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Medio Lateral and Lateral Edge Friction in Indoor Sports Shoes

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It has previously been speculated that the occurrence and severity of lateral ankle sprain injuries is linked to excessive shoe-surface friction. Especially the lateral parts of the shoe outsole are suggested to play an important role in such scenarios but have never been quantified in a systematic manner. Therefore, the purpose of this study was to investigate the variation of friction of indoor sport shoes with foot orientation and compare it to the traditional industry forefoot friction test standard. We modified the ISO:13287:2019 test for footwear slip resistance and positioned the shoe on its forefoot and lateral edge while replicating medio-lateral movements similar to previously reported ankle sprain incidents. All tests were conducted on an indoor vinyl/sport surface. The results from the modified setups were compared to those following the anterior-posterior orientated ISO standard. Medio-lateral friction was on average 17% lower, and lateral edge friction 24% lower than anterior-posterior forefoot friction ($p<0.001$). However, linear regression showed that the forefoot test could only explain 36% and 35% of the variation in medio-lateral and edge friction. This suggests that motion specific tests are necessary to determine footwear friction properties meaningfully. These findings could have important implications for future research and product testing in the field of footwear friction, safety, and injury prevention.

Keywords: footwear, friction, traction, outsole, shoe-floor interaction, ankle injury, mechanical testing

Introduction

It has been proposed that high shoe-surface friction, often referred to as shoe traction (Barry & Milburn, 2013; Shorten et al., 2003; Valiant, 1993), could be a direct risk factor for non-contact lower extremity injuries, and for lateral ankle sprains in particular (Dragoo & Braun, 2010; Frias Bocanegra & Fong, 2021; Pasanen et al., 2008). It appears plausible that the higher incidence rate of lateral ankle sprain injuries in indoor sports compared to outdoor/field sports (Doherty et al., 2014), could therefore be a direct result of the high friction between shoe and floor.

It is widely acknowledged that lateral ankle sprain injuries are caused by an excessive supination moment around the subtalar joint (Fong et al., 2009), which in turn is directly affected by the position, magnitude, and orientation of the ground reaction force vector with respect to the ankle joint centre (Wright et al., 2000). Here, the orientation of the ground reaction force vector is dependent on the friction between shoe and surface (Frederick, 1993). Therefore, it seems reasonable to speculate that excessive friction in cases where the foot is placed in a vulnerable position (i.e., inversion and plantar flexion) (Nie et al., 2017) might have a causal effect on the occurrence and severity of a lateral ankle sprain injury. This speculation is particularly fuelled by the way in which the application of a low-friction patch on the lateral side of indoor sports shoes has effectively reduced both injury incidence rate and severity of lateral ankle sprain injuries in a recent clinical trial (Lysdal et al., 2020).

Indoor sports show a high occurrence of high intensity sprints, shuffling, change of direction, and jumping movements (Stojanović et al., 2018). This does not only demand appropriate friction in the anterior-posterior movement direction of the shoe outsole, but also in the medio-lateral direction (Luo & Stefanyshyn, 2011; Worobets et al., 2014). Landing on the lateral edge of the foot with an inverted ankle joint position has been identified as a ‘particularly vulnerable’ position and a possible cause for lateral ankle sprains (Delahunt & Remus, 2019). During this position the contact area of the shoe is usually decreased, which is known to influence the friction coefficient (Persson et al., 2005). In summary, this suggests that inappropriate friction in the medio-lateral direction, specifically on the lateral edge of the shoe sole, and an uneven

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distribution of friction properties throughout the outsole could be important external risk factors.

Testing friction properties of footwear is commonly used to assess the risk of injuries in sports, leisure activity, and work environments. In this discipline, measurement results can vary significantly between the testing device used, type of movement performed (linear vs. rotational), and the surface the test is performed against. For the field of sport this is specifically crucial when distinguishing between soft and hard grounds where shoe surface interactions can be dramatically different (Silva et al., 2017). When the available dynamic coefficient of friction (ACOF) is lower than the required coefficient of friction (RCOF) the probability of falling due to slipping increases (Hanson et al., 1999). On the other hand, longitudinal studies indicate that an excessively high shoe-surface friction coefficient increases the risk of lower-limb injury in sports (Dragoo & Braun, 2010). This implies that the ACOF of footwear should neither be too low or too high. Quantifying the ACOF in different areas of the outsole and various movement directions may furthermore have a high relevance for a better understanding and prevention of lateral ankle sprain injuries. However, traditional slip-resistance tests used in the footwear industry do not take lateral friction or edge friction into account (ISO: 13287:2019).

Consequently, the purpose of this study was to propose and conduct medio-lateral and lateral edge friction tests representative for indoor sports playing situations and assess if the outcome of these new tests would vary from that of the traditional forefoot friction test in the test standard (ISO: 13287:2019).

