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

OPEN ACCESS

Authors
Sylvain Blanchard[1], Jérôme Palestri[2], Jean-Luc Guer[2], Michel BEHR[1]

Affiliations
1 Laboratoire de Biomécanique Appliquée, Aix-Marseille Univ, IFSTTAR, LBA UMR_T24, Marseille, France
2 Wizwedge SARL, Research Department, Marseille, France

Key words
sports medicine, athletic injuries, biomechanics, footwear

received 11.12.2017
revised 24.03.2018
accepted 30.03.2018

Bibliography
DOI https://doi.org/10.1055/a-0608-4229
Sports Medicine International Open 2018; 2: E52–E61

ISSN 2367-1890

Correspondence
Dr. Sylvain Blanchard
Laboratoire de Biomécanique Appliquée
Aix-Marseille Univ
IFSTTAR, LBA UMR_T24
boulevard Pierre Dramard
13015, Marseille
France
Tel.: +33/491/658 014, Fax: +33/146/316 625
sylvain.blanchard@ifsttar.fr

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

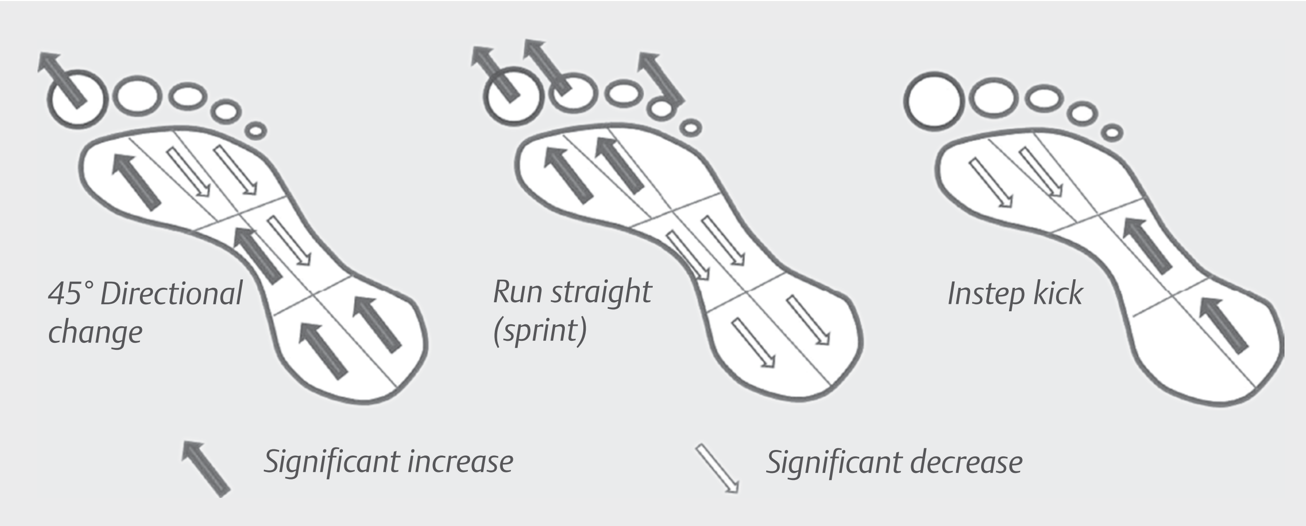
In order to improve the foot-shoe interface, avoid bothersome slips and improve sensing the ball, players also tend to severely tighten their shoe laces and compress their feet in the shoe, and often buy shoes one or two sizes too small [44]. Compressing the forefoot is apt to result in a hallux valgus, 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.

References

[1] Alfredson H, Cook J. A treatment algorithm for managing Achilles tendinopathy: New treatment options. Br J Sports Med 2007; 41: 211–216

[2] Allard P, Bianchi JP. Analyse du mouvement humain par la biomécanique. Mont-Royal: Décarie Editeur Inc; 1996

[3] Amos M, Morag E. Effect of shoe mass on soccer kicking velocity. Proceedings of the Fourth World Congress of Biomechanics. Calgary: Omnipress; 2002

[4] Baldassin V, Gomes CR, Beraldo PS. Effectiveness of prefabricated and customized foot orthoses made from low-cost foam for noncomplicated plantar fasciitis: A randomized controlled trial. Arch Phys Med Rehabil 2009; 90: 701–706

[5] Barker HB, Beynnon BD, Renström PA. Ankle injury risk factors in sports. Sports Med 1997; 23: 69–74

