in this task. To ensure the correct side-cut angle was performed, a pair of cones were placed at 20º a metre behind the left side the centre of the force plate in the running direction. Participants accelerated maximally to complete the 180º turns, but decelerated in order to successfully change direction, thus pace was slower than the side-cut task. The order of task and insole conditions was mixed between participants. There was a 2-minute rest in between trials to avoid fatigue.

**Figure 2 near here**

Ground reaction forces were collected during the change of direction steps by a force plate (0.6 m by 0.9 m, Kistler, Winterhur, Switzerland), sampling at 1500 Hz. Data were filtered with a fourth order zero-lag Butterworth filter with a 50 Hz frequency cut-off. A 10 N threshold of the vertical ground reaction force component determined initial ground contact and toe-off events to determine ground contact time.

Six Oqus cameras (Qualisys, Gothenburg, Sweden), sampling at 500 Hz, were positioned within 2 m of the force plate in order to record close-up foot and shoe kinematics. Additionally, an extra small calibration wand (110 mm in length) ensured the maximum camera residuals did not exceed 0.3 mm. This allowed sub-millimetre accuracy in terms of relative displacement between markers placed on the shoe and foot. Four reflective spherical markers (5 mm Ø) were attached onto the anterior and posterior lateral border, and anterior and posterior medial border of the shoe sole. Additionally, markers were attached directly onto the foot at the rearfoot, midfoot and forefoot from circular holes cut into the lateral side of the right shoe upper and socks (Figure 1). The rearfoot, midfoot and forefoot marker regions were defined by dividing the shoe upper into equal thirds and holes were cut on the lateral side in the middle of each region. This assessed foot sliding at different regions because reported shear stress levels vary across the foot during cutting tasks (Cong et al., 2014). Hole diameters were 25 mm to prevents the foot marker motion being deflected by the shoe upper (Bishop, Polman, R, & O'Donoghue, 2015). Participants were provided with a pair of low-cut standard athletic socks (94% Polyester, 4% Spandex, 2% other fibers) to wear during testing.

Biomechanical data was analysed in Visual 3D software (C-Motion, Rockville, MD, USA). Raw co-ordinate data was filtered with a fourth order bi-directional Butterworth filter with 20 Hz frequency cut-off. To limit the influence of soft tissue artefact and inter-segmental foot motion, foot sliding was investigated during the shoe-flat period. Observation from high-speed video footage from preliminary testing displayed the foot bulging onto the lateral wall of the shoe indicating sliding predominated during this period. This phase was manually identified using the minimum vertical position averaged across shoe sole markers to identify when the shoe was flat on the ground. The shoe-flat period ended when there was a peak in the vertical acceleration of the shoe-sole segment. Across all trials, sole-flat time (Mean contact time % (SD)) occurred at 15.5 (4.5) and 14.7 (4.0) in the side cut, and 9.9 (5.5) and 10.6 (5.4) for the turn, in SI and TI respectively. Sole-off time (Mean contact time % (SD)) occurred at 66.5 (6.5) and 64.4 (6.2) in the side cut, and 85.6 (9.2) and 83.7 (4.9) in the turn, in SI and TI respectively. In-shoe foot sliding was calculated by computing the distance between each individual foot marker to midpoint of the posterior-lateral and posterior-medial shoe sole markers. The value at the frame when the sole flat period started was subtracted from this signal so the initial value was zero. The resultant horizontal displacement of each foot marker to the sole segment was computed to monitor foot sliding.

Maximum resultant horizontal displacement of the rearfoot, midfoot and forefoot markers relative to the shoe sole (foot-sliding) were extracted for analysis during the braking and propulsive phase, defined by the first and second 50% of the foot-flat period. This was to determine when the insoles were influencing performance. Kinetic variables included the average COF and average angle of the resultant ground reaction force vector to the horizontal during the first and second 50% of stance, to correspond to the braking and propulsive phase. These were computed between one frame after initial ground contact and two frames before toe-off to remove artefacts caused by dividing by low forces.