We hypothesized that the ACOF in a medio-lateral and lateral edge test would correlate with the ACOF obtained in the standard anterior-posterior friction test. Furthermore, it was assumed that there would be no difference in ACOF between anterior-posterior and medio-lateral test

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but differences between anterior-posterior and lateral-edge test due to changes in contact area between footwear and surface.

Materials and Methods

Design

We designed and conducted an experimental study to determine whether a change in shoe orientation would result in similarity in friction coefficient to the traditional forefoot friction test. To accommodate the relevance to indoor sports we retrieved information on the most commonly used indoor sports shoes in Denmark (season 2017-18) from a nation-wide survey among indoor sports athletes (Lysdal, 2020). The 12 most popular models from well-known sport brands (Adidas, Asics, Mizuno, Nike, Yonex) were purchased and tested conforming to the 'Personal protective equipment - Footwear - Test method for slip resistance' (ISO 13287:2019).

Test Setup

A recently presented mechanical test setup was used (Jakobsen et al., 2022). It consisted of a steel frame that was bolted to the floor above a force plate-equipped mechanical hydraulic platform (Serman & Tipsmark, Brønderslev, Denmark). Hydraulic actuators were controlled using Mr. Kick software (Mr. Kick 3.0, Knud Larsen, Aalborg, Denmark) to provide robust and repeatable vertical and horizontal movements (van Doornik & Sinkjaer, 2007), also making it possible to mimic different shoe-floor interactions.

All tests were conducted against a standard vinyl indoor sports floor (7.5 mm Taraflex – Evolution, Gerflor, Lyon, France) which was attached to the force plate using double-sided tape. We adjusted for the change in surface position of the force platform by including the height of the added floor in the settings.

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Vertical and horizontal ground reaction forces were recorded using a force plate (AMTI-OPT464508HF-1000, Advanced Mechanical Technology, Watertown MA, USA) operating at a sample frequency of 1000 Hz. The force platform was auto-zeroed prior to each acquisition. The movement of the force plate was captured via a single retro-reflective marker which was fixed on the hydraulic platform, using eight infrared cameras sampling at 500 Hz (Oqus 300+, Qualisys AB, Gothenburg, Sweden).

A constant normal force of 500 N was achieved using weight plates atop the test shoe through a vertical lead. The vertical lead allowed for free vertical movement of shoe and passive load while ensuring a fixed position in horizontal direction. Each shoe was tested five times against the floor surface at a speed of 0.3 m/s, as recommended by the test standard (ISO: 13287:2019). Translation distance was 120 mm.

Before the sliding motion, a contact time of 200 ms was initiated to guarantee for a static contact period between shoe and surface and to reach the full normal load of 500 N. The shoes were mounted on a shoe last (framas Kunststofftechnik GmbH, Pirmasens, Germany) and fixed tightly with their shoelaces. Between test setups, shoes were sanded with 400 grit paper, cleaned under rinsing water with a medium stiff brush, and air dried at room temperature, as recommended by the test standard (ISO: 13287:2019). Floor surface and shoe outsole were cleaned with alcohol after every five measurements. All these parameters were identical for the anterior-posterior, medio-lateral and lateral edge friction setup respectively.

Anterior-Posterior Forefoot Friction Test

For the anterior-posterior test, and according to ISO:13287:2019, the shoe was positioned on the forefoot with the help of a 7º aluminium wedge. The shoe was positioned in alignment with the movement direction of the force plate (see Figure. 1a). This allowed an anterior-posterior movement of the shoe in order to simulate a push off movement similar to running and walking.

Medio-Lateral Forefoot Friction Test

The shoe was positioned with the forefoot pointing downwards at a 7° pitch angle like the anterior-posterior test. Additionally, the last was rotated by 90° (Figure. 1b) which enabled us to perform a medio-lateral translation. This was supposed to simulate cutting or sideward movements.

Lateral Forefoot Edge Friction Test

For the lateral edge test the last was also rotated by 90º to perform a lateral translation. Additionally, we placed it in a 15º pitch and 30º roll angle in relation to the floor surface, so that the primary ground contact area was the lateral edge of the shoe (Figure. 1c) (Lysdal et al., 2022; Mok et al., 2021). An excessive inversion in combination with a plantarflexion of the foot are a common cause for lateral ankle sprains and was therefore chosen to simulate such injury situations (Delahunt et al., 2010; Delahunt & Remus, 2019; Gribble et al., 2016; Lysdal et al., 2022).

The outsole hardness of each shoe model was evaluated using a Shore A durometer (PCE-DX-A, PCE Instruments UK Ltd., Southampton Hampshire, United Kingdom), and presented as the mean of five measurements.

