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Fuelling performance of female soccer players: appraisal of the likelihood of between-sex differences in carbohydrate requirements

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Appraisal of sex differences in fuelling requirements

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ABSTRACT

Skeletal muscle glycogen depletion is considered one of the key contributing factors toward fatigue and associated performance decrements in soccer. Ensuring adequate carbohydrate availability before and during training and matches is widely-advised as a priority for players, and for that reason, carbohydrate-based fuelling guidelines for soccer have been developed. However, the lack of female-specific research used to inform the development of these guidelines raises important questions regarding their applicability for female soccer players. This review critically appraises the likelihood of there being between-sex differences in carbohydrate requirements for soccer performance. Males and females exhibit differences in substrate utilisation during exercise, substrate storage capacity, relative quantities of fat and fat-free mass, and running demands of soccer match-play, but the extent to which these differences translate into practically-meaningful differences in carbohydrate requirements for soccer performance remains unclear. Based on current evidence, we consider it premature to suggest that female players will require sex-specific guidelines in relation to carbohydrate-based fuelling strategies for performance in soccer. However, intervention studies in female players investigating carbohydrate-based fuelling strategies before and during soccer match-play or simulated soccer protocols are warranted.

KEYWORDS

football; muscle glycogen; running demands; substrate utilisation; team sport;

Introduction

Carbohydrate (CHO) is the primary fuel source for skeletal muscle during high-intensity exercise (Anderson et al., 2022; Hargreaves & Spriet, 2020; Vigh-Larsen et al., 2021). Soccer is characterised by repeated high intensity activities interspersed with prolonged periods of low- to moderate-intensity activity, resulting in a substantial reliance on glycogen stores in both skeletal muscle and the liver (Krustrup et al., 2022; Krustrup et al., 2006; Vigh-Larsen et al., 2021). For example, skeletal muscle glycogen concentrations can decline by ~40% from pre- to post-match (Krustrup et al., 2022; Krustrup et al., 2006), with 80% type I fibres and 69% type II fibres being observed to be "almost empty" or "completely empty" of glycogen in one study of female soccer players (Krustrup et al., 2022). Therefore, muscle glycogen stores are inherently limited in their capacity relative to the fuel demands of training and matches (Krustrup et al., 2006; Vigh-Larsen et al., 2021). Consequently, ensuring adequate CHO availability before and during training and matches is often advised as a key priority for players to support performance (Collins et al., 2021). Current guidelines for acute intake of CHO before and during soccer performance are shown in **Table 1**.

Table 1. Current guidelines on carbohydrate-based fuelling strategies for before and during soccer performance (Collins et al., 2021)

Strategy/time period	Current recommendations
Carbohydrate loading	6 to 8 g/kg BM on MD-1
MD	6 to 8 g/kg BM on MD
Pre-match	1 to 3 g/kg BM 3 to 4 hours before kick-off
During exercise	~30 to 60 g after warm-up and at half-time

Abbreviations: g/kg BM, grams of carbohydrate per kilogram of body mass; MD, match day.

Although these guidelines are intended to apply to both male and female players, the authors acknowledge that the data on female soccer players is sparse (Collins et al., 2021). Indeed, our recent audit revealed that females accounted for less than 4% of participants in the evidence base that informed the development of these guidelines (McManus et al., 2025). The lack of female-specific research in this area raises important questions regarding the applicability of existing CHO guidelines for female soccer players (McManus et al., 2025; Randell et al., 2021), given that there are various physiological and metabolic differences between males and females that could impact CHO-based fuelling requirements for soccer performance. Males and females exhibit differences in substrate utilisation during exercise (Lundsgaard & Kiens, 2014), muscle fibre composition and capillarisation (Haizlip et al., 2015), substrate storage capacity (Tarnopolsky et al., 1995), relative quantities of fat and fat-free mass (FFM) (Randell et al., 2021; Sebastiá-Rico et al., 2023), and physical demands of soccer match-play (Datson et al., 2017; Ju et al., 2025) which may influence dietary needs, nutrient-exercise interactions, and performance outcomes. Therefore, this review critically appraises whether these differences are likely to result in between-sex differences in CHO-based requirements for fuelling soccer performance, as well as considering the extent to which any differences could translate into practically-meaningful differences in CHO requirements between male and female soccer players.

