Thieme

# Current Soccer Footwear, Its Role in Injuries and Potential for Improvement



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**ABSTRACT**

Soccer is the most popular sport in the world and generates great financial revenue. It is also a sport whose practice has evolved considerably in terms of intensity and commitment, and in which the intrinsic risk of injury (not directly related to an interaction with the environment) is particularly high. In this context, the cleated shoe as a major component of soccer equipment may play a key role in the overexposure to injury. Soccer shoe evolution is all the more challenging, because design and mechanical structure differ in many points compared to other modern shoes developed for sports such as running, tennis and basketball.

This critical review aims to elucidate the characteristics of modern soccer footwear and their possible link to soccer-specific injuries, focusing on the following areas: (1) ergonomics, comfort and proprioception; (2) shoe mechanical characteristics; (3) field surfaces and shoe design.

## Introduction

Soccer is a very popular sport worldwide and generates great financial revenue [78]. It is also a sport whose practice has evolved significantly in terms of intensity and commitment. Athletic and technical skills such as speed, strength, vertical jump, endurance and reactivity are continually increasing [43]. These expanded athletic and technical skills correlate with an increase in injuries, averaging 8 per 1000 h of practice, with an overall average of 2 injuries per player/per season among professional players [29]. It represents significant health costs, estimated at 1.6 billion USD each year worldwide [107]. The most common injuries are hamstring strain (12 %), adductor pain/strain (9 %), ankle sprain (7 %), quadriceps strain (5 %) and MCL knee sprain (5 %) [43]: the majority of these injuries concern intrinsic mechanisms (i. e., not directly related to an interaction with the external environment, ball or another player) and are located in the lower limbs. Otherwise, overuse injuries are consistent, accounting for almost one third of total injuries [43]. The cleated shoe, the main equipment of the soccer player, is the interface between the player and the surface on which he evolves: as such, it represents a critical point of injury prevention.

When considering other popular sports, one can note that iconic models, such as basketball's Converse All Star (1921) or tennis's Adidas Stan Smith (1964) shoes are characterized by a single-material outsole with minor anterior-posterior pitch. However, the

modern versions of these sports shoes are much more complex: several different materials, significant anterior-posterior pitch, greater arch support, and stress absorption and/or motion control elements. Compared to these shoes, the soccer shoe outsole may appear less technical. As emphasized in Walter [112], regular soccer outsoles do not include specific devices for absorbing impacts or supporting plantar arches. In the most recent models, the vamp is often directly stuck to a mono-material polyurethane outsole without significant anterior-posterior pitch and with a relatively constant thickness.

In this context, the objective was to identify the possible links between soccer shoe design and the most common soccer-specific injuries in order to suggest possible directions for improvement.

A comprehensive and critical review of the current available literature regarding the main characteristics of modern soccer shoes, their link to constraints and biomechanics and finally their potential role in injury is proposed. Papers were collected through a review of the literature using PubMed and ScienceDirect databases, targeting the following terms: "soccer, football, footwear, shoes, cleat, boot, biomechanics, risk of injury, risk factor, injury and prevention". All titles and abstracts were carefully read and relevant articles were retrieved for review. Running shoe research predates that of soccer shoe research and is more complete. Thus, some key words were cross-referenced with the term "running" in order to collect data that could provide transposable and comparative analyses to those of the soccer shoe. Results were grouped and commented according three major themes: (1) ergonomics, comfort and proprioception; (2) shoe mechanical characteristics; (3) field surfaces and shoe design.

## Ergonomics, Comfort and Proprioception

### Ergonomics and comfort

Comfort was previously reported as being paramount when purchasing a pair of soccer shoes [44]. The ergonomic inadequacies of the soccer shoe have been regularly associated with a feeling of impaired comfort as well as an increased risk of injury [56, 57, 68, 78]. In a study conducted among professional rugby players, it was emphasized that a program of customization of footwear would offer higher levels of protection against injuries, as well as comfort perception [58]. More recently, same authors correlated comfort with improved performance in soccer and concluded by recommending greater consideration for playing conditions, particularly playing field surfaces [57]. They added that inadequacies of today's soccer shoe lead to a decrease in movement efficiency and serve as an obstacle to performance and injury prevention.