Data Processing

Raw GRFs were imported into MATLAB (R2020a, The MathWorks, Massachusetts, USA) and low-pass filtered with a cut-off frequency of 30 Hz, using a bidirectional 2nd order Butterworth filter. All measurements were synchronized using the kinematics of the single retro-reflective

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marker by calculating cross-covariance and aligning data by circular shift. Ten empty (no contact) force plate movements were recorded for later subtraction of the inertial contribution from the hydraulics accelerating the force plate.

The friction coefficient (μ) was calculated for the time of horizontal plate movement via Equation 1, where F_x and F_y are the horizontal reaction forces and F_z the reaction force in the vertical direction (normal force). The ACOF was ultimately calculated as an average over the plateau following the peak in static friction, similar to ISO: 13287:2019 but with a different timing and shorter length of the plateau (Figures 2 & 3). This was necessary due to movement limitations of our test setup.

$$\mu = \frac{\sqrt{(F_x{}^2 + F_y{}^2)}}{F_z} \tag{1}$$

Statistical Analysis

A two-way ANOVA was performed to analyse the effect of test type and shoe model on ACOF. Afterwards we conducted Tukey's HSD post-hoc test to investigate differences between test setups and shoe models. All five trials of every shoe and test conditions were considered for the statistical analysis. Due to the large number of possible comparisons, the most commonly used shoe indoor sport survey ("Asics 2") was used as reference in the Tukey's HSD post-hoc test. Finally, to determine if lateral edge friction can be described by anterior-posterior forefoot friction, we conducted a linear regression analysis to test for possible relationships between testing conditions. A significance level of $\alpha = 0.05$ was chosen for all statistical tests. Python's SciPy environment (www.scipy.org) and statsmodels (www.statsmodels.org) were used for analysis.

Results

The linear regression analysis (Figure. 4a/b) revealed that the ACOF of the anterior-posterior test was significantly related to the medio-lateral and lateral edge ACOF, confirming our first hypothesis (y=0.52x+0.38, p=0.04 and y=0.55x+0.25, p=0.042). Here the anterior-posterior test result accounted for 36% of the variation in medio-lateral (R^2 = 0.36, p=0.04), and 35% of the variation in lateral edge (R2 = 0.35, p=0.042).

Simple main effects analysis showed that test type (p<0.001) and shoe model (p<0.001) both did have a statistically significant effect on ACOF. The mean ACOF for all shoes for the anterior-posterior test was 1.21 (±0.14). On average, this was 17% lower for medio-lateral (1.01±0.12, p<0.001) and 24% lower for the lateral edge test (0.92±0.12, p<0.001) (Table 1; Figure 5).

Most shoes varied significantly in their frictional properties. The shoe used for reference (Asics 2) had a significantly higher friction coefficient than the majority of the other models in the anterior-posterior and lateral edge slip-resistance tests. For the medio-lateral test more than half of the shoes were significantly different from the reference (p<0.001). The total difference in friction coefficients between the highest and lowest ACOF was 0.38 (31% of average ACOF) in the forefoot test, 0.5 (50%) in the medio-lateral, and 0.5 (54%) in the lateral edge test.

The mean ACOF of the Asics 2 reference shoe for the anterior-posterior test was 1.33 (±0.019). The Tukey post-hoc test revealed that one shoe (Adidas 2) had a significantly higher ACOF while seven shoe models were significantly lower. For the medio-lateral test, the Asics 2 reference shoe had an ACOF of 1.01 (±0.022), two shoes were significantly lower, and four shoes were significantly higher. In the lateral edge test, the mean ACOF of the Asics 2 reference shoe was 1.04 (±0.032). One shoe had a significantly higher ACOF (Adidas 5), while nine shoes scored significantly lower (Table 1).

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Discussion

This study was designed as a first attempt to investigate the variation of friction of indoor sport shoes for different foot orientations.

The regression analysis showed that the anterior-posterior test is significantly related to the results of the lateral edge test, confirming our first hypothesis. However, our pre-experiment assumption was that a strong correlation ($R^2>0.7$) would exist between test conditions, but we could only observe a correlation coefficient of $R^2=0.35$ which is only considered 'weak' to 'moderate' (Schober et al., 2018). A similar observation was made for the medio-lateral test, which was found to be described with a correlation coefficient (R^2) of 0.36 with the anterior-posterior setup. Both tests leave nearly two thirds of the variability in the other variable unexplained. In addition, the individual behaviour of shoes is not consistent. The ranking between shoes changes distinctly and several shoes did not vary in ACOF between conditions (Table 2). This implies that if one wishes to accurately assess traction in other directions or areas, one should perform such specific tests accordingly.