### *Performance and subjective perception*

Eleven participants (6 ♂, 5 ♀) completed a slalom course to evaluate agility performance. The 26 m slalom course design has previously differentiated traction properties of various cleated soccer footwear and surfaces (Sterzing et al., 2009). Three maximal effort trials in each insole condition were recorded. After every trial, there was a mandatory 3-minute rest period to avoid fatigue, during which the insole condition was swapped by the investigator. The insole order was mixed between participants. Prior to testing, except for those who completed the agility testing directly after the biomechanical protocol, participants underwent a 10-minute dynamic warm-up. All participants completed 2-submaximal familiarisation trials in their own footwear and a further submaximal followed by maximal trial in each insole condition.

To evaluate performance, running time was monitored by a single pair of timing gates positioned at the start and end of the course (Brower Timing Systems, Draper, UT, USA). The mean time of the three maximal trials were computed for statistical analysis. To evaluate subjective perception of running speed and in-shoe grip, 150 mm visual analogue scales (VAS) were marked after each maximal trial. The VAS was anchored with the terms ‘very slow’ to ‘very fast’ and ‘very low to very high’ for running speed and in-shoe grip respectively (adapted from Starbuck et al., 2016). Subjective perception of footwear comfort was also assessed using a 150mm VAS after a further two trials at a self-selected submaximal pace, in each insole, after completing the maximum trials. The VAS was anchored with the terms ‘very uncomfortable’ to ‘very comfortable’. The VAS ratings were selected because they are reliable for assessing footwear comfort (Mills, Blanch, & Vicenzino, 2010) and in order to maintain consistency across variables.

### ***Statistics***

For each participant, parameter mean values were computed across trials in each insole for statistical analysis (SPSS v24, SPSS Inc., Chicago, IL, USA). All data were visually checked with box-plots and histograms to identify deviations from normality and detect outliers. To test hypothesis (1) and hypothesis (2) slalom performance times and subjective perception, and average COF values and the horizontal angle of the ground reaction force were compared statistically by paired t-tests, respectively ($p<.05$). In-shoe foot sliding variables contained outliers. A $\log_{10}$ transformation was applied to this data allowing assumptions of normality to be met. To test hypothesis (3), repeated measures multivariate analysis of variance (rMANOVA) tests were applied to determine foot-sliding differences between the insole conditions (SI, TI) across the rearfoot, midfoot and forefoot regions (the dependant variables) on the log transformed data. Separate tests were applied to the side-cut and turn tasks in both the braking and propulsive phase. Prior to the rMANOVA tests, dependant variables were checked for multicollinearity. All correlation coefficients were not highly correlated (<0.9) which ensured data met the required assumptions of the rMANOVA (Brace, Snelgar, & Kemp 2012). Univariate follow-up tests were performed on significant results to determine which foot regions differed between insole conditions ($p<.05$). Effect sizes were computed using Cohen's d. A small, medium and large effect were defined by $d < 0.5$, $0.5> d < 0.8$, $d > 0.8$ respectively (Field, 2015). Due to the accuracy of the motion analysis system being limited by the camera residuals (0.3 mm), only displacement differences greater than 0.5 mm will be interpreted if the result is statistically significant.

## Results

### *Mechanical testing*

Results revealed TI increased the force needed to begin moving the sled by 35 % (19.34N vs. 14.31N), also resulting in an increased static coefficient of friction by 35% (0.62 vs. 0.45). Additionally, the TI was found to have a 49% increase in the dynamic coefficient of friction (0.56 vs 0.38).

### *Biomechanical measurements*

*Side-Cut:*

In the side-cut, there were no differences in the average COF values during the braking or propulsive phase between SI compared to TI ($p = .49$, $d = .19$; Figure 3a). There were also no differences in the ground reaction force angle during the braking phase ($p = .40$, $d =.23$) or the propulsive phase ($p = .16$, $d =.38$). Neither was there a difference between contact times, although the p-value was close to being significant due to TI reducing contact time by 4 ms on average across participants compared to SI ($p = .06$, $d =.53$) (Table 1). The rMANOVA revealed a significant foot-sliding difference during the braking phase ($F_{(3,12)} = 3.77$; $p = .041$; $\eta^2 = .49$). Univariate follow results indicated reduced sliding in the TI compared to SI at the rearfoot, but no difference at the midfoot or forefoot (Table 2). No differences were observed in the propulsive phase ($F_{(3,12)} = 1.68$; $p = .244$; $\eta^2 = .296$).

