Title:
Applied Physiology of Female Soccer: An Update

Authors:
Naomi Datson[1,2], Andrew Hulton[2], Helena Andersson[3], Tracy Lewis[1], Matthew Weston[4], Barry Drust[2] and Warren Gregson[2,5]

[1] The English Football Association, St. George's Park, Burton Upon Trent, UK
[2] Research Institute of Sport Sciences, Liverpool John Moores University, Liverpool, UK
[3] The Swedish Football Association, Stockholm, Sweden
[4] School of Social Sciences and Law, Teesside University, Teesside, UK
[5] ASPIRE, Academy for Sports Excellence, Doha, Qatar

Corresponding Author:
Name: Naomi Datson
Email Address: Naomi.Datson@thefa.com
Telephone Number: +44844 980 8200 (6940)

Abstract
The popularity and professionalism of female soccer has increased markedly in recent years, with elite players now employed on either a professional or semi-professional basis. The previous review of the physiological demands of female soccer was undertaken two decades ago when the sport was in its relative infancy. Increased research coupled with greater training and competition demands warrants an updated review to consider the effect on physical performance and injury patterns.

The physical demands of match-play along with the influence of factors such as the standard of competition, playing position and fatigue have been explored. Total distance covered for elite female players is approximately 10 km, with 1.7 km completed at high-speed (>18 $km.h^{-1}$). Elite players complete 28% more high-speed running and 24% more sprinting than moderate level players. Decrements in high-speed running distance have been reported between and within halves, which may indicate an inability to maintain high-intensity activity. Although physical capacity of female players is the most thoroughly researched area comparisons are difficult due to differing protocols. Elite players exhibit maximal oxygen uptake (VO_{2max}) values of 49.4 - 57.6 $ml.kg^{-1}.min^{-1}$, Yo Yo Intermittent Endurance test level 2 (YYIE2) scores of 1774 ± 532 m (mean ± SD) and 20 m sprint times of 3.17 ± 0.03 s (mean ± SD). Reasons for the increased prevalence of anterior cruciate ligament injuries in females (2-6 times greater than males) are discussed with anatomical, biomechanical loading and neuromuscular activation differences being cited in the literature. This review presents an in-depth contemporary examination of the applied physiology of the female soccer player.

1) Introduction

The last review of the physiological demands of female soccer was undertaken two decades ago [1] . At the time of that review, women's soccer was in its relative infancy with the inaugural Women's World Cup having taken place in 1991. The popularity of women's soccer has increased markedly in recent years with 29 million participants recorded in 2011, an increase of 34% from 2000 [2]. The 2015 Women's World Cup will have 24 participating nations, an increase of eight from the previous tournament.

Since the previous review, increasing attention in the scientific literature has focused on women's soccer with over two thousand scientific articles published. There has been a drive towards professionalism in the sport with players at the highest level now employed on a professional or semi-professional basis. Current elite players are exposed to greater training volumes and competition demands than ever before, consequently these increased physical demands may have implications for both physical performance levels and injury patterns. In-line with these changes, advances in technology available for monitoring athletes has led to greater opportunities to scientifically support players and thus information regarding the modern elite female player is increasingly available. It is evident that an updated review into the applied physiology of the female game and its players is warranted to examine the recent research while also highlighting directions for future work. To ensure all relevant empirical studies on female soccer players were examined, a search on PubMed and Google Scholar was performed using a combination of the following terms: 'soccer', 'football, 'female' and 'women'. Manual secondary searches were undertaken on the reference lists of recovered articles. As this was a narrative and not a systematic review, the papers that were believed to be the most relevant were selected. No date limit was set for the search period and only articles written in English were considered. Articles that did not focus on the physical aspects of performance and injury were excluded.

2) Match Physical Performance

A comprehensive understanding of the demands of the game is necessary to apply a systematic approach to training [3]. The use of technologies such as Global Positioning System (GPS) devices and semi-automated camera systems are now relatively commonplace within men's soccer. These technologies are more time efficient than the traditional video-based time motion analysis systems and offer greater objectivity and volume of information [4]. Furthermore, more detailed evaluations of specific elements of a player's physical performance as opposed to generic time-motion analysis can be undertaken [5-8]. Despite advancements in the understanding of match-play in elite male players, published research on elite female players is lacking [9], predominantly due to stadium access and financial considerations.

At the time of the previous review [1] there were no published findings on the activity profile of female players. Early unpublished data collected via video-tape [1] (n = 7) of national team players showed individuals covered a total distance of 8.47 ± 2.2 km (mean ± SD) and average sprint distances were 14.9 ± 5.6 m (mean ± SD), although the speed zone for sprinting was not defined. More recent studies [10-13] , using larger sample sizes (n = 13 - 58) have reported an increase in total distance covered (~10 km) for national team players when measured using video-tape and GPS technology. Whilst a trend exists for an increase in total distance covered compared to early reports, these differences may also to some extent reflect differences in data collection methods [4]. Total distance covered provides a global estimation of physical match-play but it is high-speed running which is deemed to be more informative and reflective of the game [5,7]. In the previous review [1], the only reference to high-speed activity was the average sprinting distance. However, since this time national team players have been reported to cover a distance of 1.53 – 1.68 km at high speeds (>18 km.h^{-1}) [10,12,14]. Repeated sprinting and high-intensity bouts have also been examined with elite players performing 5.1 ± 5.1 and 31.2 ± 18.7 (mean ± SD) respectively [15]. Explosive events and game specific skill involvements are also deemed important markers of physical match performance yet these areas have been subject to little attention in the literature. Game specific skill involvements (including passing, dribbling, tackling and trapping) have been quantified as 76 ± 30 events per match [11] and specifically 11 ± 1 headers and 16 ± 1 tackles [14] (mean ± SD) with players also undertaking between 1350 and 1650 changes of activity [10,11,14].