Across all shoe models we found that medio-lateral ACOF on average was 17% lower than anterior-posterior ACOF ($p<0.001$), and that lateral edge friction was 24% lower than anterior-posterior ACOF ($p<0.001$). Therefore, our second hypothesis was rejected, and our third hypothesis confirmed. For the lateral edge test these results are in line with existing knowledge on viscoelastic friction, where the effective friction coefficient usually decreases with a decrease in contact area (Persson et al., 2005). We assume that this is not the case for the medio-lateral test since the contact area should be the same as for the anterior-posterior test, at least before the movement occurs. How much the contact area changes during the sliding motion is something we were not able to quantify. Still, most ACOF values are lower for the medio-lateral condition, therefore indicating that other mechanisms may come into play. These could be related to a different outsole deformation, caused by possible anisotropic properties or different

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behaviour of outsole elements, and consequently a different contact area. Also, the shoe movement around the last, as well as shoe and surface abrasion can play a role, though we could not observe any occurrence visually of the latter.

Not many studies could be identified that compare anterior-posterior to medio-lateral traction. A recent study tested one shoe model under a range of normal loads while varying the movement direction of the shoe (Ura et al., 2013). Tests were conducted on the forefoot of the shoe with 0º, 30º, 60º and 90º of rotation on an acrylic hard court tennis surface. Here the ACOF increased when sliding the shoe medio-laterally, which is opposite to the trend that most shoes showed in our study. However, since only one shoe was used, this could be an effect of the surface, outsole design or material of that specific model. Recent tribological research has shown an effect of shape orientation of rubber blocks in respect to their sliding direction (Hale et al., 2020). When visually inspecting the outsoles geometries of the shoes used in this study, we observed a high variation of shapes in most models. This variation combined with the theory of Hale et al. (2020) might explain some of the change in ACOF under different sliding directions. This supports our observation that shoe orientation affects the friction properties at the shoe-surface interface, and that this change in behaviour cannot be predicted from a simple anterior-posterior traction test.

Furthermore, it has been shown that shoe-surface friction is complex due to the viscoelastic nature of elastomer outsoles (Clarke et al., 2013; Jakobsen et al., 2019; Shorten et al., 2003; Valiant, 1993). Because of the high design variability of shoes used in the present study, it was not possible to identify the exact mechanism of the foot ground interaction, including localized deformation and other non-linear, or non-Coulomb effects. Furthermore, we could not observe a relevant connection between outsole hardness and friction properties. This leads to the

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assumption that the outsole pattern design may play an important factor for the friction properties of indoor shoes.

The results of the different test setups show a large variability in ACOF between commercially available shoe models. Contemplating the notion that the friction coefficient might not just be a unitless descriptor, but could be directly related to the moments around the ankle joint and a direct risk factor for the occurrence of a lateral ankle sprain injury (Frias Bocanegra & Fong, 2021; Pasanen et al., 2008), one would arguably assume that the ‘Adidas 5’ would carry the highest risk for such injuries. This particular model provides high values in all three friction tests. Overall, the ‘Adidas 3’ had the lowest ACOF values of all tested models. This could be explained by the specific outsole material and more simplistic retro design of this shoe. Also, it is recommended to be used on polished indoor floors, which did not match to the setup in our present study. Still, it is a popular indoor sport shoe, most likely because of its versatility. These properties seem to resonate a lot with goalkeepers in the sport of handball, which was a strongly represented sport in the Danish indoor sport survey (Lysdal, 2020).

Previous research has identified a minimum ACOF between 0.6 - 0.7 as ideal for participants to feel confident and not afraid of slips during changes of direction (Keshvari & Senner, 2015; Morio et al., 2017). Furthermore, performance is no longer enhanced above a value of 0.82 in curved running (Luo & Stefanyshyn, 2011), assuming that the ideal ACOF value would lie between 0.6 and 0.82. All shoes, except for one in the medio-lateral test, exceeded these values by 22-68% in anterior-posterior and 8-48% in medio-lateral friction characteristics. Considering the potentially heightened risk of non-contact lower extremity injury in general (Dragoo & Braun, 2010), more traction is not necessarily better. Despite the fact that Morio et al. (2017) have shown that ACOF and utilized COF (UCOF) are related, results from mechanical and biomechanical tests can vary a lot. Therefore, comparing both parameters with each other is more of a hypothesis than an applicable rule, also due to the different nature of movements used in these biomechanical studies. We do not know if, and to which degree, our results are transferable to change of direction tasks or other sports maneuvers that include a laterally oriented foot placement. Because of the lower average in both tests, compared to the anterior-posterior test, one would assume that the threshold should also be lower for the medio-lateral and lateral edge test procedures respectively. But how low they can or should be, and if this is in agreement with functional demands is still unknown. However, clear friction guidelines for changes of direction and lateral movements are still missing. In addition, no optimal range for any of the discussed shoe friction properties has been established yet which considers, and at the same time minimizes, the risk for ankle sprain injuries.