[6] Barrett JR, Tanji JL, Drake C, Fuller D, Kawasaki RI, Fenton RM. High- versus low-top shoes for the prevention of ankle sprains in basketball players. A prospective randomized study. Am J Sports Med 1993; 21: 582–585

[7] Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Rodriguez-Sanz D. Static and dynamic plantar pressures in children with and without Sever disease: A case-control study. Phys Ther 2014; 94: 818–826

[8] Bentley JA, Ramanathan AK, Arnold GP, Wang W, Abboud RJ. Harmful cleats of football boots: A biomechanical evaluation. Foot Ankle Surg 2011; 17: 140–144

[9] Bere T, Flørenes TW, Krosshaug T, Koga H, Nordsletten L, Irving C, Bahr R. Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing: A systematic video analysis of 20 cases. Am J Sports Med 2011; 39: 1421–1429

[10] Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: Abnormalities in hip and ankle kinematics. Am J Sports Med 2009; 37: 252–259

[11] Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: The Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. Am J Sports Med 2009; 37: 2108–2116

[12] Bonanno DR, Landorf KB, Menz HB. Pressure-relieving properties of various shoe inserts in older people with plantar heel pain. Gait Posture 2011; 33: 385–389

[13] Che H, Nigg BM, de Koning J. Relationship between plantar pressure distribution under the foot and insole comfort. Clin Biomech 1994; 9: 335–341

[14] Chen TH, Chou LW, Tsai MW, Lo MJ, Kao MJ. Effectiveness of a heel cup with an arch support insole on the standing balance of the elderly. Clin Interv Aging 2014; 9: 351–356

[15] Chew-Bullock TS, Anderson DI, Hamel KA, Gorelick ML, Wallace SA, Sidaway B. Kicking performance in relation to balance ability over the support leg. Hum Mov Sci 2012; 31: 1615–1623

[16] Clarke JD, Carré MJ. Improving the performance of soccer boots on artificial and natural soccer surfaces. Procedia Eng 2010; 2: 2775–2781

[17] Cortes N, Morrison S, Van Lunen BL, Onate JA. Landing technique affects knee loading and position during athletic tasks. J Sci Med Sport 2012; 15: 175–181

[18] Coyles VR, Lake ML. Forefoot plantar pressure distribution inside the soccer boot during running. Research Institute for Sport and Exercise Science 1999. UK: Liverpool John Moores University;

[19] De Castro MP, Meucci M, Soares DP, Fonseca P, Borgonovo-Santos M, Sousa F, Vilas-Boas JP. Accuracy and repeatability of the gait analysis by the WalkinSense system. Biomed Res Int 2014; 348659

[20] De Noronha M, França LC, Haupenthal A, Nunes GS. Intrinsic predictive factors for ankle sprain in active university students: A prospective study. Scand J Med Sci Sports 2013; 23: 541–547

[21] De Wit B, De Clercq D, Aerts P. Ground reaction forces and spatio-temporal variables during barefoot and shod running. In: Abrantes J. (ed.), Proceedings of the XIVth symposium on biomechanics in sports. 1996: 252–255

[22] De Wit B, De Clercq D, Aerts P. Biomechanical analysis of the stance phase during barefoot and shod running. J Biomech 2000; 13: 269–278

[23] Debiasio J, Russell M, Butler R, Nunley J, Queen R. Changes in plantar loading based on shoe type and sex during a jump-landing task. J Athl Train 2013; 48: 601–609

[24] Divert C, Mornieux G, Baur H, Mayer F, Belli A. Mechanical comparison of barefoot and shod running. Int J Sports Med 2005; 26: 593–598

[25] Drakos MC, Hillstrom H, Voos JE, Miller AN, Kraszewski AP, Wickiewicz TL, O'Brien SJ. The effect of the shoe-surface interface in the development of anterior cruciate ligament strain. J Biomech Eng 2010; 132: 011003

[26] Dueñas L, Ferrandis R, Martinez A, Candel J, Arnau F, Villanueva J. Application of biomechanics to the prevention of overload injuries in elite soccer players. In: Gianikellis KE. (ed.), Proceedings of the XXth Symposium on Biomechanics in Sports. Cácares: 2002: 585–588

[27] Eils E, Streyl M, Linnenbecker S, Thorwesten L, Völker K, Rosenbaum D. Characteristic plantar pressure distribution patterns during soccer-specific movements. Am J Sports Med 2004; 32: 140–145