The relationship between plantar pressure peak levels and perceived comfort was previously underlined in several studies [13, 45, 50, 73, 97]. The soccer shoe's lack of protection against high peak pressures had already been pointed out by the 1990s [67]. The surface distribution of plantar pressure decreases by 8 % in a soccer shoe compared to a running shoe, while pressure peaks rise 35 % [19, 89]. Debiasio et al. [23] recorded plantar pressures during jumping on three different shoes: cleated soccer shoes, artificial-turf-specific soccer shoes, and running shoes. Forefoot pressure was found to significantly increase with cleated shoes, while the running shoes presented lower overall peak stress levels and larger contact surface in the midfoot region. These effects of midfoot arch support have been also clearly described by Zhang and Li [122].

### Proprioception

The importance of improving proprioceptive stimulation was recently pointed out [110]–[111]. Inadequate sensory feedback induces poor balance control and is correlated with a high risk of ankle sprain [109]–[110]. This proprioceptive alteration in soccer players is even more negative because stability diminishes with fatigue, thus increasing the risk of injury [120]. It seems that there is also a strong interest in developing models of boots that include a midfoot arch support. Indeed it significantly increases the area of plantar contact and thus the sensatory input and balance control [12, 14, 66, 76, 121]. At the same time, it improves constraints distribution and comfort with a positive correlation with injury prevention [56, 58] and performance [57].

As proposed in Waddington [111], an original sole design with textured areas of plantar stimulation could be incorporated to improve proprioception. Furthermore, an unsmooth insole surface could limit the foot slipping inside the shoe. However, the comfort or discomfort that such relief might produce needs to be considered.

### Fit

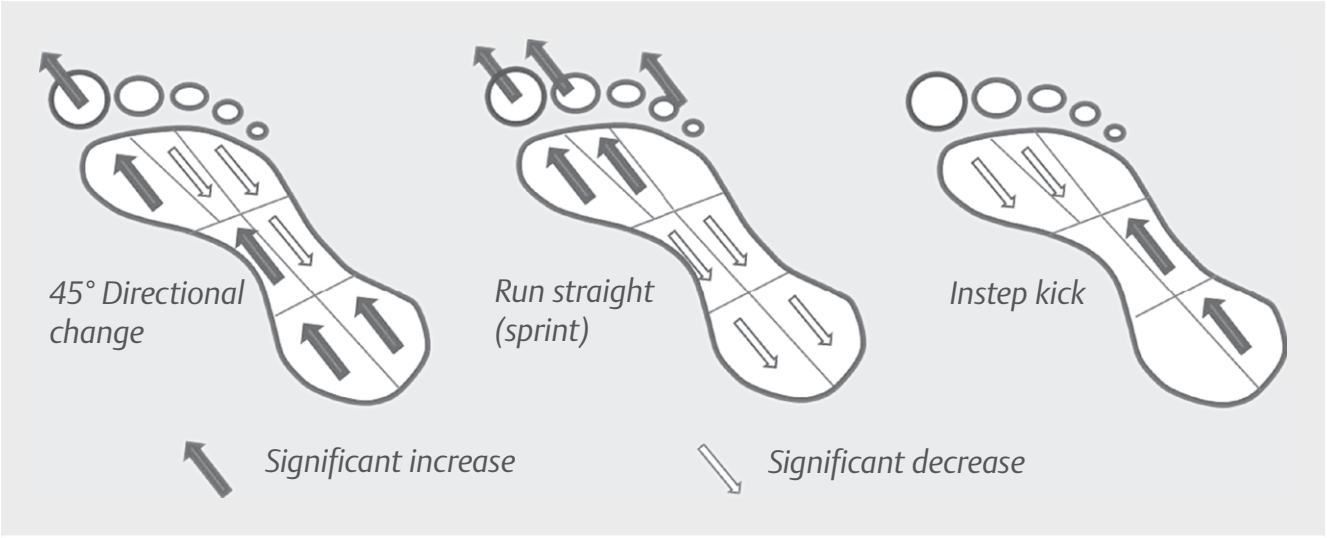
In order to improve the foot-shoe interface, avoid bothersome slips and improve sensing the ball, players also tend to severely tighten their shoe laces and compress their feet in the shoe, and often buy shoes one or two sizes too small [44]. Compressing the forefoot is apt to result in a hallux valgus, tensing up the medial collateral ligament and risking "turf toe" [108]. In addition, the narrowness of the vamp is probably linked to toe convergence and deformities such as hallux valgus, quintus varus, corns, calluses and nail lesions or fungi [26]. Kinchington et al. [58] suggested that programs of individualization and customization of soccer shoes should be proposed, in order to prevent inadequate behaviors such as voluntarily choosing a model that is too small.