In summary, considering the significant results in ACOF, the weak correlation coefficients, the observable variation of shoes between tests, and the lack of friction guidelines for lateral movements, it is recommended to test friction properties for different shoes and conditions separately.

Strengths and Limitations

Identifying the plateau for the ACOF calculation was more challenging for the medio-lateral and lateral edge test than it was for anterior-posterior. Depending on the shoe model the characteristics of the ACOF curves were often less consistent, by showing some artefacts of greater magnitude at the beginning or end of the measurement. These irregularities were always consistent for the respective shoe model. For that reason, the plateau sometimes had to be shifted forth and back on the time axis and eventually shortened by some frames to not include such artefacts in the calculations.

Due to the limited size of the force plate, it was not possible to achieve a plateau length of 300 ms like it has been proposed in ISO: 13287:2019 (Jakobsen et al., 2022). In our setup 200 ms were identified as a feasible plateau length, which could be obtained in most measurements. Anyhow, there were still some exceptions: two shoe conditions produced plateaus of 190 ms each and two other of 180 ms (all in the lateral edge test). One shoe produced a plateau of 160 ms and another of 150 ms respectively (both medio-lateral). This is however not seen as a limitation to the results obtained, since time intervals between 0-200 ms show sufficient validity and repeatability after reaching the desired normal force (Beschorner et al., 2020). Therefore, no tests were excluded from the analysis. A possible reason for the artefacts may have been a higher outsole and midsole deformation or an increased movement of the shoe around the last during the sideway sliding movements, resulting in some parts of the outsole to lose contact with the test surface. Because of the high forces and moments that occurred during these kinds of tests the shoes tended to twist around the last. We were constantly observing the shoe-surface interaction to assure that no abnormal movement or a clear loss in contact area was the case. When mimicking these kinds of tests and test setup, attention must be paid to select the appropriate plateau area for analysis.

We did not control for wear and tear of the surface which might have affected the obtained ACOF. We did not observe any visual sign of wear or smoothening of the surface asperities when cleaning the floor between each test. This could still have been more meticulously evaluated by e.g., optical estimation of the surface roughness. However, since the order of testing was consistent throughout (i.e., no randomization) and with a relatively small total number of cycles, the potential wear effect is not considered to have had any major influence on the relative differences observed between testing orientations.

Perspectives

Recent research has shown that having different traction properties in different zones of a shoe can have a positive effect on ankle sprain injury risk and severity (Lysdal et al., 2020), strongly suggesting that this might be beneficial for a vast variety of different sport movements. With the setup of the lateral edge test we tried to replicate a foot position that is comparable to actual injury scenarios reported previously (Lysdal et al., 2022; Mok et al., 2021). Current literature shows a high variability of joint angles during ankle injuries such that no injury resembles another. Therefore, we had to choose a realistic value and started with a position that seemed most reasonable for us. However, previous research may not have considered certain injury scenarios of ankle sprains when only looking at anterior-posterior traction properties of shoes. In recently reported studies, anterior-posterior tests are often used to define the overall shoe friction properties even if lateral or cutting movements are performed (Wannop et al., 2010; Worobets & Wannop, 2015). Therefore, medio-lateral traction tests are expected to be of high relevance for injury research focusing on lateral movements.

This study sets the foundation for investigating if different shoe outsole areas can be identified and how they stand compared to existing shoe-friction injury knowledge. It could be speculated that varying friction properties in different areas of a shoe could lead to an unexpected shoe-surface interaction for the athlete and therefore cause involuntary movements in critical match situations. Furthermore, it needs to be questioned if a noticeable change in friction coefficient is also a ‘valuable change’, hence having clinical implications for injury prevention. Future research could tackle these questions in more depth and establish friction guidelines for particular areas of shoe outsoles.

Conclusions

This study showed that a traditional forefoot friction test can only poorly explain the results of a medio-lateral and a modified lateral edge friction test. Furthermore, we could observe significant differences in friction coefficient between all tests. We suggest that if specific footwear friction properties need to be assessed meaningfully, then movement direction-specific tests should be conducted. Future research should look to establish a link between these specific friction parameters and their implications for sports injury.

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Disclosure Statement

The authors report no conflict of interest.

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Table 1. Mean available dynamic friction coefficient (ACOF) for all test setups; absolute and relative changes compared to the anterior-posterior test.