The amount of high-speed running and sprinting undertaken by female players increases at higher standards of competition. Top-level players perform 28% more high-speed running (1.68 ± 0.09 km v 1.30 ± 0.10 km; effect size 4.0 (mean ± SD)) and 24% more sprinting (0.46 ± 0.02 km v 0.38 ± 0.05 km; effect size 2.2 (mean ± SD)) than moderate-level players [12] . Players produce more repeated-sprint bouts during international matches compared to national league (4.8 ± 2.8 bouts/match v 1.0 ± 1.0 bouts/match; effect size 2.0 (mean ± SD) [11]. Additionally, female players complete more high-speed running (13%) and sprinting (14%) when playing an international game compared to a domestic game [10]. An overview of the demands of elite female match-play taken from recent studies is shown in Table 1.

An evaluation of the demands of different playing positions is essential to ensure specificity of training and potential talent identification of players. Despite the previous review [1] stating that further investigation of positional variations was warranted there still appears to be a lack of information in this area. Observations indicate that midfielders cover greater total distance (10.67 ± 1.34 km) compared to defenders (9.62 ± 1.20 km) and attackers (9.61 ± 0.36 km) (mean ± SD) [11]. These findings have been confirmed by GPS technology with midfielders covering over 1000 m more than attackers (9.64 km v 8.51 km) and 600 m more than defenders (9.64 km v 9.01 km) (mean ± SD) [13]. Differences in high-speed activity also exist with central defenders performing less high-speed running (1.26 ± 0.11 km) than both midfielders and attackers (1.65 ± 0.11 km and 1.63 ± 0.10km, respectively) (mean ± SD) [14]. Attackers complete a greater amount of sprinting (>25km.h^{-1}) (0.52 ± 0.03 km) than both midfielders and defenders (0.43 ± 0.04 km and 0.33 ± 0.05 km, respectively) (mean ± SD) [14]. Future studies investigating the physical demands of different playing positions should consider the use of more specific positions (e.g. central defenders, wide defenders, central midfielders, wide midfielders and attackers) that are now commonly applied to research focussed on the male game [5,7]. The need to differentiate between central and wide positions in female soccer research is in accordance with recent studies, which have observed differences between these positions [16].

A change in physical performance, particularly high-speed running within and between each 45-minute half has frequently been used as a marker of progressive match fatigue, with results indicating that players experience temporary fatigue during and towards the end of a game [16] . Total distance covered has been shown to be consistent between halves (5.23 ± 0.09 km v 5.21 ± 0.08 km; effect size 0.2), however, significant reductions in high-speed running (0.68 ± 0.06 km v 0.62 ± 0.04 km; effect size 1.2) and sprinting (0.20 ± 0.03 km v 0.17 ± 0.02 km; effect size 1.0) occur (mean ± SD) [17]. Some alterations in game specific skill involvements have also been demonstrated between halves with the number of tackles being greater in the first half compared to the second [14]. Reductions in repeated sprint and repeated high-intensity activity have not been observed between halves in elite players, however, an increased amount of low-intensity recovery between efforts occurs [15]. In an attempt to further examine the occurrence of fatigue, previous research has examined changes in physical performance within each half. Reductions in high-speed running distance have been reported with a 30% (0.27 to 0.19 km) and 34% (0.24 to 0.16 km) decrement from the first to the last 15-minute period observed in both the first and second half, respectively [18]. This reduction in high-speed running distance is even more pronounced when the same players compete in different levels of competition, with an 18% and 40% decline in the last to first 15 minutes of the second half for domestic and international competition, respectively [12]. The 5-minutes subsequent to the peak 5-minute period of high-speed running during match-play has frequently been used as an indicator of temporary fatigue and a 17% decrement in high-speed running was apparent in top-level players but not moderate-level players [14]. These findings suggest an inability to maintain high-intensity running and thus a failure to perform at the required intensity for the duration of the match. However, due to the tactical constraints of match-play these findings do not provide direct evidence of fatigue and as such a number of studies have assessed isolated physical performance parameters before and after match-play since these measures are not affected by tactical and technical decisions [19]. Decrements in sprint (3.0 ± 0.5%) [20], counter movement jump (4.4 ± 0.8%) [20], repeated sprint (4%) [21], intermittent endurance as measured by the Yo Yo Intermittent Endurance test level 2 (YYIE2) (62%) [21], peak torque knee extension (7.1 ± 1.9%) [20] and peak torque knee flexion (9.4 ± 1.8%) [20] have been highlighted (mean ± SD). These types of assessment may give a clearer indication of fatigue development following a game.

The published studies to date indicate differences in the motion analysis of soccer players based upon the level of competition, stage of the game and playing position. The majority of these studies have been conducted using traditional single camera time-motion analysis methods pioneered in the 1970s. Modern technologies such as GPS and semi-automated camera systems are able to provide more detailed information across large samples of players relative to video-based approaches [4,22]. Consequently, more comprehensive evaluations of the physical characteristics of elite female match-play using contemporary analysis methods and more specific playing position classifications are warranted. The defining of individual speed threshold zones relative to a player's physical capabilities could also be considered for future studies. Male players have been shown to have individual thresholds for high-intensity running, as defined by the speed at the point of the second ventilatory threshold [23]. Accordingly, there is an apparent need to individualise the speed thresholds utilised. Furthermore it has been demonstrated that the use of default thresholds in semi-automated camera systems substantially underestimated the amount of high-intensity running distance completed [23]. Recent research [24] has examined maximum sprinting speed for female soccer players and these values could be used to contribute to a framework of speed threshold classification for female players. However, consideration must be given to classification and justification of the different match activity zones.

3) Physiological Demands of Match Play

3.1) Aerobic

Heart rate measurement is often used as an indirect measure of intensity of exercise and the validity of heart rate monitoring in soccer has formerly been described [25]. In the previous review [1], the only referenced heart rate data was during small-sided games. Since then, several studies have determined heart rate during competitive female match-play and noted average and peak heart rate values of 86 ± 3% of maximum heart rate (HR_{max}) and 98 ± 1% HR_{max} respectively (mean ± SD). The assessment of heart rate and subsequent use of pre-established heart rate and maximal oxygen uptake (VO_{2max}) relationships are frequently used to estimate the aerobic contribution to match-play [26]. Average VO_2 during match-play in elite female players has been estimated at 77-80% of VO_{2max} [17,18], with peak values of 96% of VO_{2max} [18]. These values for heart rate and VO_2 suggest the aerobic energy system is highly taxed throughout female soccer match-play with periods of near maximal exertion exhibited [18]. It should be noted, however, that heart rate values during match-play might overestimate the actual physical demands [10,17,21].

