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Actual and perceived running performance in soccer shoes: A series of eight studies

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Soccer shoes in general but especially their outsoles are important for running and consequently playing performance. This article aims to quantify running performance and perception of running performance due to type of footwear and surface condition by use of Functional Traction Courses (FTC). Soccer players were required to run through slalom and acceleration courses as fast as possible providing running time and perception of running time variables due to wearing different soccer footwear. A series of eight single studies featuring different types of soccer footwear and different surfaces was conducted. The influence of footwear (subject Means and SD) was analyzed by Repeated Measures ANOVA, followed by post-hoc *t*-tests when appropriate. Slalom running times were considerably affected by altered shoe/surface interface conditions, whereas acceleration running times were affected only to lesser extent. Running time perception of athletes generally reflected actual running performance. Running performance differed about 3% when altering stud type or stud geometry. Thus, players benefit by the appropriate choice of footwear for a given surface. Complete elimination of studs resulted in a running time difference of 26% compared to normal condition. Surface conditions may be responsible for up to 20% of performance differences. It is recommended to include FTC testing in the evaluation of soccer footwear to get an idea of potential running performance benefits for players.

Keywords: football; soccer; soccer shoes; shoe-surface interaction; running performance; performance perception

Introduction

Soccer requires players to perform multiple different types of movements at all speed levels. Thereby, running performance depends on multiple factors, e.g., player anthropometrics, physiological aspects, and skill level. Additionally, footwear and playing surface are of considerable importance, especially when considering highly dynamic movements. Traction as a function of shoe/surface interface is marked to be the second most important soccer shoe feature according to a players' survey on soccer shoe properties (Sterzing *et al.* 2007). Good traction is crucial for players as it might give them the decisive edge over their opponents during soccer-specific acceleration, deceleration, cutting or turning movements. By this, traction characteristics influence the quality of motor performance which may be assessed by running times on given agility courses. For soccer, suitable courses include sections of linear accelerations, cutting movements, and turns to mimic manoeuvres of the game. A game analysis showed that straight and oblique acceleration are the most frequent soccer specific movements observed in actual matches (Sterzing and Hennig 2005).

For sprinting and jumping the degree of shoe bending stiffness influences athlete performance. Sprinting performance was shown to increase with stiffer sprint shoes. However, the specific shoe stiffness for maximal sprint performance was athlete specific but not related to anthropometric factors or skill level (Stefanyshyn and Fusco 2004). In jumping, stiffening of shoes led to a reduction of energy loss at the metatarsophalangeal joint and in consequence to an improvement of vertical jump height (Stefanyshyn and Nigg 2000). Besides traction and shoe bending stiffness, further shoe features like comfort and weight may also influence running performance in soccer.

Rodano *et al.* (1988) described the soccer shoe to be fundamental for the athlete's performance and referred to the specific interface between the player's foot, the shoe, and the ground. Soccer shoes feature different stud configurations on the outsole to address the characteristic traction demands of the game. These demands in general depend on pitch conditions and on changing circumstances like weather conditions. Natural grass surface conditions are generally characterized as hard ground, firm ground or soft ground. Based on this categorization three corresponding

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concepts of soccer stud types were developed. Slight modifications of these concepts incorporate number of studs, stud geometry, stud length, and exact stud positioning. Recently, artificial soccer turf is used more frequently also on top level match play. The latest, third generation of artificial turf systematically combines an infill of sand and rubber. The latter is responsible for providing grip to the player by interaction with the studs of the shoes. Specific drainage systems incorporated in artificial soccer turf pitches help to maintain their original surface characteristics during rain. A comprehensive evaluation of the traction properties of traditional stud designs on top notch artificial soccer turf showed that hard ground and firm ground stud designs are superior with respect to functional traction characteristics compared to a soft ground stud design (Müller *et al.* 2008; Sterzing *et al.* 2008).

Various approaches are used to adequately characterize and quantify traction properties of soccer shoes. Generally, assessment of athletic footwear should consist of mechanical, biomechanical and subjective-sensory testing (Hennig and Milani 1996; Lafortune 2001). Additionally, sport-specific motor performance testing provides valuable information by direct parameters assessing the functionality of footwear (Sterzing *et al.* 2007). Thereby, these direct parameters, e.g., running and ball velocities, allow quantifying the benefit of footwear for the player when comparing different shoes. Mechanical traction measurements provide reliable data of shoe–surface interface characteristics. However, the validity of these data for athletic performance is to be questioned as mechanical testing protocols do not reflect natural movement adaptation of athletes in response to altered traction conditions. Additionally, different traction needs due to gender and age cannot be addressed by mechanical traction measurements. Traction needs for children are lower than those for adults during cutting and acceleration movements as shown by biomechanical measurements (Morag and Johnson 2001). Suited biomechanical ground reaction force parameters of traction properties are shear forces and their ratio towards vertical forces (Valiant 1987). Shear force rates provide insight in adaptation strategies of athletes due to altered traction conditions (Sterzing *et al.* 2008). Only few studies quantify the effect of traction properties on playing performance. In full instep kicking the influence of suited stance leg traction gives the athlete a 3% margin with respect to resulting ball velocity (Sterzing and Hennig 2008). During agility runs different footwear was shown to evoke different running times when wearing tennis, soccer and football shoes on natural grass compared to Astroturf (Krahenbuhl 1974). This was the first scientific attempt to functionally assess traction properties of footwear and surfaces with regard to sports performance.

For good playing performance actual traction properties as well as perceived traction properties are important. Well suited actual traction properties allow players to conduct movements more efficiently. Good perception of traction properties by itself makes players feel to be quicker during play and thus enhances performance. Coyles *et al.* (1998) reported only little differences between measured and perceived grip during turning movements. Furthermore, they showed grip performance to be dependent on posture of the pivot foot at foot strike.

