Ten questions in Sports Engineering: Technology in elite women's football

ABSTRACT

Use of technology in football is increasing, though, products predominantly focus on men's football in performance, safety, comfort, and fit considerations. A recent scoping review identified just 32 published scientific articles on technology in women's football, despite demands of those playing/working in the women's game increasing. We wish to highlight the progressions made so far and barriers remaining in elite women's football technology to shed a light on this topic and prod researchers and manufacturers to help support the evolution of women's-football-focussed technological considerations. The ten questions presented in this paper address the generic question on whether women's specific tailoring is needed (Question 1) as well as addressing specific questions on football technology and engineering such as the progressions made and ongoing issues in the following areas: football kits, religious considerations (hijab designs), sports bras, football boots, balls, football pitches, performance tracking devices, menstrual cycle tracking devices (Question 2-10). It is evidence that certain areas have received more attention than others and with these ten questions we hope to steer readers towards research and engineering gaps for future work.

Keywords: Soccer, female, design, manufacturing, pitch, cleats

Introduction

The field of sports engineering and technology is broad and diverse. The engineering and technology required in football is similarly vast with new technologies frequently introduced on the market. However, technology and engineering focus in football have and still are heavily targeting men's football. The women's side of the game is currently taking momentum in growth and professionalisation [1], which has changed the football technology and engineering demands of players and staff in elite women's football.

As a diverse author group composed of researchers, staff, and a player from elite women's football, we wish to highlight the progressions made so far and barriers remaining to shed a light on this topic and prod researchers and manufacturers to help support the evolution of women's-football-focussed technological considerations. The ten questions presented in this paper address the generic question on whether women's specific tailoring is needed (Question 1) as well as addressing specific questions on football technology and engineering such as the progressions made and ongoing issues in the following areas: football kits, sports bras, football boots, football pitches, tracking devices, menstrual cycle tracking devices and other more overlooked areas (Question 2-10).

Question 1 – Why do we need tailored technology designed for women in football?

Use of technology in football is increasing. Most products are still predominantly designed for men's football. This is not an issue specific to football. Similar issues have been addressed in e.g., the space industry where space suits previously did not fit women astronauts [2] and toilets used in space were not designed for women's bodily functions causing issues with leakage [3]. Similarly, respiratory personal protective equipment (PPE) for healthcare workers during the COVID-19 pandemic was designed for men, which left women at risk of contamination [4]. Highlighting the sex-biased issues in football is important to steer research and the industry to address these, similarly to the cases mentioned, and now addressed, in the aeronautical and healthcare world.

A recent review scoped just 32 scientific articles on technology in women's football [5], indicating that little attention has been given and hence little is known about the technological requirements of women's football. Development of products and research on the men's side of the game has progressed for decades [6–8]. In the meantime, women were left to use these technologies and equipment designed predominantly for men, such as balls, kits, and boots.

Staff and players in the elite women's football have voiced concerns on social media platforms about multiple issues such as kit colour [9] and football boot fit issues [10] yet these issues are

not backed by evidence to date. We, therefore, hope readers will take these concerns and observations as guidance on where research on technology is needed to ensure evidence-based practice in women's football.

The demands and views of those playing/working in the elite women's game are changing. Previously, gratitude was high for any gifted garment/equipment/device. Today, focus has shifted to constructive collaborations and player/staff demands for change towards woman specificity. Changes have started but more attention is still needed to ensure the kit meets the requirements and desires of players.

Question 2 – How should football kits be designed to meet elite women footballers' needs?

Bespoke women's fitted kits were not available until the FIFA 2019 Women's World Cup (WWC) [11]. Designing optimal kits is an ongoing conversation; bra and skin exposure through the top have not been fully appreciated, causing distress in some players.

Short colour is a neglected subject. Both football players and staff question why kit colour must match teammates from the men's team. Fear of sweat marks and visible leakage during menstruation is a concern for many players, with staff reporting that players ask them to keep an eye on their shorts when playing in light colours. Some players even report lack of game focus due to concerns about exposing themselves on live streaming with visible blood stains on their shorts [9]. Similar concerns have been raised in other sports such as tennis [12]and rugby [13].