Heart rate responses to match-play do not appear to vary for position during domestic competition with values of 86 - 88% of peak heart rate (HR_{peak}) reported for defenders, midfielders and attackers [18]. Slightly lower (82 ± 3% HR_{peak}) (mean ± SD) average heart rate values were reported during an international friendly [27]. Peak heart rate values achieved during match-play have been shown to be similar for international (97 ± 3% HR_{peak}) and domestic games (97 ± 2% HR_{peak}) (mean ± SD), despite differences in workload as measured by high-speed running [9]. Heart rate values in females are reported as similar during the first and second halves or indeed in any 15-minute period of the game [21]. Furthermore, match-play heart rate was not found to correlate with VO_{2max},, which is likely due to the limitations of heart rate for assessing exercise-intensity during match-play [10,17,21].

3.2) Anaerobic

Still little information exists on the anaerobic energy contribution to female match-play. Traditionally anaerobic capacity has been evaluated using blood lactate with elite female players exhibiting mean blood lactate concentrations of 5.1 ± 0.5 $mmol.L^{-1}$ and 2.7 ± 0.4 $mmol.L^{-1}$ (mean ± SD) following the first and second halves respectively [21]. Decreased blood lactate concentrations following the second half have been attributed to a reduction in distance covered and intensity [28]. However, it is important to highlight that blood lactate concentration depends largely on the activity pattern of the player in the minutes preceding blood sampling and consequently may over or underestimate the overall demands [28]. Further insight into the anaerobic demands of female match-play is warranted, particularly in relation to playing position and standards of competition.

4) Physical Capacity

Identifying the physical capacity of an individual player represents a central component of the ergonomic model discussed by Reilly [3]. A comprehensive understanding of a player's strengths and weaknesses informs selection, tactical decisions and ultimately the specifics of a detailed training programme. Moreover, the testing of physical capacity can help identify talent and differentiate between standards of competition [29].

4.1) Anthropometry

Female national team players and those competing in the highest domestic leagues are on average 20 - 27 years old, 1.61 – 1.70 m in stature, weighing 57 – 65 kg, with a body fat percentage of 14.6 - 20.1% and lean muscle mass of 45.7 ± 3.9 kg (mean ± SD) [10,13,17,18,21,27,30-36] (see Table 2). Height and body mass of elite female players remains comparable to earlier reports, however, percentage body fat is now lower than previously observed (20.8 - 22%) [1]. These alterations in body composition likely reflect greater training volume and improved access to support staff such as nutritionists.

The large variation in anthropometric measures highlights the heterogeneity amongst the elite female population. Height and body mass have previously been reported to be similar between playing positions in elite Norwegian [33] and North American [37] players. However, contradictory evidence exists showing that defenders tend to be taller than attackers and heavier than all other outfield positions [33,35]. Similarly, goalkeepers have been shown to be taller and heavier than midfielders and attackers [33,35]. Goalkeepers were reported to have the highest fat mass, which could be attributed to reduced energy expenditure in training and games [35]. Full backs were found to have the lowest body fat percentage and highest muscle mass [35] which may be related to differing physical demands of their playing position although this finding cannot be corroborated as current match analysis literature fails to differentiate between wide and central defenders.

Conversely, older studies [38,39] have found no significant differences in body fat percentage between outfield playing positions. It can be speculated that the positional differences demonstrated in recent studies are a result of increased training specificity for playing positions or indeed that player's with particular anthropometric characteristics are assigned to certain playing positions.

The basic physical characteristics of female players across a spectrum of playing standards have been documented within the literature. Researchers have described anthropometric characteristics of high school [40], university [37,41,42], lower division domestic league [32], higher division domestic league [21,33] and national team players [10,13]. However, the anthropometric profile of elite youth players has yet to be fully examined. Some information exists regarding differences in anthropometric variables based on the level of competition, with differences in body mass and body fat percentage being demonstrated between elite and non-elite players [35,38]. Specifically, elite Spanish players were found to be lighter and have lower percentage body fats than their non-elite counterparts [35].

4.2) Maximal Aerobic Power

The aerobic system is highly stressed during soccer match-play [28]. The direct measurement of VO_{2max} in female soccer players has been reported in a number of studies with values for elite players ranging from 49.4 - 57.6 $ml.kg^{-1}.min^{-1}$ and are similar to those reported in the previous review [1]. Some studies [37,43,44] have estimated VO_{2max} using the equation derived from the distance achieved in the multistage fitness test [45]. However, the predictive power of the multistage fitness test to estimate VO_{2max} in young women soccer players has recently been questioned [46]. A summary of direct and indirect values for VO_{2max} values in elite female soccer players is shown in Table 3.

Similar VO_{2max} levels have been observed between playing positions [33] although midfielders often record higher values than those in other positions [33]. When using the multistage fitness test to estimate VO_{2max} the findings are equivocal with some studies showing no differences in aerobic capacity between playing positions [37,38], whereas one study highlighted significant differences between midfielders and defenders [39]. The VO_{2max} of female players has been reported by a number of researchers at various levels of competition and descriptions for university [37,42,47] and lower division domestic league players [44] generally show a lower capacity than higher division domestic league [17,18] and national team players [48,49]. In addition, a positive correlation has been demonstrated between VO_{2max} and the amount of high-intensity running completed during a match [18]. However, when VO_{2max} for international and regional English players was directly compared, no significant differences were reported [38]. The failure to discriminate between standards of competition in this study may be a result of both groups being non-professional at this time and therefore the differentiation between weekly training volume and intensity may have been slight. Furthermore, the specificity of VO_{2max} for soccer performance has been questioned [50,51], consequently more intermittent based assessment tools are now commonly used.