This article evaluates soccer specific running performance in relation to players' perception by use of Functional Traction Courses (FTC). Thereby, the functionality of different soccer shoes, especially of different outsole stud configurations, on given surfaces was investigated in a series of eight studies.

Methods

The studies were carried out either at the University of Duisburg-Essen or at Chemnitz University of Technology over a period of 6 years between 2002 and 2007. Originally, the single studies were performed to evaluate soccer running performance with respect to shoe models and surfaces in question during this period of time.

The concept of FTC testing is described in general as it applies to all studies presented thereafter. It is based on motor performance testing procedures in which participants are asked to show their best performance for a given task (Roth and Willimczik 1999). The idea of FTC testing in this paper is that foremost traction, but also weight and comfort may instantaneously affect running performance. A lack of functional traction may result in stumbling or slipping, reducing running speed. With increase in movement speed and number of direction changes traction properties become more important for the player. Therefore, FTC testing incorporates multiple accelerations, decelerations, and cutting and turning movements. Two different FTC were used in the following studies: (I) slalom course, (II) acceleration course (Figure 1). The slalom course incorporates 12 accelerations, 10 cuttings, and one turning movement having a total length of 26m. The acceleration course simply requires 6 m of maximum straight acceleration by the players. However, FTC II (acceleration) was added only in the later studies.

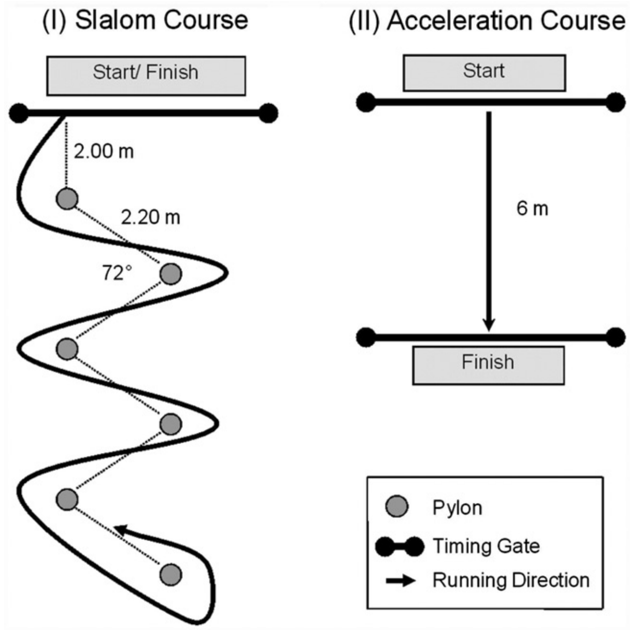

Figure 1. Soccer-specific functional traction courses.

Variability of single foot strikes within players is taken care of by incorporating numerous movements. Variability between participants is addressed by recruitment of a sufficient number of athletes. Traction conditions are altered by use of footwear with different outsole configurations or different surface conditions. Participants have to run through the FTC in each shoe condition as fast as possible. Shoe order is randomized between different participants who perform at least three repetitive runs in each shoe/surface condition. Shoe conditions have to be switched after each single run. A resting period after each single run is mandatory in order to eliminate or at least reduce fatigue during testing. Running times (RT) are taken with single or double light barriers if available. Additionally, running time perception (RTP) of players is taken by requesting a shoe ranking from the participants after all runs are completed.

For statistical analysis means and standard deviations are calculated for each subject and shoe–surface condition for FTC I and II. A one-way repeated measures ANOVA and post hoc *t*-tests (Fisher's PLSD) compare performance of the different shoe-surface conditions with levels of significance at $P < 0.05$ (*) and $P < 0.01$ (**).

In the following the series of FTC studies is presented, addressing different aspects of soccer footwear and surface:

(a) stud type
(b) stud type and wet weather conditions
(c) stud geometry
(d) stud geometry and firm ground vs. ice-snow weather conditions
(e) stud length
(f) shoe weight
(g) shoe comfort
(h) specific shoe model

In the studies the surface conditions were either natural grass (d, f, g) or FIFA 2-Star artificial turf: *Liga Turf 240 22/4 RPU brown; Polytan, Burgheim/Germany* (a, b, c, e, h). As research took place at two universities over a period of 6 years, over time and place different subject pools had to be recruited and FTC I differed slightly concerning its exact length. Due to this, results of the different studies are not comparable with regard to absolute running times. Participants in all studies were amateur to sub-elite soccer players having a minimum of five years of soccer experience and thus with cleated footwear. Altogether, 52 players (age: 24.5 years (±4.2), height: 177.9 cm (±4.8), weight: 73.2 kg (±7.0)) took part in the different studies. Soccer experience, skill level, and anthropometric characteristics of player groups participating in the single studies did not differ meaningful between studies. All participants had shoe size UK 8 as required by the shoe samples available. Prior to the testing all participants had to sign informed consent. All procedures adhered to the requirements of the University of Duisburg-Essen and Chemnitz University of Technology for subject testing.

In the following the specific background of the different studies is explained and the respective shoe/surface conditions for the single studies are characterized:

Stud type

Shoe conditions were Puma® commercially available as shoe models with different stud types (Figure 2): hard ground (HG), firm ground (FG), and soft ground (SG) on artificial turf. Thus, the running performance characteristics of traditional natural grass stud designs on artificial turf were examined. This allows to suggest which of these stud types work best on the latest, third generation, artificial soccer turf. Furthermore, it provides valuable information with respect to shoe design directions for a specific artificial soccer turf outsole configuration.