[28] Ekstrand J, Hägglund M, Kristenson K, Magnusson H, Waldén M. Fewer ligament injuries but no preventive effect on muscle injuries and severe injuries: An 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med 2013; 47: 732–737

[29] Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: The UEFA injury study. Br J Sports Med 2011; 45: 553–558

[30] Ferran NA, Maffulli N. Epidemiology of sprains of the lateral ankle ligament complex. Foot Ankle Clin 2006; 11: 659–662

[31] Fong CM, Blackburn JT, Norcross MF, McGrath M, Padua DA. Ankle-dorsiflexion range of motion and landing biomechanics. J Athl Train 2011; 46: 5–10

[32] Fong DT, Chan YY, Mok KM, Yung PS, Chan KM. Understanding acute ankle ligamentous sprain injury in sports. Sports Med Arthrosc Rehabil Ther Technol 2009; 1: 14

[33] Ford KR, Manson NA, Evans BJ, Myer GD, Gwin RC, Heidt RS, Hewett TE. Comparison of in-shoe foot loading patterns on natural grass and synthetic turf. J Sci Med Sport 2006; 9: 433–440

[34] Franz JR, Wierzbinski CM, Kram R. Metabolic cost of running barefoot versus shod: Is lighter better? Med Sci Sports Exerc 2012; 44: 1519–1525

[35] Frederick EC. Physiological and ergonomics factors in running shoe design. Appl Ergon 1984; 15: 281–287

[36] Fu W, Fang Y, Liu Y, Hou J. The effect of high-top and low-top shoes on ankle inversion kinematics and muscle activation in landing on a tilted surface. J Foot Ankle Res 2014; 7: 14

[37] Galbusera F, Tornese DZ, Anasetti F, Bersini S, Volpi P, La Barbera L, Villa T. Does soccer cleat design influence the rotational interaction with the playing surface? Sports Biomech 2013; 12: 293–301

[38] Giannini S, Buda R, Mosca M, Parma A, Di Caprio F. Posterior ankle impingement. Foot Ankle Int 2013; 34: 459–465

[39] Gutierrez GM, Jackson ND, Dorr KA, Margiotta SE, Kaminski TW. Effect of fatigue on neuromuscular function at the ankle. J Sport Rehabil 2007; 16: 295–306

[40] Handoll HH, Rowe BH, Quinn KM, De Bie R. Withdrawn: Interventions for preventing ankle ligament injuries. Cochrane Database Syst Rev 2011; 5: CD000018

[41] Hennig EM. Plantar pressure measurements for the evaluation of shoe comfort, overuse injuries and performance in soccer. Footwear science 2014; 6: 119–127

[42] Hennig EM. The influence of soccer shoe design on player performance and injuries. Res Sports Med 2011; 19: 186–201

[43] Hennig EM, Sterzing T. The influence of soccer shoe design on playing performance–a series of biomechanical studies. Footwear Sci 2010; 2: 3–11

[44] Hennig EM, Sterzing T. Special Issue: Soccer shoes: Enhancing fit and performance. Footwear Sci 2014; 67–68

[45] Hinz P, Henningsen A, Matthes G, Jäger B, Ekkernkamp A, Rosenbaum D. Analysis of pressure distribution below the metatarsals with different insoles in combat boots of the German Army for prevention of march fractures. Gait Posture 2008; 27: 535–538

[46] Hreljac A, Marshall RN, Hume PA. Evaluation of lower extremity overuse injury potential in runners. Med Sci Sports Exerc 2000; 32: 1635–1641

[47] Hägglund M, Waldén M, Ekstrand J. UEFA injury study–an injury audit of European Championships 2006 to 2008. Br J Sports Med 2009; 43: 483–489

[48] Johanson MA, Cooksey A, Hillier C, Kobbeman H, Stambaugh A. Heel lifts and the stance phase of gait in subjects with limited ankle dorsiflexion. J Athl Train 2006; 41: 159–165

[49] Johnson GR, Dowson D, Wright V. A biomechanical approach to the design of football boots. J Biomech 1976; 9: 581–585

[50] Jordan C, Payton C, Bartlett R. Perceived comfort and pressure distribution in casual footwear. Clin Biomech 1997; 12: S5

[51] Kapandji AI. Anatomie fonctionnelle T.2–Membre inférieur. 6ème édition, Paris: Maloine; 2009

