

Deconstructing Soccer Footwear: An Anatomical Review with Implications for Female Athlete-Specific Design

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Abstract: This review article provides a comprehensive anatomical analysis of soccer footwear, delving into the intricate structure and functional roles of its constituent components, including the upper, heel counter, tongue, toe box, outsole/sole plate, studs, and insole. Manufacturing processes influencing these structural elements are also discussed. Current market offerings and patented innovations in soccer cleat technology are examined through a biomechanical lens, highlighting their intended functions and limitations. A critical synthesis of existing knowledge underscores the anatomical and biomechanical distinctions between male and female athletes' feet, arguing for the necessity of sex-specific footwear design. This review culminates in emphasizing the imperative for specifically engineered soccer footwear for female athletes to optimize performance, enhance comfort, and mitigate the elevated risk of lower extremity injuries prevalent in the female game, thereby identifying crucial directions for future research in sports biomechanics and footwear engineering.

Keywords: Soccer Cleats, Athletic Footwear, Foot Anatomy, Biomechanics, Women's Soccer, Injury Prevention, Sports Equipment Design

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1. Introduction

Footwear plays a critical role in athletic performance and injury prevention across all sports, and soccer is no exception. The complex and dynamic movements inherent in soccer, including running, sprinting, rapid acceleration and deceleration, sharp changes of direction, pivoting, and kicking, place significant demands on the athlete's feet and lower limbs. Consequently, the design and construction of soccer footwear, specifically cleats, are paramount in facilitating these movements efficiently while providing adequate support and protection. This review article provides a detailed anatomical exploration of modern soccer cleats, dissecting their structural components and elucidating their functional roles in the context of the biomechanical demands of the sport. Furthermore, it critically examines current cleat technologies and innovations available in the market, considering their implications for athlete performance and safety. Building upon this comprehensive anatomical and functional overview, the review culminates in a persuasive argument for the critical need to develop and implement soccer footwear specifically designed to accommodate the distinct anatomical and biomechanical characteristics of female athletes, a demographic historically underserved by footwear innovation.

Soccer requires a unique blend of agility, speed, power, and endurance. Athletes perform a multitude of high-impact activities that generate substantial ground reaction forces and place considerable stress on the musculoskeletal system. Understanding the biomechanics of these movements, including the phases of gait during running and sprinting, the forces involved in cutting and pivoting, and the foot-ground interaction

during kicking, is fundamental to appreciating the demands placed on soccer footwear (Thomson et al., 2021) [1]. The distribution of plantar pressure, the range of motion at the ankle and foot joints, and the activation of specific muscle groups during these actions are all influenced by the structure and properties of the athlete's footwear.

Historically, soccer footwear has evolved from simple leather boots with rudimentary studs to highly engineered athletic tools incorporating advanced materials and sophisticated designs. Early iterations focused primarily on protection and basic traction on natural grass surfaces. However, as the game became more dynamic and the understanding of sports biomechanics advanced, the demands on footwear increased, leading to the development of specialized cleats for various playing surfaces and player positions. This evolution reflects a continuous effort to optimize the interaction between the athlete's foot and the playing surface, enhancing performance and minimizing the risk of injury (Wood, 2008).

2. Limitations of Women's Soccer Cleats: Limited Research and Development

A significant limitation in the realm of women's soccer cleats is the historical lack of dedicated research and development focused specifically on the biomechanical and anatomical needs of female athletes (Karolidis & Hahn, 2023; PMC, n.d.) [2,3]. Historically, female players often had to choose from cleats designed based on male foot morphology or children's sizes (Full article: A mechanical comparison, 2024) [4]. This "shrink it and pink it" approach, where male designs were simply scaled down and given feminine colorways, failed to address the distinct differences in female foot shape (narrower heel, wider forefoot, higher arch) and biomechanics (e.g., greater knee valgus) (Soccer.com, 2014) [5]. Consequently, ill-fitting boots could lead to discomfort, blisters, altered movement patterns, and potentially contribute to the higher incidence of certain injuries like ACL tears in female players (UO researchers study how cleats, 2024) [6].

While some companies have begun producing cleats claiming to be designed for women using female-specific lasts or incorporating features to accommodate anatomical differences, the underlying research to inform these designs is still limited (Full article: A mechanical comparison, 2024; Ten questions in sports engineering, 2022) [4,7]. Many traction and biomechanical studies, even those involving female athletes, have historically required them to wear male-specific boots (Full article: A mechanical comparison, 2024) [4].

The lack of comprehensive research on the interaction between cleat design (stud configuration, material properties) and the specific movements and injury mechanisms prevalent in female soccer further compounds this limitation (UO researchers study how cleats, 2024) [6]. Understanding how different cleat features affect ground reaction forces and lower limb loading in female athletes is crucial for developing safer and more performance-enhancing footwear.