Stud type and wet weather conditions

The same shoe conditions as in study (a), hard ground (HGWA), firm ground (FGWA), and soft ground (SGWA) were examined on wet artificial turf (WA). The goal of this study was to see whether artificial soccer turf also calls for different stud configurations of shoes due to changing weather conditions as much as natural grass surfaces do. Therefore, the testing field was watered in the same controlled manner prior to each subject's testing session.

Stud geometry

Shoe conditions were the Nike® Tiempo Premier FG with an elliptic (TPE) and a bladed (TPB) stud configuration (Figure 3) on artificial turf. Thus, the performance characteristics of different stud geometries incorporated in otherwise relatively similar outsole configurations on artificial turf were examined.

Stud geometry and firm ground vs. ice-snow weather conditions

Traction was altered due to surface conditions while the shoe conditions, an elliptic firm ground design (E) and a bladed firm ground design (B), remained the same. Thus, the influence of severely different surface conditions was examined as well as the suitability of two different stud geometries for the given surfaces. Testing took place in summer and winter. As subject groups were not exactly the same for the summer and winter comparison, they were considered independent populations in the statistics evaluating the surface effect. Surface conditions were firm ground natural grass (FGNG-E and FGNG-B) and natural grass covered by ice and snow (ISNG-E and ISNG-B). The stud geometry effect on each surface condition was evaluated by statistics for dependent populations like in the other studies.

Stud length

Shoe conditions were the Nike® Mercurial Vapor II FG with different stud lengths on artificial turf: 100% length (FFG), 50% length (HFG), and

Figure 2. Shoe conditions: stud type (a) HG: hard ground, (b) FG: firm ground, (c) SG: soft ground.

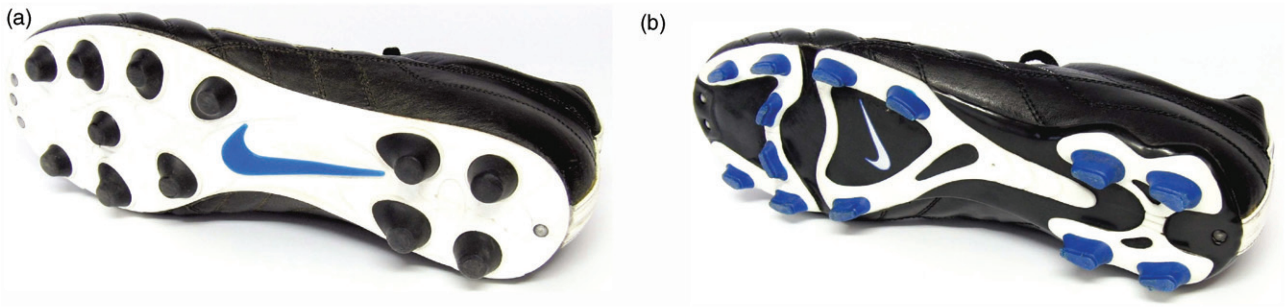

Figure 3. Shoe conditions: stud geometry (a) TPE: Tiempo Premier elliptic, (b) TPB: Tiempo Premier bladed.

Figure 4. Shoe conditions: stud length (a) FFG: full firm ground with stud length 100%, (b) HFG: half firm ground with stud length 50%, (c) ZFG: zero firm ground with stud length 0%.

0% length (ZFG). Stud length was shaved by an orthopaedic shoe technician (Figure 4). Thus, the fundamental influences of studs versus no studs as well as different stud lengths on running performance were examined.

Shoe weight

Shoe weight was altered by a 70-g rubber insole placed in the 200-g Nike® Mercurial Vapor II FG (VO2 and VO2 + 70) to examine its influence on running performance. In this study, it was assumed that other shoe features were only slightly affected by the additional insole, if at all. Testing took place on natural grass.

Shoe comfort

Shoe comfort was altered by use of a given shoe model (VO2) and its, with respect to comfort, improved successor Nike® Mercurial Vapor III FG (VO6). Both shoe models featured the same outsole stud configuration. In this study comfort improvement refers to a softer better fitting heel counter. Comfort differences were confirmed by perception testing (Figure 11). Thus, the influence of shoe comfort on running performance was examined.

Specific shoe model

Shoe models were the Puma® King elliptic (PKE), designed for playing on natural turf and the Puma® King Synthetic (PKS), designed for playing on artificial turf. Testing took place on artificial turf (Figure 5). This study serves as an example for a shoe comparison in which shoes with various, potentially interacting features may have a summed influence on running performance.

In the majority of these studies the predominant shoe modification is the systematic alteration of either

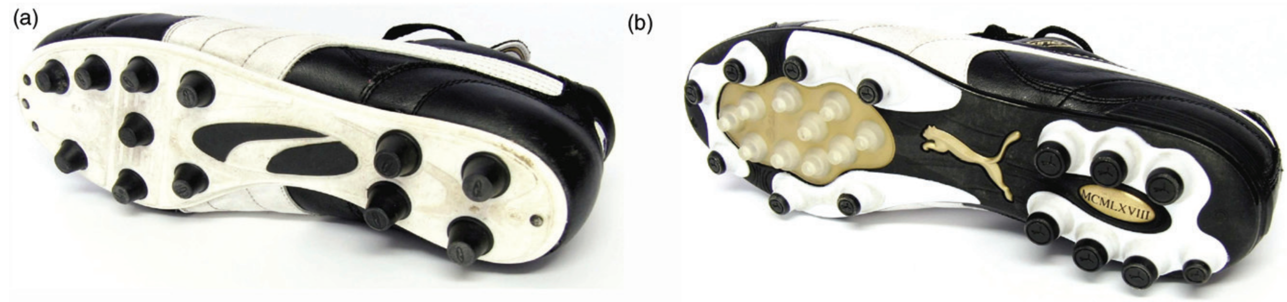

Figure 5. Shoe conditions: shoe model (a) PKE: King firm ground, (b) PKS: King synthetic.

outsole configuration or surface condition. Additionally, the features shoe weight and shoe comfort were specifically examined in two studies. In all studies shoe weight was within the well accepted weight range of today's soccer shoes. The principle testing aspect in all these studies was running performance as measured by running time. In the later studies subjective-sensory testing was added in order to evaluate participants' perception of their running performance.