**Table 1 near here**

**Figure 3 near here**

*Turn:*

In the complete turn, there was an increased average COF in TI compared to SI during the braking phase ($p < .01$, $d = 1.1$) and propulsive phase ($p < .01$, $d = 1.0$). Larger resultant horizontal forces across most of the contact time in TI were responsible for this (Figure 3b). The ground reaction force angle was more horizontally orientated in TI compared to SI in the braking phase ($p < .01$, $d =1.2$) and the propulsive phase ($p < .01$, $d =.1.0$). No significant differences occurred between contact times ($p = .10$, $d =.45$), although SI did have a longer contact time by 30 ms on average across participants

(Table 1). In-shoe foot sliding results showed a significant difference during the braking phase ($F_{(3,12)}$ = 5.48; p = .013; η2 = .578). Univariate follow results indicated reduced sliding in the TI compared to SI at the forefoot and midfoot, but no difference at the rearfoot (Table 2). The was no significant foot sliding effect in the propulsive phase ($F_{(3,12)}$ = 0.31; p = .817; η2 = .072).

**Table 2 near here**

### *Performance and subjective perception*

All participants completed the slalom course faster ($p<.001$, d = 1.8) in TI (Mean (SD):15.5 (1.0) seconds) compared to SI (Mean (SD): 16.3 (1.3) seconds). Unanimously, speed was perceived to be faster ($p < .001$, d = 2.0) and in-shoe grip greater ($p < .01$, d = 4.5) in TI compared to SI (Figure 4). No differences in footwear comfort were perceived (p = .94, d = 0.02) (Figure 4). Seven participants perceived TI more comfortable and four participants SI.

**Figure 4 near here**

## Discussion

This study investigated whether an insole with increased mechanical friction enhanced perceived and actual performance during rapid changes of direction, applicable to team sports manoeuvres. To assess the biomechanical mechanism of any performance enhancements, the COF and in-shoe foot sliding were measured. Findings confirmed our first hypothesis; performance time did improve in TI compared to SI in a slalom course, with multiple changes of direction, and that participants perceived this (Figure 4). Alike stiffer uppers and construction support features (Stacoff et al., 1996), one mechanism which TI enhanced performance during the 180º turn and side-cut (Figure 2) was by reducing the in-shoe foot sliding during the braking phase. This supports our third hypothesis. Interestingly, foot sliding in different foot regions was dependant on the change of direction manoeuvre. The largest in-shoe sliding reductions were observed at the forefoot and midfoot during the turn, which had increased shear forces. Observational analysis revealed greater in-shoe sliding during the turn compared to the side-cut across foot regions during braking, with TI having a greater influence opposed to foot region (Figure 5). This suggests frictional properties of footwear insoles can provide greater performance gains during severe changes of direction. During the side-cut, which was less well represented by movement directions in the slalom course, TI reduced in-shoe sliding of the rearfoot compared to SI. Notably in the side-cut, the rearfoot had greater in-shoe foot sliding than the midfoot and forefoot during breaking and propulsion (Figure 5). This indicates additional support from the heel counter or midsole wrap may be required to prevent rearfoot sliding and improve performance during slight changes of direction. Thus, these results provide guidance for athletic footwear design features to help limit in-shoe foot sliding and improve change of direction performance.

**Figure 5 near here**

The true applications of our study are restricted because the testing shoe had reduced shoe support features to isolate the effect of the insoles. Future investigations of

TI in a regular shoe would benefit by recording in-shoe shear forces, as well as, in-shoe foot sliding. This would allow the relative in-shoe foot sliding and the insole frictional resistance to be recorded, thus removing the influence of biomechanical adaptations. Lafortune (1999) assessed this by attaching piezoceramic pressure sensors to inside the wall of the postero-lateral heel upper to measure support inside the shoe, avoiding issues of placing shear sensors inside the midsole. Findings revealed additional upper support constructions reduced the ratio of the peak heel wall pressure relative to its angular displacement during lateral cutting tasks.