	Anterior-posterior forefoot friction	**Medio-lateral forefoot friction**			**Lateral forefoot edge friction**		
Shoe ID	**Mean (SD)**	**Mean (SD)**	**Δ**	**Δ%**	**Mean (SD)**	**Δ**	**Δ%**
Adidas 1	1.36 (0.012)	1.07 (0.030) *	-0.28	-21%	0.91 (0.033) *	-0.45	-33%
Adidas 2	1.38 (0.017) *	0.99 (0.021)	-0.39	-28%	0.88 (0.033) *	-0.50	-36%
Adidas 3	1.03 (0.034) *	0.71 (0.008) *	-0.32	-31%	0.69 (0.020) *	-0.34	-33%
Adidas 4	1.21 (0.025) *	1.10 (0.018) *	-0.11	-9%	1.04 (0.020)	-0.16	-13%
Adidas 5	1.35 (0.013)	1.21 (0.017) *	-0.14	-10%	1.19 (0.027) *	-0.16	-12%
Nike 1	1.01 (0.018) *	1.04 (0.026)	0.03	3%	0.77 (0.086) *	-0.24	-23%
Nike 2	1.00 (0.014) *	0.89 (0.020) *	-0.12	-12%	0.92 (0.024) *	-0.08	-8%
Asics 1	1.32 (0.026)	1.02 (0.053)	-0.30	-23%	0.92 (0.030) *	-0.39	-30%
Asics 2 (*REF*)	1.33 (0.019)	1.01 (0.022)	-0.32	-24%	1.04 (0.032)	-0.29	-22%
Mizuno 1	1.25 (0.015) *	1.08 (0.018) *	-0.17	-14%	0.91 (0.032) *	-0.34	-27%
Mizuno 2	1.21 (0.013) *	1.01 (0.022)	-0.20	-16%	0.93 (0.021) *	-0.28	-23%
Yonex 1	1.13 (0.015) *	0.97 (0.021)	-0.16	-14%	0.83 (0.032) *	-0.30	-26%
Test Mean	**1.21 (0.135)**	**1.01 (0.117)**	**-0.20**†	**-17%**	**0.92 (0.124)**	**-0.29**$^{\dagger/\sim}$	**-24%**

(*) indicates statistically significant difference in ACOF compared to REF within test condition (*: p<0.001), (†) compared to anterior-posterior (†: p<0.001), ($^{\sim}$) compared to medio-lateral ($^{\sim}$: p<0.001).

Table 2. Shoes that did **not** show a significant difference between test conditions.

Shoe ID	**Test conditions being compared**	**p-value**
Nike 1	Anterior-Posterior – Medio-Lateral	0.8
Adidas 3	Medio-Lateral – Lateral Edge	0.9
Adidas 5	Medio-Lateral – Lateral Edge	0.9
Nike 2	Medio-Lateral – Lateral Edge	0.46
Asics 2	Medio-Lateral – Lateral Edge	0.74

Table 3. Shoe characteristics

Shoe Model	**ID**	**Size EU**	**Product #**	**Sport**	**Weight [g]**	**Outsole Hardness [Shore A]**	**Forefoot Height [mm]**	**Rearfoot Height [mm]**
Adidas Counterblast	Adidas 1	43 1/3	CG2763	Handball	354.9	61.2	23.1	12.8
Adidas CrazyFlight X	Adidas 2	43 1/3	BB6123	Handball	369.2	62.0	25.6	13.5
Adidas Handball Special	Adidas 3	43 1/3	M18209	Handball	332.7	61.4	18.7	9.0
Adidas Stabil Boost X	Adidas 4	43 1/3	BB6343	Handball	434.2	73.8	25.9	14.0
Adidas James Harden Vol. 1	Adidas 5	43 1/3	CQ1404	Basketball	432.6	68.8	24.7	12.3
Asics Gel-Beyond 5	Asics 1	43.5	B601N	Hand-/Volleyball	328.4	63.0	26.1	12.1
Asics Gel-Netburner Ballistic	Asics 2	42.5	B507Y	Hand-/Volleyball	338.8	66.8	26.0	14.7
Mizuno Wave Lightning Z3	Mizuno 1	43	V1GA170 048	Handball	325.8	63.4	26.6	12.6
Mizuno Wave Mirage 2	Mizuno 2	43	X1GA175 091	Handball	312.0	64.2	23.1	10.4
Nike Hyperdunk X Low TB	Nike 1	43	AR0463 600	Basketball	352.1	72.6	26.4	15.7
Nike Kobe Mamba Focus	Nike 2	43	AJ5899-004	Basketball	341.5	62.6	22.7	14.3
Yonex Power Cushion SHB 65 Z 2	Yonex 1	43	BADM	Badminton	333.3	63.4	24.5	10.5

Figure 1a.