Results and discussion

FTC testing discriminated between different shoe/surface interface conditions with respect to running performance as shown by our studies. The slalom FTC was better suited to discriminate between different shoe-surface interfaces than the acceleration FTC. This is most likely due to bigger length of the course and due to the multiple changes of direction incorporated in the slalom course.

The first and most important result of the series of studies is that different shoe/surface interface conditions affect running performance. Secondly, running time perception of the subject group is in general related to objectively measured running times. Table 1 provides an overview of achieved running times (RT) in absolute (s) and relative values (%) as well as their perception by the participants (RTP) for the single studies. Furthermore, it shows statistical differences between the different testing conditions of the single studies with respect to RT and RTP. Across all studies the benefit of different shoe/surface conditions was up to 26.34%.

More detailed results of the single studies' running times are displayed in bar graphs presented as percentages (Figures 6–12). Running times of all participants were normalized to the mean running time of the slowest shoe-surface condition for each study separately. Therefore, 100% running time marks the shoe mean across all subjects of the slowest shoe/surface condition and lower percentages mark faster shoe performances in each study. This procedure allows the comparison of running time differences between the slalom and the acceleration FTC. Also, it allows comparing results of different studies as this type of data representation is independent of subject pool, number of tested shoes, and surface conditions.

Stud type

Running performance of stud types originally designed for natural grass shows considerable differences when being used on artificial turf (Figure 6). Slalom running time was slowest for the soft ground design ($P < 0.01$) which tended to be slowest also in the acceleration course ($P = 0.07$). Perception of running performance showed the same differentiation between stud types ($P < 0.01$) and reflected the actual running times in both FTC. The hard ground and the firm ground stud configuration performed equally. However, participants perceived the hard ground stud configuration to be faster with respect to the slalom FTC. The results recommend that when playing on artificial soccer turf and no specific artificial turf stud design shoe is available players should use a hard ground or firm ground stud design. Furthermore, a future artificial turf stud design should be oriented towards these two stud types suggesting a rather low stud design incorporating multiple single studs.

Stud type and wet weather conditions

The three traditional stud designs were specifically designed to respond to different natural grass weather conditions. This functionality needed to be examined when playing on wet artificial turf. Our pilot study ($n = 5$) revealed the same trend of results like study (a) when testing on dry artificial turf. Due to the small number of participants inferential statistics need to be interpreted with caution and perception data were not considered at all. Nevertheless, it seems safe to

Table 1. All studies: overview, running time (RT) and running time perception (RTP).

	Shoe condition	Surface condition	FTC	Participants [*n*]	RT Min–Max [s]	RT Range [s]	RT Min–Max [%]	RT Range [%]	RT Discrimination	RTP Discrimination
a	Stud type	Artificial turf	Slalom	20	10.73–11.03	0.30	97.32–100.00	2.68	$P < 0.01$	$P < 0.01$
			acceleration	19	1.19–1.22	0.03	98.37–100.00	1.63	$P = 0.07$	$P < 0.01$
b	Stud type	Artificial turf (wet)	Slalom	5	10.37–10.73	0.36	97.60–100.00	2.40	$P = 0.19$	–
			acceleration	5	1.19–1.22	0.03	98.12–100.00	1.88	$P = 0.24$	–
c	Stud geometry	Artificial turf	Slalom	13	12.03–12.39	0.36	97.06–100.00	2.94	$P < 0.05$	$P = 0.18$
			acceleration	10	1.22–1.22	0.00	99.84–100.00	0.16	$P = 0.88$	$P = 0.22$
d	Elliptic	FGNG vs. ISNG	Slalom	18	12.15–15.40	3.25	79.10–100.00	20.90	$P < 0.01$	–
	bladed	FGNG vs. ISNG	Slalom	18	12.20–14.98	2.78	79.40–97.51	18.11	$P < 0.01$	–
e	Stud length	Artificial turf	Slalom	15	12.12–16.48	4.36	73.56–100.00	26.34	$P < 0.01$	$P < 0.01$
			acceleration	15	1.17–1.37	0.20	85.38–100.00	14.62	$P < 0.01$	$P < 0.01$
f	Shoe weight	Natural grass	Slalom	20	11.47–11.47	0.00	99.99–100.00	0.01	$P < 0.98$	–
g	Shoe comfort	Natural grass	Slalom	20	11.47–11.47	0.00	99.95–100.00	0.05	$P < 0.98$	–
h	Shoe model	Artificial turf	Slalom	13	11.94–12.35	0.41	96.74–100.00	3.26	$P < 0.01$	$P < 0.01$
			acceleration	10	1.22–1.22	0.00	99.46–100.00	0.54	$P = 0.59$	$P = 1.00$

Note: –, no data available.