4.3) High-Intensity Endurance Capacity

It has previously been described [1] that in order to be successful a player must have the capacity to recover rapidly from high-intensity exercise. The use of the Yo Yo Intermittent Recovery (YYIR) [53] and Yo Yo Intermittent Endurance tests (YYIE) [54] are now commonplace in field-based testing protocols for team sports. An overview of published literature can be found in Table 4.

Published data for national team female players shows distance of 1774 ± 532 m being attained on the YYIE2 test [54], however, non-published data reports distances of up to 2182 ± 89 (mean ± SD) [55]. There appears to be no published data for national team players using the Yo Yo Intermittent Recovery test level 1 (YYIR1) test, however, domestic players from the Danish and Spanish leagues cover 1379m (600 – 1960 m) [18] and 1224 ± 255 m (mean ± SD) [32], respectively. Some positional differences in YYIE2 have been identified [54], with senior wide midfielders covering more distance than central defenders and attackers, similarly, wide and central midfielders covered more distance than central defenders at under nineteen (U19) level. Moreover, large differences (48%) in YYIR1 performance have been demonstrated (1224 m versus 826 m) between first and second division female Spanish players [32]. These large differences can likely be attributed to female players in lower leagues operating at a recreational level with a lower training volume.

4.4) Speed

A plethora of studies [22,29,37,40-44,56,57] have undertaken speed testing with female soccer players, however, the use of different assessment protocols limits comparison. For example, the distance that a player stands before the first timing gate is variable with 0 cm [41,58] and 88 cm [21] being used in the literature. Nevertheless, Table 5 highlights the studies to date that have described speed characteristics of female players.

The previous review [1], could only reference one report of sprint time in elite players 3.31 ± 0.11 s (mean ± SD) for 20 m by Australian national team players [43]. More recent findings have shown 20 m sprint times of 3.26 ± 0.06 s [57] with the same protocol and 3.17 ± 0.03 s [21] when using a greater distance between the start line and first timing gate (mean ± SD).

Limited information exists on the differences in speed characteristics between playing positions. Vescovi and colleagues [37] evaluated differences in speed variables (10 - 40 yard sprints) and they concluded there were no significant differences between playing positions, despite a trend for defenders to be slower. It has been proposed that sprint performance can distinguish between standards of competition [24,29]. Selected players from trials for an American professional soccer league were between 0.5 and 0.8 $km.h^{-1}$ faster than their non-selected equivalents [24]. Similar findings were reported during an Australian talent identification project with selected players recording faster times over 5 m, 10 m and 20 m, respectively than the non-selected players [29].

4.5) Repeated Sprint Ability

Repeated sprint ability is acknowledged as an important aspect of team sports [15,22]. However, very few studies have reported assessments of this fitness characteristic in female soccer players. Furthermore, the published papers to date [44,47,58] have used different protocols making comparison difficult. One study [44] adopted a method that involved players completing a 34.2 m sprint course seven times with 25 seconds rest between sprints [59]. The reported mean sprint time to complete the course ranged from 8.79 - 9.13 seconds following a training intervention. Gabbett [58] designed a repeated sprint test specifically to reflect the demands of international female soccer. The test involved 6 repetitions of a 20 m maximal sprint, on a 15 second recovery cycle which represents the most extreme repeated-sprint demands of the international game [11]. The total sprint time was found to be reliable (1.5% typical error of measurement) and able to discriminate between elite and sub-elite players and thus this protocol could be used in future to advance research in this area.

4.6) Power and Strength

The assessment of jumping capability is an accepted functional measure of power in soccer players [28]. Furthermore, a significant relationship has been demonstrated between team success and average jump height and leg extension power, thus demonstrating the importance of this physical component for soccer-specific performance [60]. There are numerous reports within the literature detailing the power performance of female players across differing competition levels; university [37,41,42], high school [56,61], lower division domestic league [32,44], higher division domestic [20,21,35], national team youth [36] and senior national team players [11,36,43,49]. As with the other components of physical fitness previously described, the ability to compare data between studies is hindered by the different protocols and equipment adopted by researchers. A summary of results for vertical jump ability in elite players can be found in Table 6.

Playing position does not seem to be a distinguishing factor relating to performance in jumping assessments. However, trends are apparent with goalkeepers recording the lowest scores [35,37] and midfielders and forwards recording greater scores than defenders [37]. Vertical jump performance has been shown to differentiate between age groups [36,61]. Specifically, U19 Italian national team players produced higher countermovement jumps (CMJ's) and squat jumps (SJ's) than their under seventeen (U17) counterparts [36]. Additionally, an improvement in CMJ performance has been described until players reach an age of 15 - 16 and then a plateau in performance is shown until 21 years of age [61]. The data regarding competitive standard and jumping performance show no apparent differences between Spanish [35] or English [38] elite and sub-elite players.

Insightful recommendations have been made within the literature regarding the specifics of protocols that should be adopted for female players. It has been suggested that a drop jump (DJ) may not be appropriate as DJ values have been shown to be lower than CMJ scores despite the increased activation of muscle fibres resulting in increased force production [35]. Justifications for this finding include the increased technical requirement with a DJ compared to a CMJ, furthermore the CMJ has been described as being more similar to physical skills executed within soccer. Consequently, consideration should be given before including the DJ in a testing protocol [35]. Unilateral jump performance has a stronger correlation with sprint performance than bilateral jump performance and is a useful tool for assessing asymmetries, therefore the inclusion of unilateral jumps in a testing protocol is warranted [41]. Castagna and Castellini [36] have attempted to describe thresholds of acceptable vertical jump values for elite females using the data gathered from Italian national team players. The authors have suggested scores over 34.4 cm and 32.9 cm for CMJ and static jump should be regarded as superior vertical jump abilities. In addition, a CMJ of 29.8cm should be considered a threshold measure for discriminating between competitive levels in elite female players. This work could be expanded to include thresholds for different playing positions and age groups.

Investigations into muscle strength in female players are limited and the methods of data collection appear varied, thus making comparisons difficult. Limited recent [21] and historical [48] isokinetic data is available for national team players but the majority of research has been conducted using sub-elite and recreational players to examine injury risk. The scarcity of information available in this area is surprising, as female players have been regularly completing this component of training for many years.