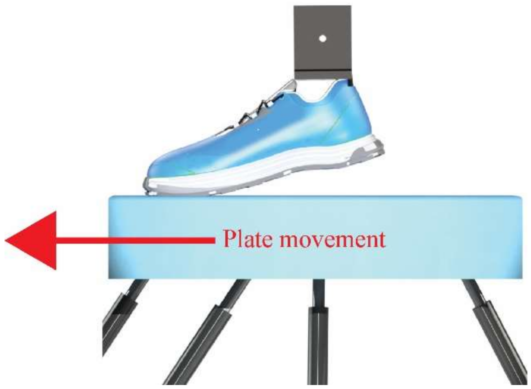
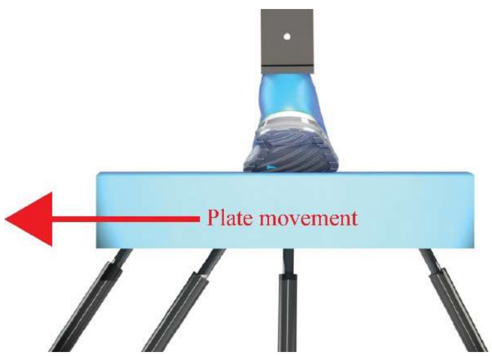


Figure 1b.



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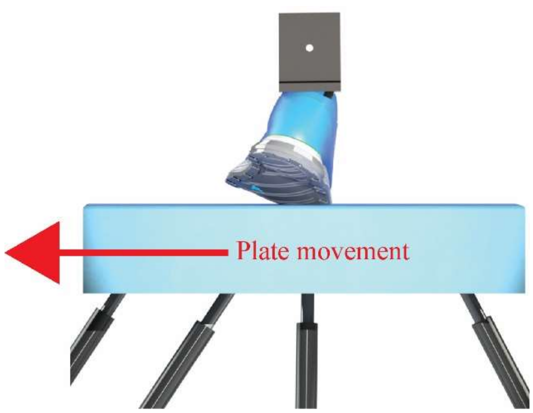

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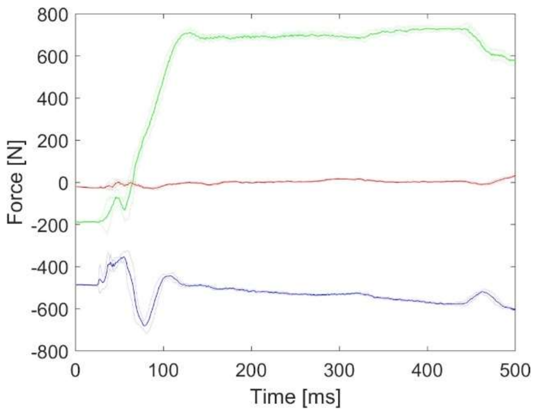

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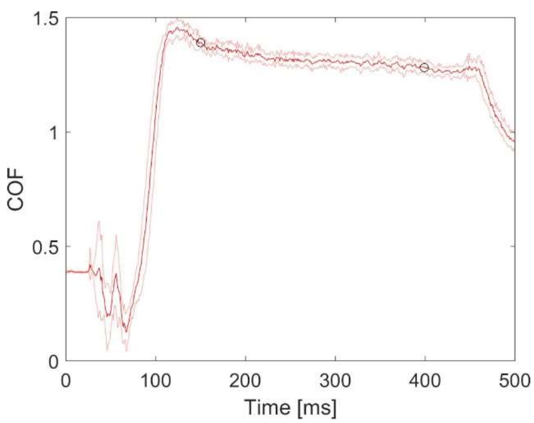
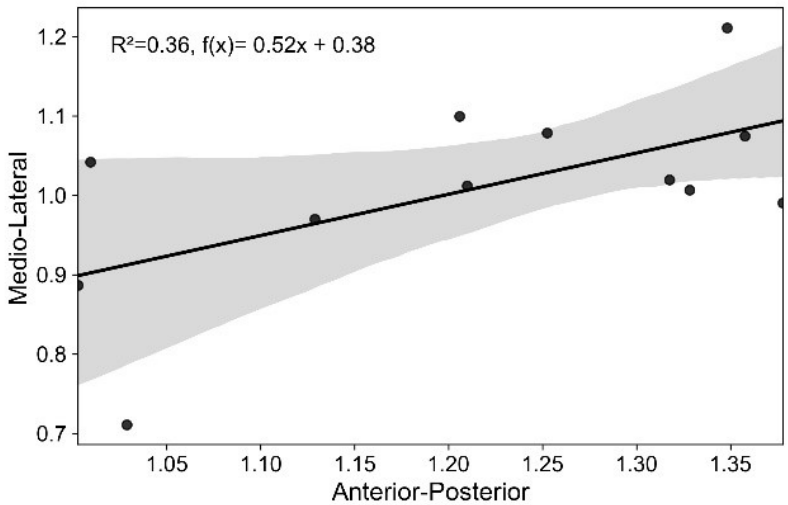


Figure 4a.