[52] Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. Am J Sports Med 1999; 27: 585–593

[53] Kavanaugh JH, Brower TD, Mann RV. The Jones fracture revisited. J Bone Joint Surg Am 1978; 60: 776–782

[54] Kerr R, Arnold GP, Drew TS, Cochrane LA, Abboud RJ. Shoes influence lower limb muscle activity and may predispose the wearer to lateral ankle ligament injury. J Orthop Res 2009; 27: 318–324

[55] Kibler WB, Goldberg C, Chandler TJ. Functional biomechanical deficits in running athletes with plantar fasciitis. Am J Sports Med 1991; 19: 66–71

[56] Kinchington M, Ball K, Naughton G. Monitoring of lower limb comfort and injury in elite football. J Sports Sci Med 2010; 9: 652–663

[57] Kinchington M, Ball K, Naughton G. Relation between lower limb comfort and performance in elite footballers. Phys Ther Sport 2012; 13: 27–34

[58] Kinchington M, Ball K, Naughton G. Effects of footwear on comfort and injury in professional rugby league. J Sports Sci 2011; 29: 1407–1415

[59] Kirk RF, Noble ISG, Miychell T, Rolf C, Haake SJ, Carré ML. High speed evaluation of football-boot-surface interactions of players in their natural environment. Sports Eng 2007; 10: 123–144

[60] Klein C, Groll-Knapp E, Kundi M, Kinz W. Increased hallux angle in children and its association with insufficient length of footwear: A community based cross-sectional study. BMC Musculoskelet Disord 2009; 10: 159

[61] Knight AC, Weimar WH. Effects of inversion perturbation after step down on the latency of the peroneus longus and peroneus brevis. J Appl Biomech 2011; 27: 283–290

[62] Kovács I, Tihanyi J, Devita P, Rácz L, Barrier J, Hortobágyi T. Foot placement modifies kinematics and kinetics during drop jumping. Med Sci Sports Exerc 1999; 31: 708–716

[63] Lambson R, Barhnill B, Higgins R. Football cleat design and its effect on anterior cruciate ligament injuries – A three-year prospective study. Am J Sports Med 1996; 24: 155–159

[64] Lanzetti RM, Ciompi A, Lupariello D, Guzzini M, De Carli A, Ferretti A. Safety of third-generation artificial turf in male elite professional soccer players in Italian major league. Scand J Med Sci Sports 2017; 27: 435–439

[65] Lee SY, McKeon P, Hertel J. Does the use of orthoses improve self-reported pain and function measures in patients with plantar fasciitis? A meta-analysis. Phys Ther Sport 2009; 10: 12–18

[66] Lee YC, Lin G, Wang MJ. Evaluating insole design with joint motion, plantar pressure and rating of perceived exertion measures. Work 2012; 41: (Suppl 1): 1114–1117

[67] Lees A, Kewley P. The demands on the soccer boot. Science and Football 1993; 2: 335–340

[68] Lees A, Nolan L. The biomechanics of soccer: A review. J Sports Sci 1998; 16: 211–234

[69] Lin CF, Gross ML, Weinhold P. Ankle syndesmosis injuries: Anatomy, biomechanics, mechanism of injury, and clinical guidelines for diagnosis and intervention. J Orthop Sports Phys Ther 2006; 36: 372–384

[70] Malliaras P, Cook JL, Kent P. Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. J Sci Med Sport 2006; 9: 304–309

[71] Mayer F, Hirschmüller A, Müller S, Schuberth M, Baur H. Effects of short-term treatment strategies over 4 weeks in Achilles tendinopathy. Br J Sports Med 2007; 41: e6

[72] Messier SP, Davis SE, Curl WW, Lowery RB, Pack RJ. Etiologic factors associated with patellofemoral pain in runners. Med Sci Sports Exerc 1991; 23: 1008–1015

[73] Milani TL, Hennig EM, Lafortune MA. Perceptual and biomechanical variables for running in identical shoe constructions with varying midsole hardness. Clin Biomech 1997; 12: 294–300

[74] Milner CE, Ferber R, Pollard CD, Hamill J, Davis IS. Biomechanical factors associated with tibial stress fracture in female runners. Med Sci Sports Exerc 2006; 38: 323–328

[75] Moschini A, Smith N. Effect of shoe mass on soccer kicking velocity. In: Bradshaw E, Burnett A. (eds.), Scientific Proceedings of the 30th Annual Conference of Biomechanics in Sports. Melbourne: Australian Catholic University; 2012: 150–153