3. Anatomy of a Soccer Cleat: A Structural and Functional Review

A modern soccer cleat is a complex piece of equipment comprising several key structural elements, each with a specific function in supporting the athlete's foot and facilitating performance.

3.1. The Upper

The upper is the part of the cleat encasing the athlete's foot, providing containment, support, and ball feel. It is typically constructed from various synthetic materials, leather (e.g., kangaroo leather), or engineered fabrics, each offering different properties in terms of weight, flexibility, durability, and water resistance (Nike, n.d.a) [8]. The design of the upper significantly influences the cleat's fit, lockdown (how securely the foot is held within the boot), and the athlete's ability to feel and control the ball. Key features of the

upper include: (1) Material Construction: Different materials offer varying degrees of stretch, breathability, and tactile feedback. Engineered knit uppers, for example, can provide a sock-like fit and enhanced ball feel, while synthetic leathers offer durability and support; (2) Lacing System: The lacing system works in conjunction with the upper to provide a secure and adjustable fit across the instep, contributing to foot lockdown and stability during lateral movements. Asymmetrical lacing patterns are sometimes employed to provide a cleaner striking surface; (3) Tongue: The tongue, located beneath the laces, serves to cushion the top of the foot, preventing lace pressure and enhancing comfort. Its material and padding can vary significantly between cleat models; (4) Collar/Cuff: Some modern cleats feature integrated collars or cuffs that extend around the ankle, often made from elasticated knit materials. These designs aim to provide added ankle support and a more seamless connection between the foot and the lower leg, although their biomechanical benefits are still under investigation; and (5) Touch Zones: Many uppers incorporate specialized textures or overlays in key areas to enhance ball control and grip during dribbling, passing, and shooting.

3.2. The Heel Counter

The heel counter is a semi-rigid or rigid insert located at the rear of the cleat that cups the heel. Its primary function is to provide stability to the hindfoot, controlling excessive pronation or supination during the gait cycle and providing support during rapid changes of direction and impact forces (Nike, n.d.a) [8]. The material and stiffness of the heel counter are crucial for maintaining rearfoot integrity and reducing the risk of ankle and lower leg injuries.

3.3. The Toe Box

The toe box is the area of the cleat that encloses the toes. Adequate space in the toe box is essential for allowing natural toe splay, which contributes to balance, stability, and force distribution during weight-bearing activities (Roach, 2023) [9]. A narrow or constricting toe box can lead to discomfort, blisters, nerve compression, and potentially long-term foot deformities. The material and construction of the toe box influence its flexibility and protection of the toes during impact.

3.4. The Outsole/Sole Plate

The outsole, or sole plate, is the structural foundation of the cleat, attaching to the upper and housing the studs. It is typically made from thermoplastic polyurethane (TPU) or other high-performance polymers, balancing flexibility and rigidity to allow for natural foot flexion while providing a stable platform for force transfer to the ground (Nike, n.d.a) [8]. Key aspects of the outsole include: (1) Material Properties: The stiffness and flexibility of the outsole influence the cleat's responsiveness and the distribution of pressure across the plantar surface of the foot. Different areas of the outsole may exhibit varying degrees of flexibility to accommodate the foot's natural movement; (2) Stud Configuration: The arrangement, shape, length, and material of the studs are critical for providing traction on various playing surfaces (e.g., firm ground, soft ground, artificial turf). Different stud patterns are designed to optimize grip during acceleration, deceleration, turning, and preventing slippage; (3) Flex Grooves: Many outsoles incorporate flex grooves or channels that allow the foot to bend more naturally at the metatarsophalangeal joints during the toe-off phase of gait; and (4) Midsole Integration: In some advanced cleat designs, a thin midsole layer made of cushioning foam (e.g., EVA, polyurethane) may be integrated into the outsole to provide additional shock absorption.

3.5. Cleats/Studs

The cleats, or studs, are protrusions on the outsole that penetrate the playing surface to provide traction. Their design varies significantly depending on the intended playing

surface. For instance, firm ground (FG) cleats typically feature a pattern of molded plastic or rubber studs, often conical or bladed in shape, designed to provide grip on natural grass surfaces that are dry and firm (Chanis, 2022) [10]; whereas soft ground (SG) cleats usually have fewer, longer, and often replaceable metal studs (aluminum or steel) that offer superior grip on wet, muddy, and soft natural grass (Chanis, 2022) [10]. Artificial ground (AG) or turf (TF) cleats feature numerous shorter, hollow, or multi-directional rubber studs designed to provide optimal traction on synthetic turf surfaces without excessive penetration.