Similar to research on shoe outsoles, an insole with greater mechanical friction enabled sports players to increase their utilised COF during the turn in the braking and propulsive phase. Utilised COF values were similar between insole conditions in the side-cut, so our second hypothesis is not supported for this change of direction manoeuvre. Although speed was increased in the side-cut compared to the turn, participants were instructed and enforced to perform at 90% of their maximal so there was no need to increase COF to change direction faster. We opted to analyse average COF values during the braking and propulsive phase to align with the foot sliding variables and indicate which phase of changing direction insole friction can benefit performance. This helps limit the effect of increased peak COF values at the end of stance due to low forces (see Figure 3c). Most previous studies report only the peak COF but it often occurs at the end of stance, when the ground reaction forces were low and the contribution to performance enhancement would be marginal (Luo & Stefanyshyn., 2011). Future studies investigating performance enhancement from footwear friction can avoid this limitation by only analysing COF values during phases of movement where the ground reaction benefits the sportsperson.

Participants perceived that they were able to complete the slalom course faster and had increased in-shoe grip in TI. It is only through detecting this change that players can actively respond and alter their technique to improve their performance (Morio et al., 2017; Starbuck et al., 2016). Although there was no difference in subjective footwear comfort.  This is an early indication that the increased friction forces (and increased internal tissue shear stresses) of TI are not likely to be a high risk in terms of soft tissue injuries. Dai, Li, Zhang and Cheung (2006) suggested socks may be more effective in reducing plantar shear forces than insoles. Moreover, military recruits perceived socks made of blended materials with reduced frictional properties to be more comfortable compared to a polypropylene sock (Bogerd, Niedermann, Brühwiler, & Rossi, 2012). Therefore, this may be more of an issue for newly developed sports sock products with rubber grip nodules (for example, Lux football socks and Rhino Gadget grip football socks) than the developed TI. However, in this study the insoles were only worn during the biomechanical and performance tests. Potentially, after longer wear this risk could increase due to increased foot sweating because moist skin actually results in higher frictional forces than dry skin (Knapik et al., 1998).

This study is subject to limitations, which should be considered when interpreting findings and planning future research in this area. Firstly, it was not possible to discern the displacement of the foot markers relative to the shoe sole due to either translational displacement of the foot sliding or soft tissue movement. However, we do not believe this confounds the result that foot-sliding displacement was partly responsible for the mechanism for the change of direction performance enhancement observed in the TI. The displacement between the foot-shoe was computed when the foot was flat on the ground, avoiding the impact at ground contact when soft tissue artefact is considered greatest in dynamic cutting movements (Miranda et al., 2013). In addition, recent evidence from biplanar videoradiography suggests soft tissue artefact is smaller in the foot compared to the shank (Kessler et al., 2019) and the same movements and footwear were used, so any minimal soft tissue movement will be equivalent across insole conditions. Secondly, we assumed multi-segment foot motion to be negligible during foot flat period, but it could also have contributed to the observed foot sliding results. Subtalar inversion-eversion range of motion is reduced during a change of direction step compared to walking (Jenkyn, Shultz, Giffin, Birmingham, 2010). However, it is unknown to what extent joint rotations are obscuring the relative translational foot-shoe motion. Lastly, only the translational friction resistance offered by insoles was measured, not the rotational resistance as this has not been linked with performance improvement. Rotational stiffness might be effected by the shoe upper materials (Villwock, Meyer, Powell, Fouty, & Haut, 2009), and shoe-surface interactions are complex (Shorten, Hudson, & Himmelsbach, 2003). The role of rotational friction in maintaining the foot on the midsole platform is unknown, and warrants investigation because of its association with traumatic injuries, such as anterior cruciate ligament tears (Livesay, Reda, Nauman, 2006). Joint loading, inferred from joint moments, increased in footwear with increased outsole traction during 45 degree maximal cuts (Wannop, Worobets, & Stefanyshyn, 2010) and a sub-maximal aerobic gym movement (Morio & Herbaut, 2018). Understanding these relationships will help optimise frictional properties of footwear designs to enhance performance and reduce injury risk during dynamic changes of direction. Thus, future research should assess the effect of in-shoe friction when the mechanical friction at the shoe-surface interface also varies.

## ***Conclusion***

A novel 3D motion analysis method recorded substantial relative motion between the foot-shoe interfaces during dynamic turns. An insole with increased mechanical friction enhanced actual and perceived change of direction performance compared to a regular insole. One mechanism for performance enhancement during severe changes of direction is by reducing the in-shoe foot sliding. Other footwear components may limit in-shoe foot sliding during slight changes of direction. This study highlights the importance of maintaining the foot position upon the midsole platform for performance gains in team sports. Future work should combine different footwear constructions and measurement techniques to assess the role of foot-shoe friction in enhancing performance and risk of plantar stress injuries.