[76] Mündermann A, Stefanyshyn DJ, Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. Med Sci Sports Exerc 2001; 33: 1939–1945

[77] Novacheck TF. The biomechanics of running. Gait Posture 1998; 7: 77–95

[78] O'Connor AM, James IT. Association of lower limb injury with boot cleat design and playing surface in elite soccer. Foot Ankle Clin 2013; 18: 369–380

[79] Peña FA, Coetzee JC. Ankle syndesmosis injuries. Foot Ankle Clin 2006; 11: 35–50

[80] Perhamre S, Lundin F, Norlin R, Klässbo M. Sever's injury; treat it with a heel cup: A randomized, crossover study with two insole alternatives. Scand J Med Sci Sports 2011; 21: e42

[81] Pohl MB, Hamill J, Davis IS. Biomechanical and anatomic factors associated with a history of plantar fasciitis in female runners. Clin J Sport Med 2009; 19: 372–376

[82] Rabin A, Kozol Z, Finestone AS. Limited ankle dorsiflexion increases the risk for mid-portion Achilles tendinopathy in infantry recruits: A prospective cohort study. J Foot Ankle Res 2014; 7: 48

[83] Ramanathan AK, John MC, Arnold GP, Cochrane L, Abboud RJ. The effects of off-the-shelf in-shoe heel inserts on forefoot plantar pressure. Gait Posture 2008; 28: 533–537

[84] Ramanathan AK, Wallace DT, Arnold GP, Drew TS, Wang W, Abboud RJ. The effect of varying footwear configurations on the peroneus longus muscle function following inversion. Foot 2011; 21: 31–36

[85] Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: A matched case-control study. J Bone Joint Surg Am 2003; 85: 872–877

[86] Rovere GD, Clarke TJ, Yates CS, Burley K. Retrospective comparison of taping and ankle stabilizers in preventing ankle injuries. Am J Sports Med 1998; 16: 228–233

[87] Ryan M, Elashi M, Newsham-West R, Taunton J. Examining injury risk and pain perception in runners using minimalist footwear. Br J Sports Med 2014; 48: 1257–1262

[88] Ryan M, Grau S, Krauss I, Maiwald C, Taunton J, Horstmann T. Kinematic analysis of runners with achilles mid-portion tendinopathy. Foot Ankle Int 2009; 30: 1190–1195

[89] Santos D, Carline T, Flynn L, Pitman D, Feeney D, Patterson C, Westland E. Distribution of in-shoe dynamic plantar foot pressures in professional football players. The Foot 2001; 11: 10–14

[90] Sarcević Z. Limited ankle dorsiflexion: A predisposing factor to Morbus Osgood Schlatter? Knee Surg Sports Traumatol Arthrosc 2008; 16: 726–728

[91] Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. Sports Med 2004; 34: 465–485

[92] Seligman DA, Dawson DR. Customized heel pads and soft orthotics to treat heel pain and plantar fasciitis. Arch Phys Med Rehabil 2003; 84: 1564–1567

[93] Shorten MR. Running shoe design: protection and performance. In: Tunstall Pedoe D.ed. Marathon Medicine. London: Royal Society of Medicine; 2000: 159–169

[94] Shuen WM, Boulton C, Batt ME, Moran C. Metatarsal fractures and sports. Surgeon 2009; 7: 86–88

[95] Shultz SJ, Nguyen AD, Levine BJ. The relationship between lower extremity alignment characteristics and anterior knee joint laxity. Sports Health 2009; 1: 54–60

[96] Sims EL, Hardaker WM, Queen RM. Gender differences in plantar loading during three soccer-specific tasks. Br J Sports Med 2008; 42: 272–277

[97] Slade SJ, Greenya JG, Kliethermes CL, Senchina DS. Somatosensory perception of running shoe mass. Ergonomics 2014; 57: 912–920

[98] Smeets K, Jacobs P, Hertogs R, Luyckx JP, Innocenti B, Corten K, Bellemans J. Torsional injuries of the lower limb: An analysis of the frictional torque between different types of football turf and the shoe outsole. Br J Sports Med 2012; 46: 1078–1083

[99] Sterzing T. Actual and perceived running performance in soccer shoes: A series of eight studies. Footwear Sci 2009; 1: 5–19

[100] Sterzing T, Henning EM. The influence of soccer shoe on kicking velocity in full-instep kicks. Exerc Sport Sci Rev 2008; 36: 91–97