The shape and arrangement of studs influence rotational traction (the resistance to twisting movements), linear traction (grip during straight-line running), and braking ability. Excessive rotational traction has been implicated as a potential risk factor for non-contact knee injuries due to the foot becoming fixed on the ground while the body continues to move (Thomson et al., 2022) [11].

3.6. The Insole

The insole is a removable insert that sits inside the cleat, directly beneath the athlete's foot. It plays a crucial role in comfort, cushioning, arch support, and moisture management (Roach, 2023) [9]. Key features of an insole include (a) top cover, the layer in direct contact with the foot, often made from moisture-wicking fabrics to help keep the foot dry and prevent slippage; (b) cushioning layer, typically made from foams like EVA or polyurethane, providing shock absorption during impact. The thickness and density of this layer influence the level of cushioning; (c) arch support, contoured arch support can help to align the foot, distribute plantar pressure more evenly, and enhance stability, particularly for athletes with flat feet or high arches; (d) heel cup, a raised or cupped heel section can provide additional stability and support to the hindfoot' and (e) metatarsal pad, some insoles include a metatarsal pad to provide cushioning and support to the forefoot.

The quality and design of the insole significantly impact the overall comfort and performance of the cleat. Many athletes, including female soccer players, often replace the stock insoles with aftermarket options that provide better arch support or cushioning tailored to their specific needs (Wrack, 2023) [12].

3.7. Manufacturing Processes Influencing Cleat Structure

The manufacturing of a soccer cleat involves several key processes that determine the final structure and properties of the footwear. First, the upper construction (i.e., lasting), is the upper materials are cut into specific patterns and then stitched together. The assembled upper is then stretched and shaped around a "last," a three-dimensional mold of a foot, to give the cleat its final form and fit. The liner materials are also lasted to provide internal comfort (Raise3D, 2020) [13].

Secondly, the soleplate tooling is particularly important, as well. This is the outsole and stud configuration are typically created using injection molding. The design of the mold dictates the shape, size, and arrangement of the studs, as well as the flexibility and rigidity of the sole plate (Thomson et al., 2021) [1].

Additionally, the next important step is in attaching the upper to the soleplate (i.e., gluing): Once the upper is lasted and the soleplate is molded, the two components are permanently bonded together using strong adhesives. Precise alignment is crucial for the cleat's structural integrity and performance.

Finally comes insole manufacturing. Insoles can be mass-produced using die-cutting of foam sheets or custom-made using 3D scanning, CAD modeling, and 3D printing with materials like TPU for enhanced durability and support (Raise3D, 2020) [13].

3.8. Existing Cleat Technologies and Innovations

The soccer footwear market is characterized by continuous innovation aimed at enhancing performance, comfort, and safety. Some key technologies and innovations include advancements in material science. For instance, advances in synthetic materials and engineered fabrics have led to lighter, more durable, and more responsive uppers that offer improved ball feel and fit (Adidas, n.d.; Nike, n.d.a) [8,14]. Further innovations include advancements to traction systems. Brands are constantly experimenting with different stud shapes, patterns, and materials to optimize traction on various surfaces while minimizing excessive rotational forces (Thomson et al., 2021) [1]. A new area manufacturers are exploring is in laceless designs; some cleats feature laceless uppers, relying on engineered knit structures and internal support systems to provide a secure lockdown and a cleaner striking surface (Adidas X Speed Portal) [15]. Modern cleats have evolved to feature adaptive fit technologies. Innovations like Nike's Flyknit and Adidas' Primeknit aim to provide a dynamic and personalized fit that molds to the athlete's foot. Finally, patented innovations, as highlighted in the initial article, patents for self-cleaning cleats (Bauldin et al., 2020) [16] and insoles with enhanced arch support (Joseph, 1963) [17] demonstrate ongoing efforts to address specific performance and comfort challenges.

3.9. Biomechanical Considerations for Female Athletes: The Need for Sex-Specific Design

A growing body of research in sports biomechanics underscores the significant anatomical and biomechanical differences between male and female athletes, particularly in the lower extremities (ACSM, 2023). These differences have critical implications for athletic footwear design in women's soccer: (a) foot morphology, e.g. women tend to have a narrower heel relative to their forefoot width compared to men (Footalk, 2019) [18]. Standard men's cleats, even in smaller sizes, may not provide adequate heel lockdown for women, leading to slippage and instability; (b) arch height and plantar pressure distribution. Women often exhibit higher arch heights and different patterns of plantar pressure distribution during dynamic movements compared to men (ACSM, 2023). Insoles in standard cleats may not provide appropriate support for these variations, potentially leading to discomfort and increased risk of plantar fasciitis; (c) biomechanical movement patterns; female athletes often exhibit different lower extremity kinematics during running, cutting, and landing, including increased knee valgus angles, which contribute to a higher risk of ACL injuries (Thomson et al., 2022) [11]. Footwear design that does not accommodate these movement patterns may exacerbate these risks; and (d) force production, e.g. Women typically generate less lower body power compared to men (News Detail, 2023) [19]. Traction patterns in cleats designed for male force output may provide excessive grip for women, potentially increasing rotational forces on the knee joint during directional changes (Thomson et al., 2022) [11].