Women's football shorts are short and perceived by some players to be exposing and sexualising them compared to their counterparts from the men's teams. Players like wearing cycling shorts (tightly fitted shorts) under their football shorts for protection of both these concerns but not all kit providers currently offer these.

Until the FIFA 2019 WWC, socks were unisex (i.e., men's fit) leaving some players to choose between something that fit their foot/boot, or their leg length/width, causing secondary issues including rubbing/slipping in the boot due to increased bulk of material. Medical staff report this as a risk factor for ankle sprains as players felt they were slipping inside the boots due to excessive sock material. In response, players commonly cut their football socks to wear grip performance socks underneath. This trend is also seen in men's football which in turn brings sponsorship-agreement failure fines.

No research was identified on the kit design for comfort, fit or performance. There is therefore a clear gap in the research field to understand the player desires and kit requirements.

Question 3 – How has religious inclusion been considered in football kit manufacturing for women?

Women's specific clothing for women who, due to religious reasons, wish to cover more body skin than the traditional kit is also worth a mention. Whilst long sleeved shirts and trousers are accepted in football, face and hair covering has received pushbacks from governing bodies. When first challenged in 2007, the FIFA chief executive officer stated that hijab did not fall within the basic equipment outlined in law four of the game [14]. The Iranian women's football team in 2011 were forced to forfeit their qualification game for the 2012 Olympics against Jordan due to the FIFA decision to ban headscarves on the pitch [15]. This ban was active despite no empirical evidence of any reported incidences of athletes being injured due to hijabs [14, 16]. Lobbying, sports hijab research and development of sport-specific products from companies such as Capsters and ResportOn, designed with safety recommendations outlined by the International Football Association Board (IFAB; the decision-making body for the laws of the game), led to a FIFA lift of the ban in March 2014 [17–19]. It was announced that religious head coverings (including hijabs, turbans for Sikh men and kippahs for Jewish men) would be permitted on the pitch where these head coverings meet IFAB medical regulations. These considerations highlight the importance of testing and development of technological alterations to women's football to allow for maximal participation in the game.

Question 4 - How are sports bras designed to match elite women footballers' needs?

The first sports bra is thought to have been developed in 1977, by sewing two jockstraps together. The sports bra industry has diversified since then, offering elite athletes and recreational exercisers many advancements in sports bra design, with level of breast support worn influencing biomechanical [20–22] and physiological [23, 24] variables. However, most research to date has focused on breast motion during treadmill walking and running [25]. This breast movement is unlikely to represent the frequency and magnitude of breast motion experienced by athletes training at high intensity or long duration, or in sports where athletes rapidly change direction, such as football. This can be detrimental for athletes as excessive breast motion during exercise has been associated with breast pain, reported by 44% of elite women athletes [26]. Furthermore, at the elite level many athletes are required to wear branded sports bras by the kit sponsors, which can negatively impact the fit, support and comfort of the bra. It is common for players to wear two bras, suffer in the pre-defined 'sponsor' bra, or risk fines for visible competing logos.

Sports bra brands commonly market their products as low-, medium, or high-impact support, suitable for specific sports. However, there has been limited research exploring breast motion in specific sports to support these categorisations [27]. To inform optimal breast support design for women footballers, the measurement of three-dimensional torso and breast motion of women footballers during training and match environments are required. The use of intelligent fabrics that respond to changes in breast motion and adjust the level of support accordingly [25] could also improve sports bra efficacy in sporting environments. However, there are challenges to overcome with integrating this technology into sports bras, including how to produce a garment that is both comfortable and robust enough to be washed [28]. At the elite level, bespoke sports bra design informed by individual breast and torso dimensions and breast biomechanical assessment, could be considered, although this has cost implications. This approach was successfully adopted at the recent Tokyo 2020 Olympic Games, where several Team GB athletes across a range of different sports were provided with bespoke bras to address their specific breast issues [29].