5) Training

Effective conditioning programmes that carefully balance training and recovery are the cornerstone of athletic development. Moreover, in soccer, those that can integrate both physical and tactical/technical training are considered superior in enhancing the effectiveness of the available training time. The issue of managing a player's training load is important for the elite player to ensure optimal preparation for performance and potentially reduce the susceptibility to injury [4,62].

5.1) Training Interventions

As the aerobic system is highly stressed during a soccer game [28], many soccer training programmes serve to increase the ability to repeatedly perform high-intensity exercise [63]. The volume of female specific training literature is sparse but two recent studies [62,64] have shown increased VO_{2max} using interval training methodologies. Specifically, an 8-week mixed-intensity interval programme significantly improved VO_{2max} capacity (49.69 ± 1.15mmol.kg.$^{-1}$ to 62.13 ± 0.96mmol.kg.$^{-1}$) (mean ± SD) [64]. Interval training sessions lasted between 12 – 36 minutes with work durations of between 30 – 90 seconds, sessions were repeated three times per week. Similarly, a 12-week individualised interval training programme consisting of intervals of between 5 – 120 seconds increased mean values for VO_{2max} (13.2%), anaerobic threshold (16.8%) and 1-minute heart rate recovery (36.9%) [62]. However, the participants in these two studies were recreational players and therefore large increases in physical markers would be expected when adhering to an organised training regime. Currently no information is available regarding high-intensity training interventions for elite female players.

It is recognised that to be successful in soccer, an individual must be able to cover short distances quickly [65], as high-intensity activities are most often associated with decisive moments in a game [1]. To date, few studies [44,65,66] have examined components of speed training using a female soccer population. Polman [44] evaluated the use of the 'Speed, Agility, Quickness' (SAQ) method of training and demonstrated improved mean performances in sprint to fatigue (11.6%), 25-m sprint (4.4%), left and right side agility (4.5% and 4.0% respectively) and vertical and horizontal power tests (18.5% and 7.7% respectively) following 12 weeks of SAQ training compared to a control group. The concept of assisted and resisted sprint training has been assessed and these methods were found to be more affective than traditional sprint training [65]. Furthermore, assisted sprint training was more suitable for improving acceleration ($\leq$ 13.7 m) and resisted sprint training for improving maximum velocity ($\geq$ 13.7 m). Bartolini [66] highlighted that when completing overspeed training (2 maximal sprints) with an elastic cord, sprint times were lowest following the use of 30% body weight assistance over distances up to 15 yards. The studies to date have examined sub-elite and collegiate level players and have expressed benefits of various forms of speed training on physical testing values. As with the high-intensity endurance training there appears to be limited available research on the interventions regarding the elite player and this is an area requiring further examination.

Explosive strength is an important determinant of high-level performance in soccer and plyometric activity is cited as a suitable training modality for improving jumping performance and explosiveness [67]. Specifically, elite female players who completed 12-weeks of plyometric training three times per week had mean increases of 3.3 cm and 4.5 cm for CMJ and DJ respectively [67]. Furthermore, female players completing combined plyometric, resistive and anaerobic programmes twice per week also experienced improvements in time to fatigue during a simulated soccer running test [68], a reduction in mean 20-m sprint time (0.10 s) [68] and a significant decrease in the percentage of VO_{2peak} at a set running speed [69]. Plyometric training has also been shown to have a role in injury prevention for female soccer players by enhancing the functional joint stability in the lower extremity [70]. These studies highlight the potential advantages of including plyometric-based activity as part of a training programme, however, as with the aforementioned training techniques further investigation using elite players is required.

6) Female Differences

There are some physiological areas of research that are exclusive to females. A full appraisal of these topics is beyond the scope of this review and in some instances has already been conducted [71-76]. However, the importance of these variables to female soccer players and the potential impact on training, performance and injury risk should not be underestimated.

6.1) Menstrual Cycle

Women aged ~13 – 50 years, experience a circa-mensal rhythm termed the menstrual cycle [77]. Alterations in the cycle can occur and cause menstrual disturbances [78]. High training loads can have an adverse effect on the normal menstrual cycle. Young females with low body mass and body fat levels who undertake intense training may experience delayed menarche [77,79]. Similarly, menstruating athletes with high training loads, low body mass, low body fat levels and/or energy imbalance [77] may suffer secondary amenorrhea, although this is uncommon in soccer players.

Physiological responses may be influenced by the variations in endocrine hormones that occur according to menstrual cycle phase [77]. As women train and compete at all stages of their menstrual cycle the possible effect on performance should be considered. These effects have received a limited amount of research attention and the findings to date have been unclear. VO_{2max} appears to be largely unaffected by the phase of the menstrual cycle [80,81]. However, some studies have shown increased minute ventilation [39,82-84], heart rate [84-86] and rating of perceived exertion [84,85] during the luteal phase, which could be attributed to an increased core temperature (0.3 - 0.5 °C) during this phase [84]. Lactate threshold findings are equivocal with some reports of stable values throughout the cycle [87,88], whilst others describe lower blood lactate concentrations in the luteal phase during moderate-intensity activity [89]. Sprint performance as measured via power output seems unaffected by menstrual cycle phase [90]. Investigations into muscle contractile strength during the cycle have produced conflicting results, however, when methodological shortcomings are addressed it appears that fluctuations in female steroid hormones do not affect muscle strength and fatigability [73]. Limited soccer-specific research exists but one study showed no performance differences in high-intensity intermittent shuttle running throughout the menstrual cycle [91], although differences in core temperature were not found in this study which may explain these findings. At present there are a number of conflicting reports within the literature, methodological concerns and a lack of specificity to team sports, specifically soccer activity.

6.2) Oral Contraceptive Pill

The oral contraceptive pill (OCP) is available in single (progesterone only) and combined (oestrogen and progesterone) formulations. Non-contraceptive benefits include cycle control and reductions in dysmenorrhoea, iron deficient anaemia and bone mineral density loss [92]. In recent years there has been an increase in the use of OCP by the athletic population with reports stating 83% of elite athletes use an OCP [93].