## Shoe Biomechanical Characteristics

### Mediolateral stresses

From a dynamic point of view, there is a natural predominance of pronation in most runners [13, 77]. As exercise time increases, pronation tends to increase due to eccentric fibular muscle fatigue [39]. The increasing distance of running in modern soccer exposes the player to this phenomenon [43]. The pronation tendency and medial stress predominance were identified in typical soccer movements (running straight, side-steps, 45 ° directional changes, jump landings) [118]–[119] (▶ **Fig. 1**). Medial hyperpressure could be the cause of overexertion injuries of the first ray such as early hallux rigidus or valgus [108] (especially from tight shoes [60]) or first metatarsal stress fracture [113]. Overpronation is also described as a risk factor for patellofemoral disorders, calcaneal tendinopathy and plantar fasciitis [11, 81, 88, 114].

Soccer is not limited to the four movements mentioned above and the tendency to medial hyperpressure does not explain the high incidence of fatigue fractures of the fifth metatarsal




▶ **Fig. 1** Pressure distribution in three typical soccer play maneuvers.

[53, 94, 96]. A supination tendency and hyperpressure at the lateral part of the support foot in movements such as the instep kick have been previously noted (▶ **Fig. 1**) [27, 41, 43].

Soccer is a multitask sport and depending on the type of movement being considered, opposite arches are respectively overstressed. Incorporating a longitudinal midfoot arch support could limit and better distribute stresses to minimize injury risks, but unlike running, which is a sport whose constraints vary little for a defined subject, it does not seem appropriate to develop specific models of soccer shoes targeted on antipronation or antisupination. Possible benefits of a midfoot support were previously supported, possibly even coupled to a wraparound heel designed to contain the mediolateral roll movements [122].

However, plantar morphotypes are extremely varied. A flat foot cannot tolerate a pronounced arch support, whereas a pes cavus requires a more pronounced height in order to receive the benefits of effective support. A design for a standardized arch support can be difficult to define and must remain moderate, even if it needs to be corrected through a custom-made orthotic for significant deformations.

## Tendency to dorsiflexion and decreased range of motion

From a static perspective, the stresses related to body weight are distributed according to a tripod formed at the rear by the calcaneal support, at the anteromedial level by the first metatarsal head, and at the anterolateral level by the fifth metatarsal head. The posterior region supports 50 % of the body weight, 35 % is supported by the anteromedial arch and the anterolateral arch supports 15 % [51].

Apart from the hard ground on which some forms of indoor football are practiced, all the playing surfaces (natural grass, synthetic turf, hybrid turf or stabilized) have a potential for compressibility. Taking into account the distribution of static body weight in the shoe, the heel, which supports most of the weight, will tend to sink more into the playing field, especially as the heel area's bearing is lower than the forefoot. Thus, as described in Walter [112], the static reference position of a shod player on the field is characterized by a slight deflection of the rear foot on the ground and a tendency to dorsiflexion (▶ **Fig. 2**).

Most soccer players are in a heel strike pattern for the greater part of their activities: most of the distance is run at a moderate pace, followed, in descending order, by walking, sprinting and running backwards [118]. During walking, the heel impacts on the ground with a force on the order of 1.5 times body weight; for running speeds ranging between 3 m/s to 5 m/s, it reaches around 2 times body weight [2, 77]. The tendency to dorsiflexion in soccer players is even noticeably stronger on soft ground.

Moreover, an athlete wearing cleated soccer shoes has an ankle dorsiflexion angle that is 7 ° greater compared to running shoes, both in the standing position and during the support phases of running [112]. This initial ankle dorsiflexion decreases the functional range of motion (RoM) of the remaining available dorsiflexion and seems to be correlated with the high stress to which the sural/Achilles/plantar complex and calcaneus is exposed: twice as much in soccer shoes as compared to running shoes, according to Walter [112]. This reduced functional RoM could be a risk factor for various lower limb disorders [52], as discussed hereafter.