Question 5 - Have football boots been designed to match elite women footballers' needs?

There are multiple concerns that surround men's football boots worn by women. These concerns are current and relevant as none of the larger manufacturers of football boots have yet invested in women's football boot designs [30]. Proper fit is an important feature related to comfort of footwear but also injury risk, fatigue, mobility, performance, and alignment of the lower limb [31–35]. Unlike running shoes, cushioning support in football boots is minimal, the outsole studs distribute pressures differently and the latter are narrower. These alterations in footwear design create around 9% less plantar surface area and 35% higher forefoot plantar pressures when walking in football boots in comparison to walking in running shoes [36], though measured on a hard surface. An optimal football boot fit is, therefore, important to ensure comfort, stabilise the foot, prevent fatigue and optimise both mobility and alignment of the lower limb.

Women's feet differ from men's feet in shape and volume [37, 38]. Though not reported in the literature, staff from the elite side report concerns with the impact of poor fit and foot deformation, skin conditions (e.g., blisters) and overuse injuries (e.g., metatarsal stress fractures). Therefore, optimal fit requires sex-specific fit requirements, and these issues are not yet solved.

Injury and performance concerns extend beyond the fit. Outsole stud/cleat types (e.g., soft ground outsoles or hard ground outsoles) aim to match a specific playing surface to optimise

traction. These optimal traction ranges have been designed and defined for men. Not obtaining optimal traction is both a concern for injury risk and performance measures [39, 40]. It is evident that anterior cruciate ligament (ACL) injuries are a big concern and a key research topic in elite women's football [5]. A common mechanism of ACL injuries in elite women's football has been identified to be non-contact with load added to an external foot position planted on the ground (identified using systematic video analysis) [41]. This mechanism is associated with findings from previous studies suggesting that increased shoe-surface traction (the boot getting stuck in the surface) is an ACL injury risk factor [42]. Therefore, applying an outsole producing too high traction may increase women's risk of injury [30]. Currently, only a single women-specific boot design is available from a start-up company [43]. Many of the major manufacturers are developing women's specific boots that should be available for the FIFA WWC in 2023, however the lack of football boots available is a general concern by researchers, players and staff working in women's football.

Question 6 – How well do football pitches in elite women's football meet the performance and safety requirements?

In a worldwide study of 1129 elite football players (n=1018 men and 111 women), 91% of players believed the type or condition of the playing surface increased injury risk. Hard, bumpy, and inconsistent playing surfaces and high or low traction (grip) were some of the major concerns [44]. During the FIFA 2019 WWC, the international level players (n = 196) ranked poor pitch quality and artificial turf as the 2nd and 3rd most important risk factors, respectively, for sustaining an injury, after low muscle strength [45]. Clearly players are concerned about surface type and/or conditions. Elite women are critical of the old or poorly maintained artificial surfaces they are often offered to play on, and although there is little (published) evidence that artificial surfaces lead to more injuries overall, most players prefer to play on natural grass [46]. International women players have for years utilised media to show pictures of skin abrasions sustained on artificial playing surfaces [47–49]. These photos were often accompanied by the player expressing their dislike for artificial playing surfaces. However, skin abrasions, while uncomfortable, will likely not cause a player to miss a match and are therefore not recorded as a 'time loss' injury in scientific studies.

Preferences are geographically dependent. Women players in Scandinavia expressed a preference for artificial playing surfaces over grass pitches via a survey-based questionnaire in 2019. However, the reason being that the natural grass pitches women were exposed to were of such poor quality that players felt artificial pitches were a superior option. This issue

complicates attitudes towards grass pitches. It was concluded that an obvious negative difference exists between the natural grass pitch quality used for women in Norway, Sweden, and Denmark play on compared to men's tournament pitches [50].