Despite the increased prevalence of OCP usage in athletic populations there is still limited research regarding its effects on athletic performance [94]. Aerobic performance as measured by VO_{2max} has been shown to reduce by 5 - 15% in trained and active women using a triphasic OCP [95,96], however, research remains equivocal when considering the monophasic pill [72]. Anaerobic performance, high-intensity intermittent performance and strength appear to be largely unaffected by OCP, however, more well-controlled studies are required [72,93]. During an investigation in to the effects of OCP on team sport athletes, reactive strength index as measured during a drop jump was significantly lower during the withdrawal phase, i.e. when exogenous oestrogen and progesterone were at their lowest. The mechanism for this finding could not be fully explained but it was suggested that increased endogenous oestrogen may have a negative impact on neuromuscular timing, muscle activation and performance [94]. It is clear that further studies are necessary to ascertain the effects of OCP on soccer-specific performance.

7) Injury

Injury is an accepted part of sports participation at all levels of competition. Variations in injury definition and methods of calculating incidence mean that it is difficult to make valid inter-study comparisons [97]. The majority of literature focuses on adult male professional players with only a few studies assessing injuries in female soccer players [98-105].

The injury incidence for females is between 1.2 and 7.0 injuries per 1000 training hours and 12.6 - 24.0 per 1000 match hours [103-107]. Longitudinal injury patterns in female soccer are of interest to assess if soft tissue injuries are becoming more frequent as the intensity of the female game increases or if the increased professionalism and training status of players decreases injury rates. An 8-season domestic French study reported no significant differences between 1998 and 2006 with injury rates fluctuating between ~4.5 - 8.0 injuries per 1000 hours [105]. Conversely, recorded injuries in the U19 European Championships decreased between 2006 and 2008 from 13.5 to 4.9 injuries per 1000 hours [108].

Soccer injuries predominately affect the ankle, knee and muscles of the thigh and calf [101]. Injuries to the hip and groin are less common in female players [98,103,106,109,110] than males [111,112] and this is attributed to the abdominal wall deficiency apparent in males [113]. Knee injuries are more frequent in females than males [114], with the knee [98,107] and ankle [110] often being cited as the most common injury sites in females. Incidences of ankle injuries have been shown as similar between elite males and females during a competitive season in the Swedish Premier League [114]. Furthermore, ankle sprains accounted for 40% of all injuries in an 8-season study in to female youth soccer [105].

Knee injuries in females are well documented [103] with ligament injuries, specifically injury to the anterior cruciate ligament (ACL) predominant in the literature [75,98,99,115,116]. The large body of evidence is in part due to the financial and emotional cost of an ACL as well as the potential impact upon the team [117]. Female athletes are reported to have between 2 and 6 fold higher incidence of non-contact ACL injury than their male counterparts [115,118]. In soccer, this has been translated to ACL injury rates of 0.4 and 0.7 injuries per season in males and females respectively [115]. Match-play poses a substantially higher risk of ACL injury compared to training (0.09 per 1000 hours versus 0.90 per 1000 hours respectively**)** [107]**.** In addition, female players sustain their knee injuries at an earlier age (14 - 19 years) [75] compared to males (~23 years) [120]. The majority of ACL injuries in soccer are non-contact and occur during landing and cutting manoeuvres [120]. Discrete classification is not always possible as ACL injuries often involve perturbation by another player [120]. The risk factors associated with ACL injury are often multi-factorial. External risk factors include environmental conditions, footwear and surface. Internal risk factors include anatomical, neuromuscular, biomechanical and hormonal variables [74,75]. Studies often concentrate on intrinsic risk factors as they can provide differentiation between the sexes.

Evidence suggests the anatomy of the female knee, specifically a smaller intercondylar notch width and ACL, are contributing factors to an increased risk of ACL injury [74,75]. A link has been established between hypermobile individuals and higher risk of ACL injuries in female soccer and basketball players [122]. A greater quadriceps angle (Q-angle) has been linked to increased injury risk in female basketball players [123] but this has not been replicated in elite female soccer players [110]. Whilst it is important to recognise these anatomical factors they should not be focussed upon as they cannot be addressed via training interventions [74]. Specific studies assessing differences between the sexes have highlighted dynamic alterations in biomechanical loading and patterns of neuromuscular activation, which may expose females to a higher predisposition to injury [124]. Knee stability during dynamic movement and landing is underpinned by muscular strength and recruitment patterns [124]. Hamstring activation patterns and knee abduction movements differ between males and females, with females exhibiting slower and less frequent contractions and increased knee valgus moments [118,125]. Specifically, female soccer players land with decreased hip and knee flexion compared to males, thus increasing force transmitted through the quadriceps relative to the hamstrings and consequently stressing the ACL [126]. Alterations in neuromuscular and biomechanical strategies may be present under fatigue [127] and contribute to increased risk of injury but cannot be considered as an isolated risk factor for ACL [128].

A recent review combined data from seven studies and concluded that female athletes may be more predisposed to non-contact ACL injuries during the pre-ovulatory phase of the menstrual cycle [129]. It has been suggested that hormonal fluctuations may have an indirect effect on neuromuscular control and consequently injury [129]. Furthermore, OCP use combined with neuromuscular training may be advantageous for increasing the dynamic stability of the knee and thus reducing injury risk [130-132]. Indirect support also exists for a link between the use of OCP and reduced soft tissue [133] and traumatic injuries [134].

8) Conclusions and Future Research

Women's soccer has changed dramatically since the previous review [1] two decades ago. The increased professionalism within the sport is represented by the increased physicality of match-play as total distances covered have increased from ~8.5 km [1] to ~10 km [10-13]. Differences in time-motion analysis have also been identified between standards of competition [11], playing position [11,13,14] and at different time-points within a match [12,14,17,18]. The majority of time-motion studies in female soccer to date have used traditional single camera analysis methods as such the ability to examine specific physical elements in detail are limited [5,22]. Consequently, more comprehensive evaluations into the physical characteristics of elite female match-play using contemporary analysis methods and larger sample sizes are warranted.