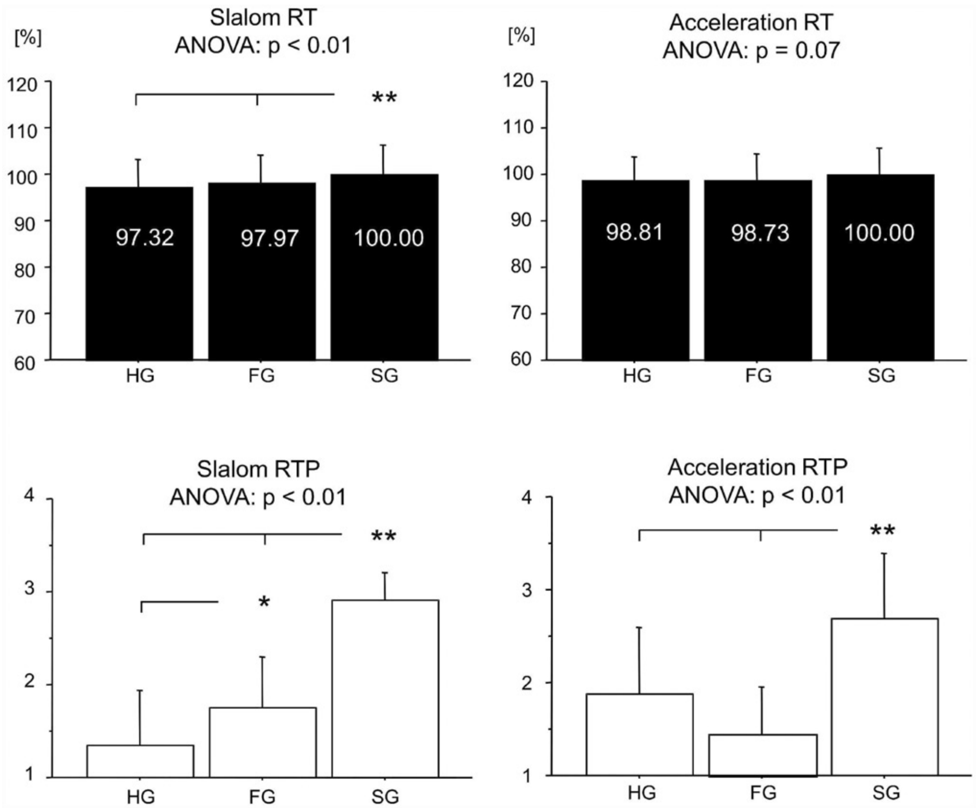

Figure 6. Means and SD for stud type results, running time as percentages (RT), running time perception as ranking from 1 (best) to 4 (worst) (RTP). Shoe conditions: hard ground (HG), firm ground (FG), soft ground (SG).

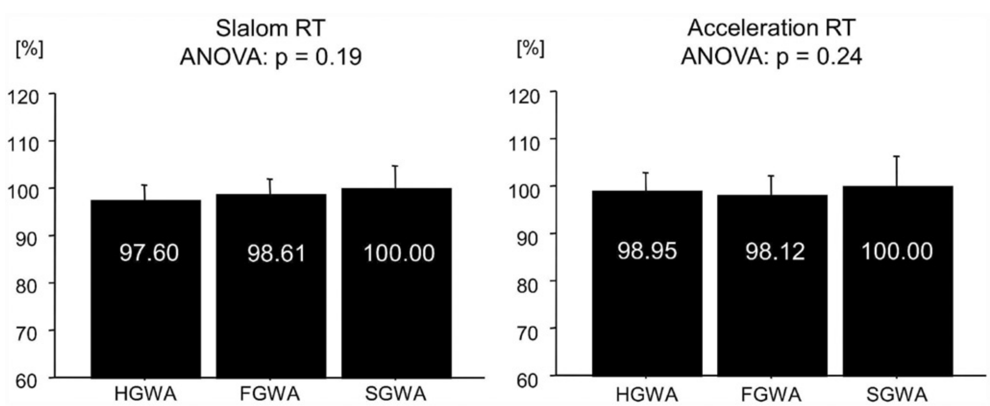

Figure 7. Means and SD for stud type and wet weather condition results, running time as percentages (RT). Shoe conditions: hard ground (HGWA), firm ground (FGWA), soft ground (SGWA).

conclude that, the soft ground stud configuration did not reveal superior functionality compared to the hard ground and the firm ground stud configuration also when used on wet artificial turf (Figure 7). This behaviour is in contrast to what is generally known for the situation on wet natural grass and should be considered in the design considerations of artificial soccer shoes.

Stud geometry

Stud geometry influenced running time in the slalom course ($P < 0.05$) but not in the acceleration course ($P = 0.88$). The bladed stud configuration allowed faster running than the elliptic stud configuration in the slalom course. However, in this case participants did not statistically perceive the performance benefit (Figure 8). The differences in statistical discrimination