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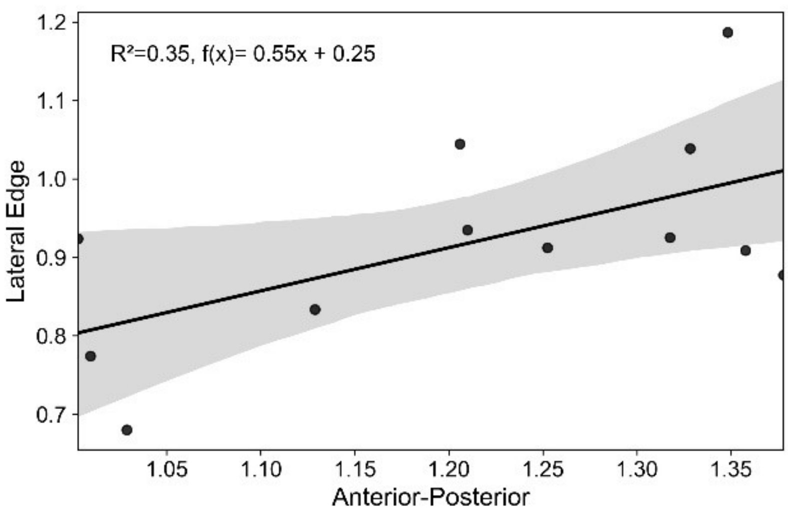

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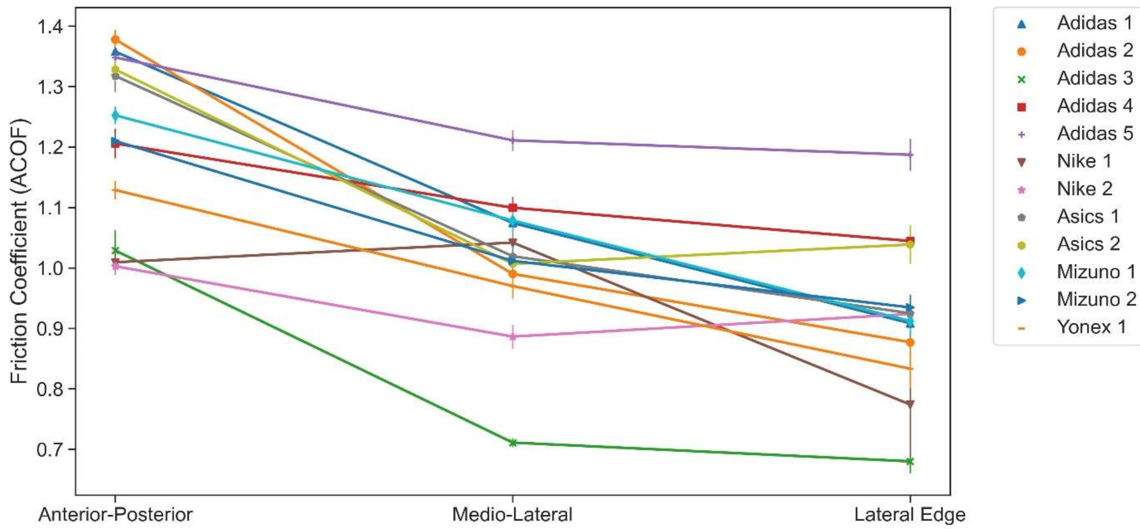

Figure 6. Adidas Counterblast

Figure 7. Adidas CrazyFlight

Figure 8. Adidas Handball Special

Figure 9. Adidas Stabil X

Figure 10. Adidas James Harden Vol. 1

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Figure 11. Asics Gel-Beyond 5

Figure 12. Asics Gel-Netburner Ballistic

Figure 13. Mizuno Wave Lightning Z3

Figure 14. Mizuno Wave Mirage 2

Figure 15. Nike Hyperdunk X Low TB

Figure 16. Nike Kobe Mamba Focus

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Figure 17. Yonex Power Cushion SHB 65 Z 2

Figure captions:

Figure 4a. Anterior-posterior test setup.

Figure 1b. Medio-lateral test setup.

Figure 1c. Lateral edge test setup.

Figure 5. Averaged raw X- (red), Y- (green) and Z-Forces (blue), including standard deviation, during the horizontal movement period of the force plate. The graph shows the average of five measurements of the same shoe model.

Figure 6. The resulting coefficient of friction (COF), including standard deviation, during the horizontal movement period of the force plate. The black circles indicate the start and end of the plateau, which was used to calculate the ACOF. The graph shows the average of five measurements of the same shoe model.

Figure 7. Mean dynamic coefficient of friction of the anterior-posterior, medio-lateral, and lateral edge traction tests. The vertical bar at each respective data point represents the standard deviation.

Figure 5a/b. Linear regression analysis between the standard anterior-posterior test (x-axes) and the newly designed a) medio-lateral test (y-axis), and b) lateral edge test (y-axis). The grey area represents the 95% confidence band

Figure 6. Adidas Counterblast
Figure 7. Adidas CrazyFlight
Figure 8. Adidas Handball Special
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