## Declarations of interest

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Table 1. Mean (SD) kinetic results and contact times across participants.

| | Average COF braking | | Average COF propulsive | | GRF angle braking (º) | | GRF angle propulsion (º) | | Contact Time (s) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SI | TI | SI | TI | SI | TI | SI | TI | SI | TI |
| Side-cut | .22 (.10) | .21 (.10) | .44 (.10) | 0.45 (.09) | 78.3 (5.3) | 78.5 (5.2) | 67.9 (4.8) | 67.3 (4.4) | .17 (.02) | .17 (.01) |
| Turn | *.58 (.06) | .63 (.05) | *.57 (.06) | .61 (.06) | *60.2 (2.8) | 58.2 (1.9) | *60.7 (2.7) | 58.7 (2.4) | 0.54 (.10) | 0.51 (.08) |

COF = coefficient of friction. GRF angle = mean ground reaction force relative to the horizontal. *Significant difference between insoles (p<.05).

Table 2. Mean (SD) foot-sliding results in millimetres across participants.

| Task, phase | Foot region | Insole | | Effect Size | Significance |
|---|---|---|---|---|---|
| | | SI | TI | | |
| *Side-cut, braking | Rearfoot | 5.5 (2.1) | 6.6 (2.0) | .65 | TI<SI p = .024 |
| | Midfoot | 2.7 (0.9) | 3.1 (1.6) | .17 | p = .529 |
| | Forefoot | 4.1 (2.1) | 3.7 (2.1) | .29 | p = .285 |
| Side-cut, propulsive | Rearfoot | 6.2 (5.7) | 5.2 (2.8) | | |
| | Midfoot | 2.4 (2.1) | 1.9 (1.6) | --- | --- |
| | Forefoot | 5.4 (7.6) | 2.9 (2.0) | | |
| *Turn, braking | Rearfoot | 14.5 (9.7) | 13.4 (7.6) | .20 | p = .446 |
| | Midfoot | 15.5 (5.8) | 12.3 (5.5) | .93 | TI<SI p = .003 |
| | Forefoot | 18.4 (8.6) | 12.4 (5.2) | 1.07 | TI<SI p = .001 |
| Turn, propulsive | Rearfoot | 4.4 (3.0) | 5.4 (4.0) | | |
| | Midfoot | 3.5 (2.4) | 4.1 (2.8) | --- | --- |
| | Forefoot | 4.0 (4.0) | 3.5 (2.3) | | |

*Denotes significant rMANOVA result (p<.05)

**Figure 1.** Insole conditions (left) and the flexible footwear (right) with reflective markers attached to the shoe sole and also three markers were placed onto the foot through holes made in the shoe.