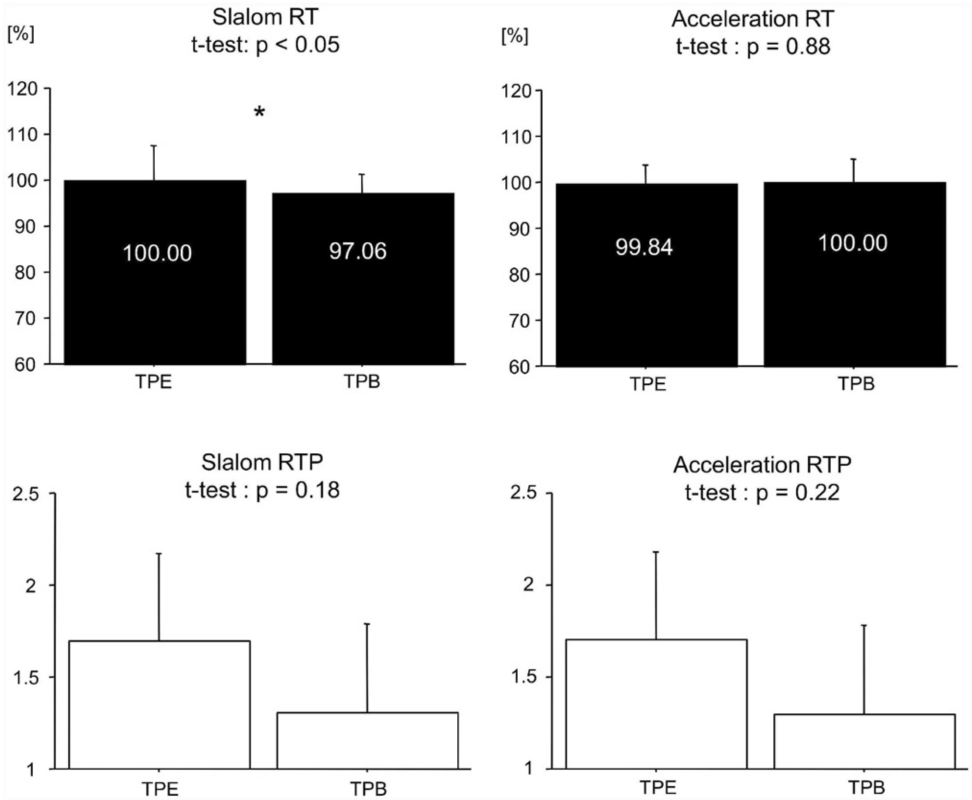

Figure 8. Means and SD for stud geometry results, running time as percentages (RT), running time perception as ranking with 1 (better) and 2 (worse) (RTP). Shoe conditions: Tiempo Premier elliptic (TPE), Tiempo Premier bladed (TPB).

between the two courses might be due to the shortness of the acceleration course. Also, the numerous cutting movements in the slalom course may require athletes to stronger utilize the peripheral bladed studs which provide better support during braking and propulsion in medio-lateral direction. This necessity may allow the slalom course to better discriminate between the shoe models in this study.

The finding that bladed studs performed better than elliptic studs confirms the results of Sterzing and Hennig (2005) reporting bladed studs to be perceived to provide better traction and stability to soccer players on natural grass turf.

Stud geometry and firm ground vs. ice-snow weather conditions

With regard to the slalom course, surface condition was responsible for 18% (bladed studs) to 21% (elliptic studs) of running performance difference ($P < 0.01$) when comparing faster running times on firm ground natural grass to slower times on natural grass covered by ice and snow (Figure 9). Additionally, results of this study indicate that a bladed stud configuration allows faster running on ice/snow surface conditions compared to an elliptic stud configuration. The reason for this is most likely that bladed studs are better suited to carve into an icy surface than elliptic studs, generating improved propulsion and braking mechanisms.

Stud length

Stud length influenced running time ($P < 0.01$) as well as running time perception ($P < 0.01$) in the slalom and acceleration course. Shortening and removal of the studs to 50% and 0% resulted in a considerable loss of running speed which was clearly matched by players' perception (Figure 10).

The results of this study, that longer studs improve functional traction properties were expected. However, it remains unanswered what the ideal stud length range is for a given stud configuration as stud length follows the rule of optimization rather than maximization. Therefore, longer studs (e.g., 110%) may further increase running performance. At the same time this might increase the risk of injuries due to creating a higher lever arm especially during medio-lateral oriented movements. Therefore, caution is required when conducting such tests or suggesting it for

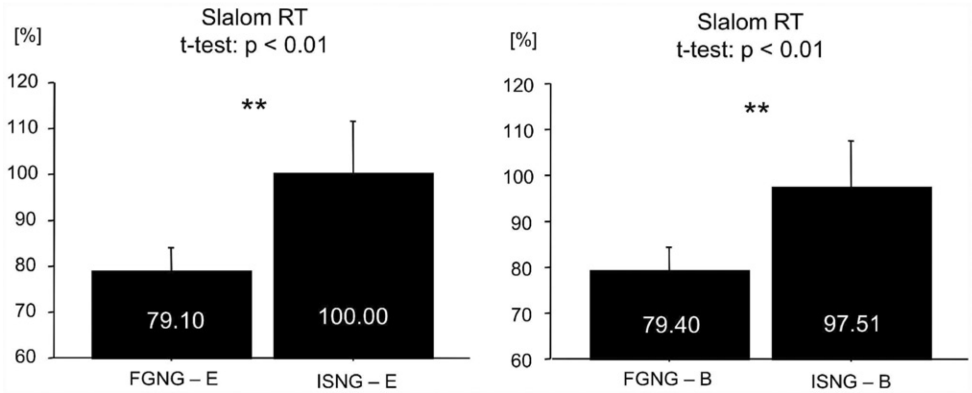

Figure 9. Means and SD for firm ground vs. ice-snow weather conditions results and stud geometry, running time as percentages (RT). Surface/shoe conditions: firm ground/elliptic (FGNG-E), ice-snow/elliptic (ISNG-E), firm ground/bladed (FGNG-B), ice-snow/bladed (ISNG-B).