The physical capacity of female players is probably the most thoroughly researched area within both this and also the previous review [1]. Data is available for most components of physical fitness; however, research focused upon the influence of competitive standard, age and playing position on performance characteristics is still lacking. This largely reflects a lack of consistency between protocols and equipment used. Data for the elite female player is lacking for YYIR and for repeated sprint activity and as such warrants further investigation. Other areas of investigation include tracking physical capacity and injury rates over time to examine potential relationships as well as the utilisation of dual-energy x-ray absorptiometry (DXA) as a sophisticated measurement of body composition to better understand lean mass.

There is still equivocal research on how the menstrual cycle and/or the usage of OCP may affect physical performance. Some studies have indicated that physiological fluctuations that occur throughout the menstrual cycle and/or as a result of OCP usage may affect physical performance [84,93,95]. One study has revealed that the use of the OCP (during the withdrawal phase) has been shown to elicit significantly lower reactive strength index scores during a drop jump. Injury data in female players has largely focussed on ACL injuries, as it is a recognised issue within female team sport athletes, with the incidence quoted as 2-6 times greater compared to males [115,118]. Numerous explanations exist for this increased incidence, some of which are anatomical [74,75,123], whilst others focus on dynamic differences in biomechanical loading and patterns of neuromuscular activation [118,124,126]. A key recent finding is that female athletes may be more predisposed to non-contact ACL injuries during the pre-ovulatory phase of the menstrual cycle [129] and therefore the advantages and disadvantages for training and competing during this phase should be considered.

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Table 1. Match physical demands for elite female soccer players

Reference	Year	N	Competition level	Nationality / region	Distance covered (km)	Number of activity changes	Number of high intensity bouts	High intensity running (km)	High intensity %	Sprinting %	Sprint distance (m) (>25km.h-1)	Number of sprinting bouts (>25km.h-1)	Method of data capture
Andersson et al. [10]	2010	17	International	Scandinavian	9.9 ± 1.8	1641 ± 41	187 ± 15	1.53 ± 0.1		0.65 ± 0.06	256 ± 57		Video tape
		17	Domestic league	Scandinavian	9.7 ± 1.4	1593 ± 30	168 ± 12	1.33 ± 0.9		0.54 ± 0.05	221 ± 45		Video tape
Andersson et al. [135]	2008	21	Highest division	Swedish	9.9			1.15					Video tape
Gabbett and Mulvey [11]	2008	13	v male youth teams	Australian	9.32 ± 0.84			1.86 ± 0.48[a]					Video tape
		13	National league	Australian	9.70 ± 0.48			2.01 ± 0.30[a]					Video tape
		13	International	Australian	9.97 ± 1.14			2.46 ± 0.49[a]					Video tape
Hewitt et al. [13]	2008	15	International	Australian	9.14 ± 1.03			0.62 ± 0.11[b]				280 ± 80[c]	GPS
Krustrup et al. [12]	2008	12	International	Scandinavian	10.0 ± 0.5			1.6 ± 0.4					Video tape
		12	Domestic league	Scandinavian	9.7 ± 0.6			1.4 ± 04					Video tape
Mohr et al. [14]	2008	19	Highest division	All – USA pro league	10.33 ± 0.15	1379 ± 34	154 ± 7	1.68 ± 0.09	6.0 ± 0.3	1.2 ± 0.1	460 ± 20	30 ± 2	Video tape
		15	Domestic league	Scandinavian	10.44 ± 0.15	1326 ± 24	125 ± 7	1.3 ± 0.10	4.4 ± 0.5	0.9 ± 0.1	380 ± 50	26 ± 1	Video tape
Krustrup et al. [18]	2005	14	Highest division	Danish	10.3	1459	125	1.31			160	26	Video tape

Data are mean ± standard deviation
GPS = global positioning system
[a] = descriptive definition
[b] = >16km.h^{-1}
[c] = >20km.h^{-1}

Table 2. Basic physical characteristics for elite female soccer players

Reference	Year	N	Competition level	Nationality / region	Age (yrs)	Height (m)	Weight (kg)	Body fat content (%)
Castagna et al. [36]	2013	21	National team players	Italian	25.8 ± 3.9	1.67 ± 0.04	59.9 ± 3.8	
Gravina et al. [31]	2011	14	Highest division	Spanish	25 ± 5		61 ± 7.4	15.5 ± 2.9
Ingebrisgten et al. [33]	2011	29	Highest division	Norwegian	20.8 ± 3.7	1.66 ± 0.05	60.7 ± 6.6	
Andersson et al. [10]	2010	17	National team players	Scandinavian	27 ± 1	1.68 ± 0.02	61.0 ± 1.4	
Andersson et al. [27]	2010	16	Highest division	Scandinavian	22 ± 3	1.67 ± 0.05	64 ± 2	
Krustrup et al. [21]	2010	23	Highest division	Danish	23	1.69	60.1	18.50
Mujika et al. [32]	2009	17	Highest division	Spanish	23.1 ± 2.9	1.65 ± 0.04	56.8 ± 5.7	
Sedano et al. [35]	2009	100	Highest division	Spanish	22.1 ± 1.1	1.61 ± 0.06	57.7 ± 7.5	20.1 ± 5.5
Hewitt et al. [13]	2008	15	National team players	Australian	23.5 ± 2.5	1.70 ± 0.05	64.88 ± 4.6	
Krustrup et al. [18]	2005	14	Highest division	Danish	24	1.67	58.5	14.6
Can et al. [34]	2004	17	Highest division	Turkish	20.73 ± 2.09	1.62 ± 0.06	56.63 ± 5.03	19.75 ± 0.69
Bunc et al. [30]	2004	14	Elite	Czech	25.3 ± 4.8	1.65 ± 0.06	64.5 ± 9.9	14.9 ± 5.7
Mohr et al. [17]	2004	18	Highest division	Scandinavian	24 ± 1	1.68 ± 0.02	61 ± 1	15 ± 1