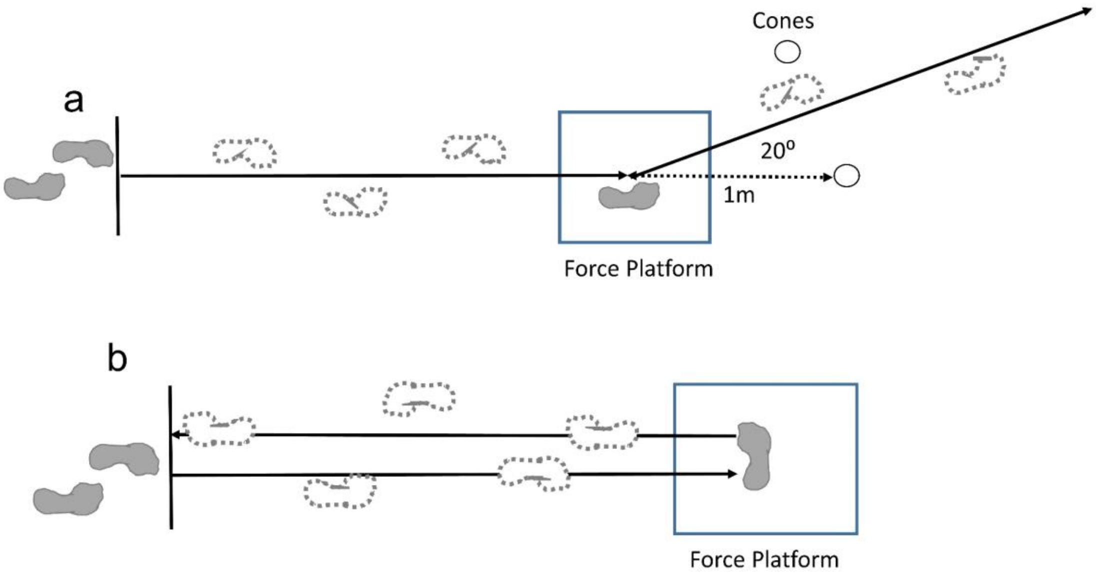

**Figure 2.** Biomechanical testing set-up. For the side-cut (a) participants completed a slight (20°) cut, which enabled approach speed to be maintained. For the turn (b), participants decelerated prior to changing direction 180°.

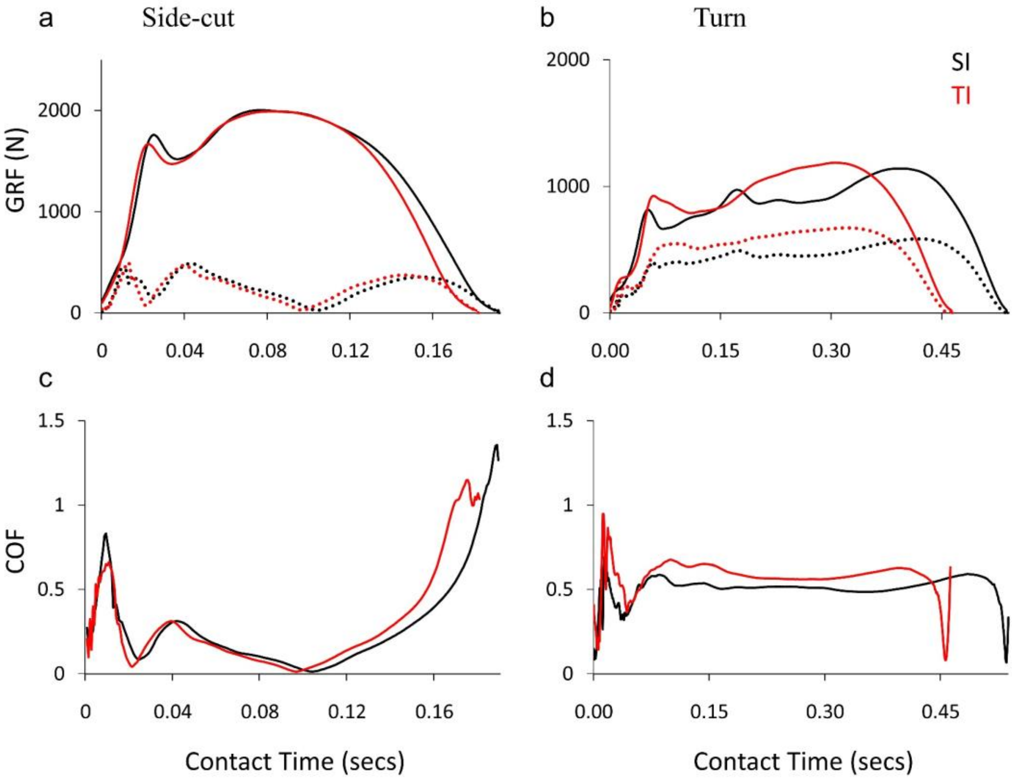

**Figure 3.** A vertical ground reaction force (solid line) and resultant horizontal (dashed line) forces during a side-cut (a) and a turn (b) of a typical participant during an example trial. The coefficient of friction for the side-cut (c) and turn (d) correspond to the same trial. The SI (black) and TI (grey) trial are displayed.