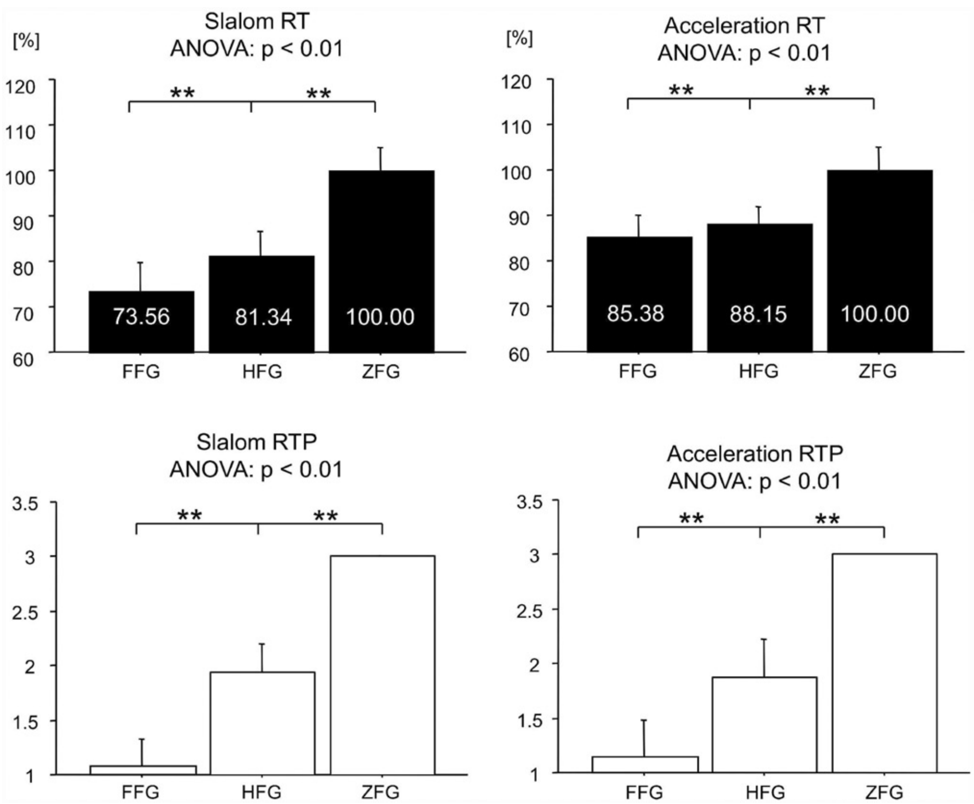

Figure 10. Means and SD for stud length results, running time as percentages (RT), running time perception as ranking from 1 (best) to 3 (worst) (RTP). Shoe conditions: full firm ground 100% (FFG), half firm ground 50% (HFG), zero firm ground 0% (ZFG).

practical use. The optimal stud length for the given stud configuration may be in between the FFG and the HFG model of this study (e.g., 60, 70, 80 or 90%). If the reduction of current stud lengths increases running performance or leaves it at least unaffected it would offer an opportunity to slightly reduce shoe weight.

Shoe weight

A considerable addition of shoe weight (70 g = > 35% increase) did not affect running performance of soccer players (Figure 11). Heavier shoes do not generally lead to reduced running performance during FTC testing. However, bigger weight increases might affect running performance. Also, considering a 90-min

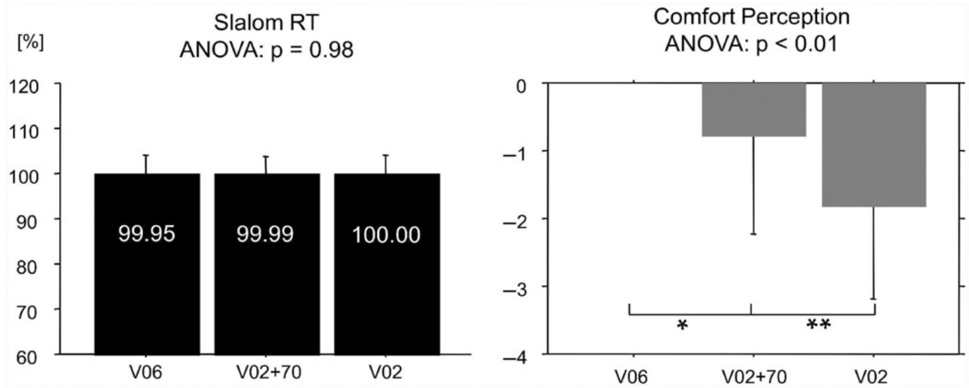

Figure 11. Means and SD for shoe weight and shoe comfort results, running time as percentages (RT), comfort perception as rating from 0 to –4: much more uncomfortable. Shoe conditions: Mercurial Vapor III (V06), Mercurial Vapor II plus 70 grams (V02 + 70), Mercurial Vapor II (V02).