Ankle dorsiflexion limitation is identified as a risk factor for both lateral ankle sprains [20, 30, 32, 101] and syndesmosis sprains [69, 80, 116]. Tibiofibular syndesmosis, and particularly the antero-inferior tibiofibular ligament, tenses up with ankle dorsiflexion. The soccer players' tendency to dorsiflexion therefore decreases ankle ability to absorb an important dynamic dorsiflexion, which thus increases the risk of injury. The functional dorsiflexion stance in soccer shoes promotes repeated microtrauma of the anterior part of talocrural joint and contributes to the development of anterior ankle impingement [102–104]. The evolution of chronic anterior ankle impingement consists in chronic inflammation with bone and fibrous remodeling that leads to a progressive anatomical and irreversible limitation of ankle dorsiflexion RoM. Thus, it ap-

▶ **Fig. 2** Schematic profile of a foot in a cleated shoes on natural grass. Tendency to dorsiflexion.

pears a vicious circle in which the functional limitation and the anatomical limitation are increased respectively.

Limitation of ankle dorsiflexion RoM is described as a risk factor in foot and ankle posterior chain disorders: Sever's disease [7, 112], plantar fasciitis [55, 85] and calcaneal tendinopathy [82]. As the posterior chain can be considered as an overall functional entity, it would be interesting to assess how ankle dorsiflexion limitations could predispose one to injuries of farther elements, whether it is calf, hamstring or even the lumbar spine erector muscles. In fact, these three entities in the large posterior chain are also frequently injured in soccer practice [28]–[29].

Limitation of ankle dorsiflexion is also suspected to increase anterior and posterior intracompartmental pressures in the leg, resulting in an accrued risk of chronic compartment syndrome and tibial fractures [105].

Several studies report that initial dorsiflexion upon landing from a jump is a risk factor for the knee, anterior cruciate ligament (ACL) injury in particular [9, 10, 17, 62]. Conversely, an increase in ankle dorsiflexion RoM during landing provides improved knee flexion, while reducing the stresses transmitted to the lower limb, thus limiting the risk of ACL injury [31]. Limitation of ankle dorsiflexion was also associated with knee pain and patellar tendinopathy [11, 70, 72, 90, 95].

To reduce the dorsiflexion RoM limitation observed in the shod soccer player, incorporating a posterior elevated heelpiece might be possible. This kind of device has already been proposed to treat primary and secondary posterior chain injuries [1, 4, 65, 71, 79, 92, 122]. The heelpiece is usually made of visco-elastic materials and it is difficult to clearly determine if the benefits come from a posterior chain release or from stress absorption by the materials [122].

The release of the posterior chain with a heel-rise poses another problem: that of mechanical efficiency and energy costs. Even if restitution of elastic energy stored at the plantar fascia and calcaneal tendon play an important role in both propulsion and energy economy while running [91], in many sports having long, significant exertion periods and varied stresses, footwear with an anterior-posterior pitch has been widely adopted. The loss of elastic energy seems to be offset by other factors such as comfort and protection, which also contribute to performance [93]. For example, the thrust in volleyball and basketball plays a fundamental role in performance, yet the shoes for these sports usually present an anterior-posterior pitch.

However, any heel elevation must be thoughtfully evaluated in order to avoid an ankle position with pronounced plantar flexion. Indeed, an ankle position in plantar flexion would expose the player to increased pressure on the forefoot [48, 89] and other specific injuries such as posterior impingement syndrome [38]. Moreover, one observes in plantar flexion an unlocking of tibiofibular syndesmosis, which could be a source of instability and damage [69].

A more acute analysis of sports shoes that present an anterior-posterior pitch determines that the heel-rise is never isolated; it is systematically associated to a midfoot arch support. Indeed, it was demonstrated that such a design allows limiting the load displacement from the rearfoot to the forefoot so that no (or less marked) overloading is observed in the forefoot [12, 66, 121].

## Field Surfaces and Shoe Design

### Field surfaces

Based on epidemiological studies, no significant difference in the average risk of acute injury (including ACL) was previously reported if we compare the practice of football on natural grass and most recent synthetic turf [64, 117].

Nevertheless, it was shown that nonfilled synthetic turf leads to lower stress levels in rotational movements than natural grass [98]. On the other hand, filled synthetic turf leads to higher stress levels so is more constraining than natural grass [33, 98]. Moreover, the feet of soccer players were reported to experience more medial edge stress on natural grass and conversely, more lateral edge stress on synthetic surfaces [33]. Bentley et al. [8] hypothesized that players are at lower risk of injury when subjected to stress levels close to those observed on natural grass. Because soccer is a multitask activity with a global tendency to pronation [119] that also induces significant hyperpressure on the lateral side of the foot during practice [27] (▶ **Fig. 1**), the safest surface between natural and synthetic grass remains unclear.