Funding to improve pitch quality is needed for integration of technologies such as hybrid pitch reinforcement and sub-soil vacuum systems that are commonplace in elite men's football [51]. A focus on preparation and maintenance of good quality natural grass pitches that have not been worn out by men's games the previous day (common in e.g., Women's Super League) or being allocated better quality neutral pitches (e.g., qualifying rounds for UEFA Champions League games) is paramount.

Question 7 – Does it impact playing performance that women play with the same footballs as men?

Women play with a ball with identical criteria set, such as size, pressure, and material, to those of men. No adjustments have been made, which contrasts with other sports such as basketball and handball, where women play with a smaller and lighter ball. Research has, however, previously investigated the impact of changing the ball size on the game for women [52, 53]. It was demonstrated that women players kick the ball faster and report lower muscular exertion during games played with a lighter, smaller ball, though locomotor activities, heart rate and overall technical-tactical game performance remained unaffected [52, 53]. Since these studies were conducted around 10 years ago, little questioning of ball size has been made in relation to performance. There has been no research on whether players prefer playing with the same size ball as men. On the contrary, some concerns have been flagged, though not researched in detail about the ball size and mass in relation to the current concerns about increased incidence and severity of concussion in women's football compared to men's football [54, 55]. This has been demonstrated further by women exhibiting higher microstructural white matter alteration than men when heading a football [56]. Despite these safety concerns and the previous research on performance impact of ball size, it is generally accepted that women can and will play with the same ball design in football.

Question 8 – What requirements are needed from tracking devices to match elite women footballers' needs?

Global Positioning System (GPS) and heart rate monitoring equipment often have sex-specific setups; however, the default setting is usually for men. For example, GPS software systems will customarily be pre-programmed with the common thresholds used to measure physical

performance in men's football. Whilst it is possible to alter these thresholds, there is currently a lack of uniformity in the published literature regarding standardised thresholds for female players [57]. This may be considered problematic as failure to use population-specific velocity thresholds may lead to erroneous interpretations of player's physical match/training data which has implications for match and training GPS monitoring. It is also important to note that any derived thresholds may need to be altered frequently as the women's game continues to evolve, as illustrated by increases in physical match performance [58].

Women's teams habitually experience difficulties with ill-fitting HR and GPS monitoring equipment. Smaller players often have issues with the fit due to wrist or chest size differences compared to the larger men, which this equipment was originally designed for. These adversities with fit can result in sub-optimal data collection due to missing data as well as issues with comfort. Consequently, a simple recommendation is to ensure both GPS and heart rate monitoring equipment are available in sizes which are appropriate to cater for women.

GPS devices were generally used in men's sports first and therefore a garment was needed to house the unit; however, for elite women there is scope to integrate GPS devices into sports bras already worn during training and matches. Some GPS companies sell pouches separately which can be ironed/sewn on to a sports bra to reduce the need to wear additional layers of clothing. Recent additions to the market also include sports bras with heart rate monitoring technology sewn directly into the fabric, as well as bras manufactured by GPS companies which incorporate the pouch to secure the GPS device. However, as discussed in question 3, development of such bespoke products may limit sports bra choice, which could impact the level of support offered and compromise fit. More widespread accommodation of these technologies within sports bra design is warranted

Whilst it appears tracking devices were designed for men at first, the customisable nature of software means that these devices can simply be reprogrammed to ensure women-specific settings. Continued consideration is needed to ensure tracking hardware (e.g., vests, straps, and watches) are provided in appropriate sizes for all players. The recent developments by some technology companies to create a more integrated use of the sports bra to house tracking devices is a positive step forwards in ensuring bespoke monitoring support for women.

Question 9 – How can menstrual cycle tracking apps be employed to manage elite women footballers' wellbeing and performance?