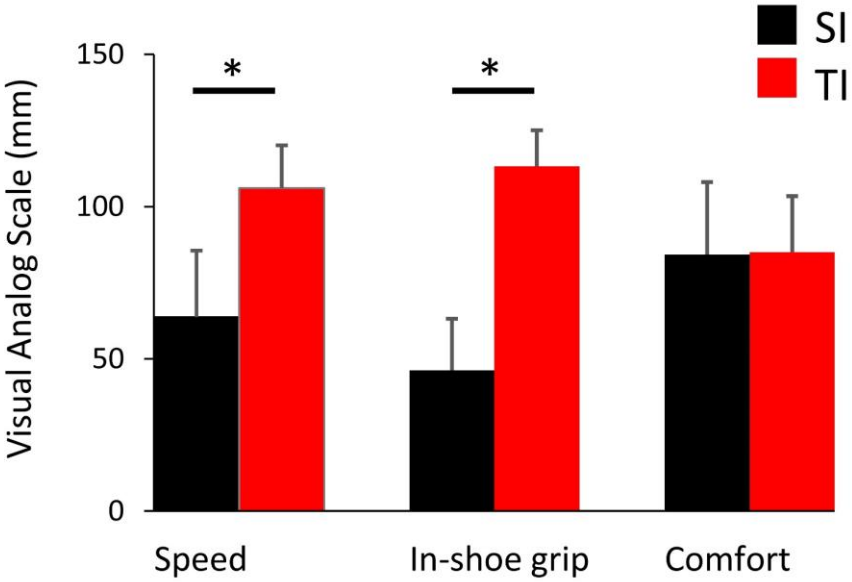

**Figure 4.** Mean (SD) subjective perception scores across participants. *Denotes a significant difference between insole conditions.

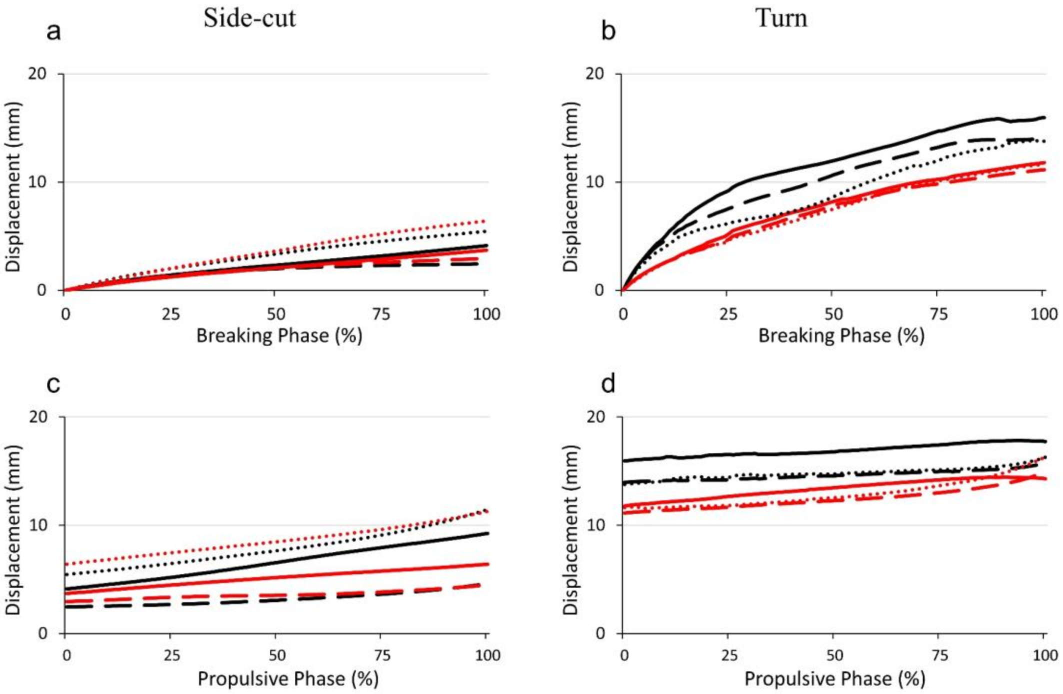

**Figure 5.** In-shoe foot sliding averaged across participants for SI (black) and TI (grey). The solid, dashed and dotted lines respectively display the forefoot, midsole and rearfoot regions. In the side-cut in the braking phase (a) and the propulsive phase (c), the foot region had the main effect. During the turn in the braking phase (b), TI had a larger effect, but not in the propulsive phase (d).