These anatomical and biomechanical distinctions unequivocally highlight the limitations of simply scaling down men's cleats for female athletes. Footwear that does not consider these sex-specific characteristics can compromise comfort, hinder performance, and, most critically, increase the risk of lower extremity injuries.

4. Conclusion: The Imperative for Women-Specific Soccer Footwear

In conclusion, the limited research and development dedicated to women-specific soccer cleats has resulted in designs that may not adequately cater to the anatomical and biomechanical profiles of female players. While progress is being made, a greater focus on research in this area is needed to optimize footwear for performance enhancement and injury prevention in women's soccer. Given both the mental and physical demands of the sport, there is a general understanding that female athletes must be in excellent physical shape. In addition to this, there is an understanding of the movements required within the process of playing at a high level. These movements include running, jumping, acceleration and deceleration, sudden changes of direction, pivoting and cutting amongst

many others. In the past, women have been expected to perform at the highest level wearing men's cleats that are essentially sized down and altered in color to give players the impression that they are women's cleats. However, doing this has only been a notion of disrespect to female soccer players at every competitive level. To properly support the health and performance of these women, it is important that they have cleats that support their functions. The lack of this form of footwear has led to far too many ACL tears at the professional level, and without a doubt has had the same effect on young women playing on the levels that precede it.

Therefore, research in this area aims to lead to the development of appropriate footwear serving women playing Division I, Division II, and National Association of Intercollegiate level soccer whose dreams and aspirations of playing professionally stand in grasping distance. This will be achieved by first raising awareness, showing appreciation for, and advocating for women in the sport. This research set out to answer the question, "how can we design firm ground cleats that consider the anatomy and biomechanics of the female athlete to enable efficient movement while mitigating lower extremity injuries in women's soccer?" Footwear developers must provide players with a cleat that enables them to move efficiently on the surface of play. For this reason, we would like to develop and provide firm ground cleats that provide optimal rotational traction to efficiently execute pivoting, cutting, and sudden changes of direction. Also in need of addressing are insoles in current cleat offerings, which lack the needed durability to sustain cushioning for a long period of time and are known to thin out after a season. Therefore, the proposed design with an innovative insole using foam that sustains its physical properties and enables players to have proper arch and heel support beyond a season of play is of additional value.

The detailed anatomical review of soccer footwear presented herein, coupled with the understanding of the distinct biomechanical profiles of female athletes, compellingly argues for the urgent need to develop and implement soccer cleats specifically designed for women. The historical reliance on scaled-down men's models disregards fundamental sex-based differences in foot morphology, biomechanics, and force production, contributing to suboptimal performance and an elevated risk of injury in female soccer players.

Future research and development in soccer footwear must prioritize a comprehensive, data-driven approach that integrates detailed biomechanical analyses of female athletes' movements with advanced material science and innovative design principles. Creating women-specific lasts, optimizing stud patterns for female force output, and incorporating insoles that provide tailored arch support and cushioning are crucial steps towards addressing the long-standing inequities in sports equipment. By acknowledging and accommodating the unique anatomical and biomechanical needs of female athletes, the sports science and footwear industries can contribute significantly to enhancing their performance, ensuring their long-term health, and fostering a more equitable and sustainable future for women's soccer.

While our ultimate goal is to design a cleat that allows female collegiate athletes to perform at the highest level without it being in exchange of their health, an additional motive of the researchers is to inspire the generations that follow those leading our country to success. It can oftentimes be hard for Black women in various spaces to feel represented and value (Prempeh & Pennington, 2025) [20]. Many of them feel as if they are unsupported and that they have no chance of representing their country. Research specifically examining the footwear needs and experiences of Black female soccer players is notably scarce within the existing literature. While studies may address general issues of fit and design limitations for women, the intersection of race, foot morphology, and footwear performance in this specific demographic remains largely unexplored (e.g., Harrison & Hardin, 2018) [21]. This lack of focused research means that the nuances of foot shape variations within different racial groups and their potential implications for

cleat design and injury prevention are not well understood, further highlighting a gap in the current knowledge base. An extension of this research may be to apply cleat and footwear innovations to an often unheard and unseen, yet very important, athlete population.

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