### Cleats

Cleats play a fundamental role in the traction process. Under optimal conditions, the type and location of cleats influence the running speed by only 3 % [99]. Still, 3 % can be a decisive factor in the game's outcome.

The number and distribution of cleats is assumed to diffuse stress, reduce pressure peaks and improve stability and comfort [63, 68], although there is no clear ideal definition of cleat positioning, given the wide variations in feet morphology [18]. Nonetheless, to reduce injury risks, Coyles and Lake [18] proposed increasing the number of cleats as well as incorporating protective materials at the forefoot.

Cleat behavior may be also sensitive to ground stiffness: cleats do not completely sink into a hard surface, and the contact does not occur on the entire outsole. In this context, changes in traction properties are observed with a greater risk of injury and impaired performance. On hard surfaces, it can be inferred that increasing the number of cleats improves stress distribution, and cleat height should be limited in order to maximize penetration and allow better-distributed stress along the outsole [16, 59]. However, increasing the number and distribution of cleats needs to be thoughtfully evaluated in order to avoid a design which might strongly resist axial rotations.

The issue of cleats involves finding a compromise between traction, penetration and stress distribution versus rotational torque, which is associated with a risk of injury to the knee central pivot. The cleat geometry debate began in the 1990s [68], and the potential risk associated with the use of bladed cleats continues. For example, publications investigating the influence of cleat geometry on ACL stress in rotation point to conflicting results [25, 37, 98]. Studies that found no significant difference used a very high pre-axial stress on the order of 1000 N [37]. Conversely, significant differences with increased constraints for the bladed design were highlighted for less significant pre-axial stress on the order of 500 N and under [98]. Drakos et al. [25] demonstrated that the ligament tension progressively increased to 500 N before reaching a steady state, probably due to the limits for joint contacts, identified by authors as a natural protective strategy for the ACL. From these results, they established that 500 N is the most indicated axial loading force that should be exerted before rotation when studying cleat effects on the ACL. For studies that did not show any difference, it seems that the level of axial stress was not realistic and did not allow for detecting any influence of cleat geometry during rotations.

Despite the lack of evidence, we observe a trend towards the gradual disappearance of blades. The bladed cleats still in use have significantly shortened longitudinally so as to reduce any resistance to rotational movements. Many new models are returning to conical shapes, offer a mix of short blades and conical cleats, or adopt original designs with poor resistance to rotation (▶ **Fig. 3**).

### The height of the ankle cut

A newly designed soccer shoe has recently emerged with a woven synthetic fiber vamp extending above the ankle in order to achieve a shoe with a high-cut ankle (▶ **Fig. 4**). Strictly speaking, a high-cut soccer shoe is not a novelty, because the first soccer shoes in the late 19th century evolved from workers' leather boots and had nails driven through the sole for cleats. The debate on the height of the ankle cut is not new and has seen lively deliberation on the risks of lateral ankle sprain in certain sports. A study by Johnson et al. in 1976 [49] suggested that high-cut shoes are effective in preventing ankle sprains provided they are, above all, rigid and of sufficient height. The efficiency of high-cut shoes in preventing lateral ankle sprains remains controversial [5, 6, 40, 87]. Based on twenty prospective studies, Barker et al. [5] reported that a high cut did not reduce the risk of recurrent ankle sprain, as opposed to using specific orthotics. More recently, it was shown that wearing high-cut shoes may cause a pre-activation delay and a decrease in the amplitude of the ankle eversion muscle activity [36], which is a risk factor for a potential lateral ankle sprain [54, 61, 84]. The recent study published by Fu et al. compared both high-cut and low-cut basketball shoes and linked the high-cut design to electromyographic disturbances of the ankle eversion muscles [36]. This raises some safety concerns about the new high-cut soccer models. Nevertheless, although still unconfirmed, it seems that the tested basketball shoe's ankle stiffness is greater than that observed in the new soccer shoe, which implies that we cannot directly transpose their results to those models.

The player's frame in basketball, his repeated jumps, reflex ground support, and contacts all overexpose him to lateral ankle sprain. This sport has kept its stereotypical high-cut shoes until recently, although more and more players, including the highest NBA achievers, are currently playing in mid-cut and even low-cut shoes.

On the one hand, the basketball shoe is evolving towards a lower ankle cut based on scientific data. On the other hand, although soccer footwear did follow that path more than 60 years ago, it seems to be taking the opposite path in the form of this new type of design (▶ **Fig. 4**).