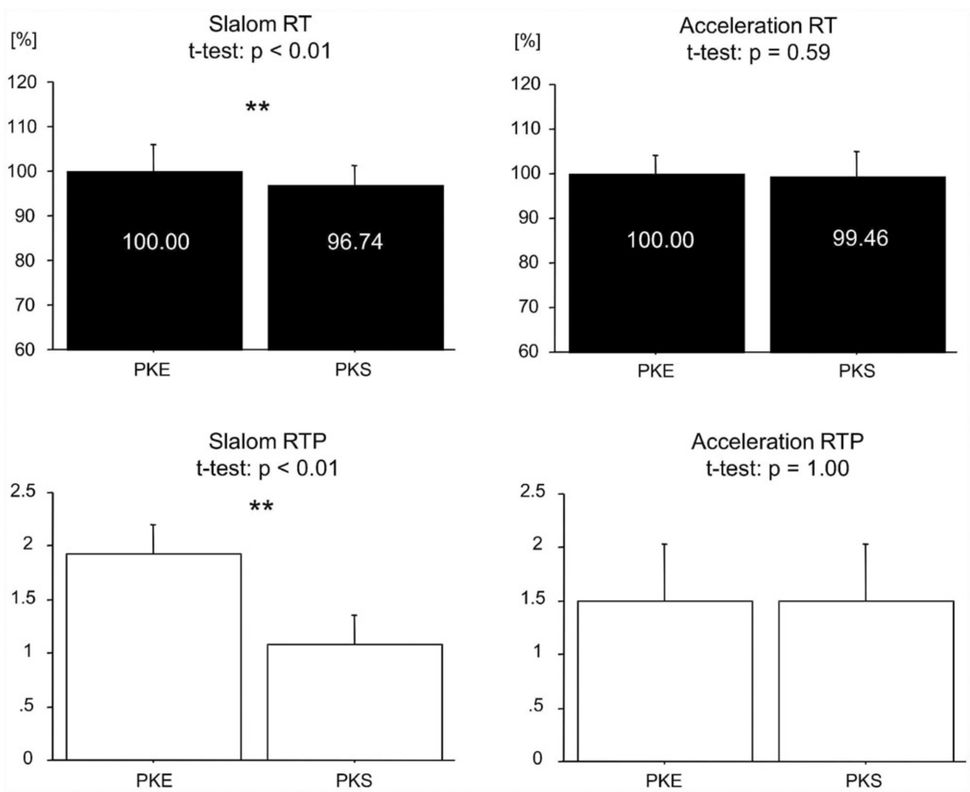

Figure 12. Means and SD for specific shoe models results, running time as percentages (RT), running time perception as ranking from 1 (better) to 2 (worse) (RTP). Shoe conditions: King firm ground (PKE), King synthetic (PKS).

game, increased shoe weight may influence the onset of fatigue. These considerations are linked to the finding that increased shoe weight in running results in higher VO_2 intake during endurance running (Frederick 1985). Therefore, weight still remains an important factor for research of running performance in soccer.

Apart from this, for this series of studies the weight indifference is an important finding as it indicates that the differences found in running performance in the other studies are not due to weight differences of the shoes.

Shoe comfort

Shoe comfort with respect to perceived heel counter stiffness did not affect running performance at all during FTC testing (Figure 11). This is remarkable as shoe comfort is given highest priority among shoe features by soccer players (Sterzing *et al.* 2007). It is concluded that soccer players are able to tolerate a certain amount of shoe discomfort during relatively short motor performance testing situations. The ability of neglecting discomfort and pain by participants during motor performance testing was also observed in a comparison of barefoot and shod kicking (Sterzing and Hennig 2008). In this study certain players did not show reduced kicking velocity when kicking barefoot despite facing an uncommon and painful situation. Although discomfort does not necessarily affect motor performance in relatively short testing situations it is likely to affect performance when being present over a longer period of time. Therefore, the importance of shoe comfort must not be neglected. Especially in full games and practice sessions shoe comfort needs to be considered as an important shoe feature in order to accommodate players' demands.

Specific shoe model

In the slalom course ($P < 0.01$) the shoe designed for artificial turf (PKS) evoked superior running performance compared to a shoe (PKE) designed for firm ground natural grass. This was reflected by participants' perception of their running speed. Increased performance of PKS is most likely due to the outsole configuration as it marks the biggest difference between both shoes. However, other shoe features might play a role, too. The acceleration course did not reveal differences between these shoes (Figure 12).

Conclusions

In this series of studies running performance differences caused by different footwear and surface conditions was up to 26.34%. Traction properties of soccer shoes were shown to be the predominant aspect with respect to running performance and thereby they affect playing performance. Perception of running performance was shown to be related to actual running performance.

Stud type, stud geometry and stud length as well as surface conditions considerably influenced running performance especially during slalom running. The influence of stud type (2.68%) and stud geometry (2.94%) on artificial turf is fairly similar. Removal of studs (26.34%) accounted for huge differences in running performance. Different surface conditions (ice/snow vs. firm ground) also showed big differences for elliptic (20.90%) as well as bladed (18.11%) stud configurations. Furthermore, specific shoe models (3.26%), incorporating several potentially interacting aspects evoked different running performance. The amount of running performance differences due to the single studies varied widely and has to be interpreted with respect to the characteristics of alteration of shoe/surface conditions.

This series of studies strongly suggests that the right choice of outsole configuration in soccer provides players with a considerable margin with respect to running and playing performance. The benefit of soccer shoe traction for running and playing performance was evidenced and quantified in these studies.

Shoe weight and shoe comfort did not show an effect on running performance in FTC testing. These observations underline that traction is the predominant influence that alters running times in functional traction course testing. As shoe bending stiffness of the test shoes was not quantified it needs to be kept in mind as another potentially influencing factor in this series of studies. Also, non-addressed properties of the shoe upper might influence running performance. Thus, the influence of lateral rearfoot and forefoot stability as well as fit on running performance and acceleration are worth to be assessed by FTC testing.

For differentiation purposes between shoe-surface conditions the slalom FTC is better suited than the acceleration FTC. This is most likely due to the longer distance of the slalom course and also due the multiple cutting and turning movements incorporated. These movements contain braking and propulsion components in medio-lateral direction as well as rotational components when turning around the pylons. It is concluded that these types of movement are much more dependent on functional traction than pure translational movement required in the acceleration course.

Players were well able to perceive running speed differences and thus performance benefits of the various shoe–surface interfaces. This confirms the observation that measured grip is similar to perceived grip (Coyles *et al.* 1998). Additionally, it confirms that traction is an important factor with regard to cognitive aspects affecting players' performance. Furthermore, a sound positive interrelation between objective running time data and subjective-sensory data was shown in the presented studies.

The concept of FTC may be easily expanded to other types of sports and their corresponding footwear. This should be done especially in these sports requiring rapid movements with active and reactive changes of directions, e.g., field hockey, basketball or handball. In contrast to soccer, traction in these types of sport is predominantly dependent on material friction characteristics of the interface between shoe and surface and to a lesser extent dependent on geometric shape of the outsoles of the specific footwear. It will be interesting to see whether running performance is also dependent on footwear in these sport specific traction circumstances.

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