[101] Tabrizi P, McIntyre WM, Quesnel MB, Howard AW. Limited dorsiflexion predisposes to injuries of the ankle in children. J Bone Joint Surg Br 2000; 82: 1103–1106

[102] Tol JL, Slim E, Van Soest AJ, Van Dijk CN. The relationship of the kicking action in soccer and anterior ankle impingement syndrome. A biomechanical analysis. Am J Sports Med 2002; 30: 45–50

[103] Tol JL, Van Dijk CN. Etiology of the anterior ankle impingement syndrome: A descriptive anatomical study. Foot Ankle Int 2004; 25: 382–386

[104] Tol JL, Van Dijk CN. Anterior ankle impingement. Foot Ankle Clin 2006; 11: 297–310

[105] Tsintzas D, Ghosh S, Maffulli N, King JB, Padhiar N. The effect of ankle position on intracompartmental pressures of the leg. Acta Orthop Traumatol Turc 2009; 43: 42–48

[106] Tung KD, Franz JR, Kram R. A test of the metabolic cost of cushioning hypothesis during unshod and shod running. Med Sci Sports Exerc 2014; 46: 324–329

[107] Van Beijsterveldt AM, Krist MR, Schmikli SL, Stubbe JH, De Wit GA, Inklaar H, Backx FJ. Effectiveness and cost-effectiveness of an injury prevention programme for adult male amateur soccer players: Design of a cluster-randomised controlled trial. Inj Prev 2011; 17: e2

[108] Vanore JV, Christensen JC, Kravitz SR, Schuberth JM, Thomas JL, Weil LS, Zlotoff HJ, Mendicino RW, Couture SD. Diagnosis and treatment of first metatarsophalangeal joint disorders. Section 2: Hallux rigidus. J Foot Ankle Surg 2003; 42: 124–136

[109] Waddington G, Adams R. Discrimination of active plantarflexion and inversion movements after ankle injury. Aust J Physiother 1999; 45: 7–13

[110] Waddington G, Adams R. Football boot insoles and sensitivity to extent of ankle inversion movement. Br J Sports Med 2003; 37: 170–175

[111] Waddington G, Adams R. Textured insole effects on ankle movment discrimination while wearing athletic shoes. Physical Therapy in Sport 2000; 1: 129–136

[112] Walter JH, Ng GK. Evaluation of cleated shoes with the adolescent athlete in soccer. The Foot 2002; 12: 158–165

[113] Weinfeld SB, Haddad SL, Myerson MS. Metatarsal stress fractures. Clin Sports Med 1997; 16: 319–338

[114] Werner RA, Gell N, Hartigan A, Wiggerman N, Keyserling WM. Risk factors for plantar fasciitis among assembly plant workers. PM R 2010; 2: 110–116

[115] Wierzbinski CM. The separate effects of shoe mass and cushioning on the energetic cost of barefoot vs shod running [Thesis]. Boulder, Colorado: University of Colorado Boulder; 2011

[116] Willems TM, Witvrouw E, Delbaere K, Mahieu N, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in male subjects: A prospective study. Am J Sports Med 2005; 33: 415–423

[117] Williams JH, Akogyrem E, Williams JR. A meta-analysis of soccer injuries on artificial turf and natural grass. J Sports Med 2013; 2013: 1–6

[118] Wong PL, Chamari K, Chaouachi A, Mao DW, Wisløff U, Hong Y. Difference in plantar pressure between the preferred and non-preferred feet in four soccer-related movements. Br J Sports Med 2007; 41: 84–92

[119] Wong PL, Chamari K, Chaouachi A, Mao DW, Wisløff U, Hong Y. Higher plantar pressure on the medial side in four soccer-related movements. Br J Sports Med 2007; 41: 93–100

[120] Yamada RK, Arliani GG, Almeida GP, Venturine AM, Santos CV, Astur DC, Cohen M. The effects of one-half of a soccer match on the postural stability and functional capacity of the lower limbs in young soccer players. Clinics 2012; 67: 1361–1364

[121] Yung-Hui L, Wei-Hsien H. Effects of shoe inserts and heel height on foot pressure, impact force, and perceived comfort during walking. Appl Ergon 2005; 36: 355–362

[122] Zhang X, Li B. Influence of in-shoe heel lifts on plantar pressure and center of pressure in the medial-lateral direction during walking. Gait Posture 2014; 39: 1012–1016