## The soccer shoe's trend towards minimalism

The minimalist running shoe is characterized by ultralightweight materials, reduced sole thickness, little to no anterior-posterior pitch, and a very thin vamp, aimed at providing the runner with a supposedly natural, almost barefoot sensation. It obviously has limited protection against shocks, and many studies underline increased stresses and injury risk with the minimalist style [21, 22, 24, 46, 74, 87].

Several authors mention that soccer shoe brands update their shoes with claims of increased player speed and power shoot, improved endurance and improved ball touch by proposing increasingly lighter and thinner materials along minimalistic lines, yet they still harbor the risks [41, 44, 75, 78].

The Amos and Morag study is the only to mention increased foot speed when kicking with lighter shoes [3]. On the contrary, Hennig and Sterzing suggest that the increased inertial energy related to weight compensates for any reduction of the kinetic energy associated with decreased speed [42]. The highest foot speed and forceful kicking strength are observed in bare feet. This phenomenon is not due to lack of extra weight but to two other parameters. First, the support foot's proprioception is significantly higher than it is with a shod foot: this has been described as crucial in both precision and kicking power [15, 42]. Secondly, without footwear, and therefore without a rear abutment at the Achilles tendon, an increased degree of plantar flexion occurs upon impact. This translates to optimal alignment, a significant lever arm and increased torque [42, 100].

Lighter shoes are often assumed to be responsible for lower energy consumption. According to Frederick, each additional 100 g of shoe weight increases energy consumption by 1 % [35]. More recently, Shorten reported that reducing energy consumption should not compromise protection against injuries: the mechanical benefits and special features incorporated for a moderate surplus weight can prevent patellofemoral pain, calcaneal tendinopathy, stress fractures or other diseases of the lower limbs [94]. Moreover, long-term performance significantly benefits from footwear with high technical characteristics, compared to the cost of any

▶ **Fig. 3** Pictures of recent models. Left, conical cleats. Right, polyhedra cleats without strong longitudinal component.


▶ **Fig. 4** **a** low-cut soccer shoe, **b** recent high-cut soccer shoe, **c** high-cut basketball shoe, **d** recent low-cut basketball shoe.

slight increase in instantaneous energy consumption. According to Wierzbinski [115] and Tung et al. [106], shoes with dynamic materials can be more efficient in terms of energy consumption than running barefoot. This result was confirmed by Franz et al. [34]: even if low shoe weight is generally related to low energy consumption, the shoe's mechanical properties with specific devices can ultimately obtain better energy efficiency.

Slade et al. reported that only 30 % of players were able to accurately perceive the shoe weight [97]. A difference of weight greater than 140 g was required in order for most subjects to be able to identify the heaviest shoe model between those tested. By contrast, 92 % of the volunteers were able to identify the heavier shoe when using their hands. When buying a pair of shoes in a store, the customer usually handles the shoes before trying them on. This first impression, along with the advertising message touting the benefits of lightweight shoes, may lead the customer to buy the lightest pair, which is sometimes at the expense of technical, comfort and aesthetic criteria.

## Conclusion

The analysis proposed in this paper reveals a number of areas in which the soccer shoe could be optimized:

(1) Optimized ergonomics such as arch supports and the use of specific materials (possibly combined) seem capable of reducing the potentially pathogenic stress peaks and improving perceived comfort. Introduction of proprioceptive stimulation devices should be considered with interest.
(2) The structure of the soccer shoe should contribute to the preservation of RoM in ankle dorsiflexion and consequently minimize exposure to acute and chronic pathologies associated with the limitation of this parameter.
(3) Given the conflicting results reported in literature, it seems prudent to opt for a cleat design that moderately resists axial rotational movements in order to avoid injuries of the knee's central pivot. In addition, simple, accurate and reliable guidelines should be developed to enable users to choose a type of cleated shoe best suited to their specific playing conditions.

(4) Woven-synthetic soccer shoe models with a high-cut ankle recently appeared on the market. To date, there is no scientific evaluation for this type of shoe. On the other hand, basketball's shift from a traditionally high-cut ankle to a lower cut is based on scientific evidence.
(5) There is no strong argument favoring extreme weight reduction of the soccer shoe, whether for comfort or for performance. On the contrary, many studies endorse a heavier shoe with embedded technical devices to improve protection, comfort and performance. The right balance between weight and technical features needs to be found.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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