Wellness monitoring apps and medical record systems commonly used in elite football do not request women's health information such as menstrual cycle logging and symptomology, or

use of hormonal contraception. Instead, some teams additionally use specific menstrual cycle tracking apps, and then have to manually interpret these data. Recent literature highlighted that 80-95% of athletes experience menstrual cycle symptoms [59, 60], with these typically occurring pre- or during menstruation. Further, athletes perceive that their menstrual cycle can adversely alter readiness, attributing this to symptoms such as heavy bleeding, mood changes, fatigue, a perceived reduction in strength and pain [13, 59]. With this in mind, better monitoring of the menstrual cycle and symptomology alongside robust screening and the provision of education and proactive management strategies is needed to best support players. Menstrual cycle tracking apps are an ideal tool for this. Further, particularly where dysfunction or irregularities are suspected, urinary ovulation testing and/serum hormonal measures could be considered.

Question 10 - Are there other areas where we need to address elite female footballers' needs from a sports technology perspective?

Larger and more commonly discussed areas of technology have been reviewed in questions 2 to 8, however the sports technology market expands beyond these discussed elements, and some will be discussed in brief below.

The development of sports friendly sanitary products and leak-proof clothing are potential strategies to address the concern raised about visible leakage due to the colour of shorts. However, to the authors' knowledge, currently no research has addressed this issue to date. Moreover, access to sanitary products – even at national team level - is not a given when assessed globally. A group of researchers conducted a survey in November 2020 on women's national team players competing in the Council of Southern Africa Football Association (COSAFA) Women's Championship. They found a low presence of access to sanitary products, with 33% expressing having used old rags and 2% expressing having used toilet paper as alternatives to sanitary products [61].

Finally, women's specific emergency medical equipment is paramount. Clear guidance on emergency medical equipment exists for both elite men's and women's football [62]. However, concerns have been raised around assumptions that equipment bought and used for men's teams can be safely used with the desired effect for the club or national women's team without the risk of issues. An example highlighted by medical staff in elite football is the standard cervical spine collars. It has been noted that, when tested on a women's team – a procedure outside the set training and planning requirements - a worryingly poor fit was observed in smaller women. Applying a poorly fitted spine collar in trauma settings increases neck motion and hence

decreases safety and may lead to malmanagement of spinal fractures [63]. Assessing and checking fit of equipment on the relevant population(s) should therefore be standard best practice.

Discussion

FIFA has identified women's football as the single biggest opportunity for growth in football [64]. With elite women's football demonstrating recent growth in popularity [65], the sport is on an upward trajectory in terms of development and investment. Building on recent investment and popularity, the elite women's game has become increasingly professional [66]. Still, the Fédération Internationale des Associations de Footballeurs Professionnels (FIFPro; World Players Union) recently reported a need for more investment and support if the women's game is to develop to its full potential [67]. As such, women's football seems to hold a complex position with both opportunities and challenges on the horizon. Women footballers are still not facing a level playing field and this is also evident from the sports technology perspective. Manufacturers are acknowledging this and a positive shift in developing women's specific football technology is happening. Though, due to a lack of research (with data often being extrapolated from men to women) not enough is known about the specific challenges facing elite women football players, thus technology advancements are limited by the level of research conducted.

To overcome these challenges, more products based on an enhanced understanding of women's specific needs are required to optimise performance, safety, and the overall experience for women's footballers. Advancements are being made, but these are often reliant on anecdotal evidence (as highlighted from this paper). A concerted effort is therefore needed from a research perspective to establish an evidence base to inform development of technologies that optimise performance and health. The authors of this paper aimed to highlight essential gaps in research and production of technology for elite women's football, which can help steer the directions of women's football attention in sports engineering research and manufacturing.

Conclusion

Elite women's football keeps growing and so do the requirements for football technology and engineering designed for women. We hope this paper has provided researchers and manufacturers with inspiration and insight into the requirements desired from the elite women's football world. As addressed, this industry is in rapid development and there are multiple issues still to be tackled. Though as a final remark, a general appreciation for the

current efforts made and increase in attention from manufacturers and researchers can also be mentioned.

Compliance with ethical standards

Not applicable.

Funding

None.

Conflict of Interest

Four authors have received funding from sports technology companies for research purposes. Six authors are or have recently worked on elite women's football for teams sponsored by sports technology companies.

One author is a professional player and is sponsored by Nike.

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