Data are mean ± standard deviation

Table 3. Maximal oxygen uptake for elite female soccer players

Reference	Year	N	Competition level	Nationality / region	Maximal oxygen uptake (ml.kg.min^{-1})	Estimated maximal oxygen uptake (ml.kg.min^{-1})
Ingebrigtsen et al. [33]	2011	29	Highest division	Norwegian	51.85 ± 5.05 (def)	
					55.36 ± 5.65 (mid)	
					52.94 ± 3.17 (att)	
					50.70 ± 4.96 (gk)	
Andersson et al. [27]	2010	16	Highest division	Scandinavian	54 ± 3	
Krustrup et al. [21]	2010	23	Highest division	Danish	52.3 ± 1.3	
Andersson et al. [20]	2008	8	Highest division	Scandinavian	55.4 ± 3.6	
Andersson et al. [20]	2008	9	Highest division	Scandinavian	53.8 ± 2.3	
Gabbett et al. [11]	2008	13	Scholarship holders	Australian	51.4 ± 5.4	
Krustrup et al. [18]	2005	14	Highest division	Danish	49.4	
Bunc et al. [30]	2004	14	Elite	Czech	53.9 ± 5.7	
Mohr et al. [16]	2004	18	Highest division	Scandinavian	49.5 ± 1	
Tumilty et al. [57]	2000	17	National team players	Australian		50.3 ± 5.1
Tamer et al. [136]	1997	22	Elite	Turkish		43.15 ± 4.06
Davis et al. [48]	1992	14	National team players	English	52.2 ± 5.1[a]	
Evangelista et al. [137]	1992	12	Elite	Italian	49.75 ± 8.3	
Jensen et al. [49]	1992	10	National team players	Danish	57.6[a]	
Tumilty et al. [43]	1992	20	National team players	Australian		48.5 ± 4.8

Data are mean ± standard deviation
[a] = following an intervention
def = defenders
mid = midfielders
att = attackers
gk = goalkeepers

Table 4. Soccer specific endurance test results for elite female soccer players

Reference	Year	N	Competition level	Nationality / region	YYIR1 (m)	YYIE2 (m)
Bradley et al. [54]	2012	92	National team players	European		1774 ± 532
		46	Highest division	European		1261 ± 449
		42	U20 national team players	European		1490 ± 447
		19	Lowest division	European		994 ± 373
Krustrup et al. [21]	2010	23	Highest division	Danish		1213 ± 90
Mujika et al. [32]	2009	17	Highest division	Spanish	1224 ± 255	
		17	Second division	Spanish	826 ± 160	
Krustrup et al. [18]	2005	14	Highest division	Danish	1379	

Data are mean ± standard deviation
YYIR1 = Yo-yo intermittent recovery test level 1
YYIE2 = Yo-yo intermittent endurance test level 2
U20 = Under 20

Table 5. Speed test results for female soccer players

Reference	Year	N	Competition level	Nationality / region	Time 5m (s)	Flying time 9.14m (s)	Time 9.14m (s)	Time 10m (s)	Flying time 18.2m (s)	Time 18.28m (s)	Flying time 20m (s)	Time 20m (s)	Time 25m (s)	Time 27.3m (s)	Time 36.56m (s)
Sjokvist et al. [42]	2011	14	University	USA								3.59 ± 0.17			
McCurdy et al. [41]	2010	15	University	USA				2.31 ± 0.25					4.52 ± 0.20		
Andersson et al. [20]	2008	8	Highest division	Scandinavian								3.18 ± 0.03			
		9	Highest division	Scandinavian								3.17 ± 0.03			
Vescovi et al. [56]	2008	83	High school	USA		1.37 ± 0.06	1.96 ± 0.10		2.67 ± 0.13	3.33 ± 0.15				4.63 ± 0.21	5.94 ± 0.28
		51	College	USA		1.38 ± 0.07	2.00 ± 0.11		2.75 ± 0.44	3.38 ± 0.17				4.69 ± 0.23	5.99 ± 0.29
Vescovi et al. [37]	2006	64	University	USA			1.98 ± 0.11			3.34 ± 0.17					5.90 ± 0.31
Polman et al. [44]	2004	36	Second division	English									4.12 ± 0.13[a]		
Siegler et al. [40]	2003	17	High school	USA							2.90 ± 0.13 [a]				
Hoare et al. [29]	2000	17	Talent identification – selected triallists	Australian	1.18 ± 0.06			2.01 ± 0.08				3.47 ± 0.14			
Tumilty [57]	2000	20	National team players	Australian	1.14 ± 0.04			1.91 ± 0.04				3.26 ± 0.06			

Data are mean ± standard deviation
[a] = following an intervention

Table 6. Vertical jump test results for elite female soccer players

Reference	Year	N	Competition level	Nationality	Squat jump (no arms) (cm)	Drop jump (no arms) (cm)	Countermovement jump (no arms) (cm)	Countermovement jump (with arms) (cm)
Castagna et al. [36]	2013	21	National team players	Italian	30.1 ± 3.7		31.6 ± 4.0	
		20	U19 national team	Italian	32.8 ± 2.9		34.3 ± 3.9	
		21	U17 national team	Italian	28.2 ± 2.5		29 ± 2.1	
Krustrup et al. [21]	2010	23	Highest division	Danish			35 ± 1.0	
Mujika et al. [32]	2009	17	Highest division	Spanish			32.6 ± 3.7	38 ± 4.8
Sedano et al. [35]	2009	100	Highest division	Spanish		25.3 ± 5.6	26.1 ± 4.8	
Andersson et al. [20]	2008	8	Highest division	Scandinavian			30.5 ± 1.2	
Krustrup et al. [13]	2008	12	National team players	Scandinavian			35 ± 1.0	
Can et al. [34]	2004	17	Highest division	Turkish			34.48 ± 7.11[a]	
Tumility [57]	2000	20	National team players	Australian			51 ± 5	
Jensen et al. [49]	1992	10	National team players	Danish			37.8[b,c]	
Tumilty et al. [43]	1992	20	National team players	Australian			40.5 ± 4.5[a]	

Data are mean ± standard deviation
[a] = recorded as "vertical jump" but assumed to be countermovement jump
[b] = jump height estimated from flying time
[c] = following an intervention
U19 = under 19
U17 = under 17

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