Differences in substrate utilisation between males and females

Developing nutrition recommendations for soccer players necessitates a comprehensive understanding of the types and quantities of energy substrates utilised during match-play. To date, no study has directly compared substrate utilisation between male and female athletes during soccer match-play or a simulated soccer protocol. More broadly, between-sex comparisons of substrate metabolism during any intermittent-type running protocol remain scarce in the literature. Consequently, findings from continuous running protocols, and continuous and intermittent cycling protocols must be relied upon to assess potential between-sex differences in substrate utilisation during exercise. Evidence from controlled laboratory settings consistently shows that when matched for training status and $\dot{V}O_2$max, and when exercising at the same relative intensity, females tend to exhibit greater reliance on fatty acids during prolonged submaximal aerobic exercise compared with males (Carter et al., 2001; Montero et al., 2018; Roepstorff et al., 2006; Tarnopolsky et al., 1990). A whole-room calorimeter study demonstrated that, relative to FFM, females exhibited 32% and 90% greater rates of fat oxidation than males during low (40%$\dot{V}O_2$max) and high-intensity (70%$\dot{V}O_2$max) exercise, respectively (Melanson et al., 2002). Even when controlling for differences in diet, training status, and menstrual cycle phase, males have been shown to utilise 25% more muscle glycogen, and exhibit higher respiratory exchange ratios than females during prolonged exercise at ~65%$\dot{V}O_2$max (Tarnopolsky et al., 1990). Other studies have reported similar observations throughout a range of submaximal exercise intensities up to ~85%$\dot{V}O_2$max (Chenevière et al., 2011; Venables et al., 2005), and this pattern persists across other modes of exercise, such as resistance exercise (Sarafian et al., 2016). Results from sprint cycling protocols corroborate these findings, with the exercise-induced reduction in muscle glycogen being smaller by ~40% in type I muscle fibres in females compared to males in response to single or repeated 30 s sprints, whereas the reduction in type II muscle fibres was similar across sexes (Esbjörnsson-Liljedahl et al., 2002; Esbjörnsson-Liljedahl et al., 1999). Between-sex differences in substrate utilisation have been proposed as being largely oestrogen-mediated (Tarnopolsky, 2008), and therefore, may be influenced by menstrual cycle phase and hormonal contraceptive use. Broad differences between sexes such as greater intramuscular triglyceride storage, and cell membrane and mitochondrial fatty acid transport proteins, as well as β-oxidation enzymes (e.g., medium chain fatty acyl-CoA dehydrogenase) and pyruvate dehydrogenase kinase 4, are likely regulated by oestrogen acting through oestrogen receptor α-mediated mechanisms, which results in greater skeletal muscle fatty acid oxidation capacity (Campbell & Febbraio, 2001; Cano et al., 2022; Oosthuyse & Bosch, 2012). Additionally, elevated concentrations of oestrogen, as observed during the late follicular and mid-luteal phases of menstrual cycle, can reduce reliance on CHO utilisation due to reduced hepatic glycogen utilisation and insulin-mediated storage, therefore shifting metabolism towards greater contribution from fat through free fatty acid mobilisation and oxidation (Cano et al., 2022; Friedlander et al., 1999). Hormonal contraception typically reduces endogenous concentrations of 17-beta oestradiol and progesterone (compared with the mid-luteal phase of the menstrual cycle), which may have implications for substrate utilisation (Elliott-Sale & Hicks, 2018). Yet, the independent effect of progesterone on substrate utilisation during exercise is still uncertain. However, one study involving eumenorrheic women compared the effects during 60 min of submaximal exercise (~60%$\dot{V}O_2$max) pharmacologically-administered oestrogen alone versus a combination of oestrogen and progesterone (D'Eon et al., 2002). The results showed that total CHO oxidation was higher when both hormones were administered (oestrogen: 1.05±0.02 g/min vs. oestrogen plus progesterone: 1.27±0.04 g/min), and the greater muscle glycogen utilisation also observed was associated with lower free-fatty acid concentrations. These data suggest that progesterone may attenuate the lipolytic effects of oestrogen (D'Eon et al., 2002).

Notably, in many studies reporting between-sex differences in substrate utilisation, participants were exercised in a fasted state. In studies where participants were fed directly before (0 to 3 h), or during, the exercise protocol, no clear differences in the relative contribution of CHO or fat to energy provision were observed (Harger-Domitrovich et al., 2007; M'Kaouar et al., 2004; Pettersson et al., 2019). Therefore, because players are likely to play competitive soccer matches in a fed state, the reported differences in substrate utilisation, i.e. greater reliance on fat in females during fasted exercise, is unlikely to be a relevant consideration to fuelling strategies for match-play. In fact, in studies where CHO was administered during exercise, the percent energy contribution from exogenous CHO sources has been shown to be up to 25% higher for females compared to males (Riddell et al., 2003; Tremblay et al., 2010). As such, ensuring adequate CHO intake directly before and during soccer matches, consistent with current guidelines (Collins et al., 2021) (**Table 1**) may be of particular importance for female players.

When expressed in absolute terms (g/min), similar exogenous CHO oxidation rates have been observed in males and females when CHO is ingested during exercise (Wallis et al., 2006). From a practical perspective, this observation implies that the current CHO-based fuelling guidelines for during matches (i.e. ~30 to 60 g CHO after the warm-up, and at half-time) (Collins et al., 2021) may be adequate for both male and female soccer players. However, a recent study observed that larger athletes (BM >70 kg; 45±13 g/h) had a higher rates of exogenous glucose oxidation (mean difference: 13 g/h) than smaller athletes (BM <70 kg; 33±8 g/h) during 120 min of cycling at 95% of lactate threshold (Ijaz et al., 2024). This difference may have been partly due to differences in absolute exercise intensity as much as differences in BM itself, and is somewhat in contradiction to a previous analysis that showed no relationship between BM and rates of exogenous CHO oxidation (Jeukendrup, 2010). Despite those caveats, a BM-dependent effect on exogenous CHO oxidation would translate as female players requiring smaller amounts of CHO during exercise given their typically smaller body sizes, but this contention would need be explored specifically in the context of soccer training and match-play.

Notably, the CHO intake practices of elite female soccer players during match-play have been reported as considerably less than current recommendations. For example, only 3 out of 19 Spanish first division players consumed CHO during a competitive match, with an average group intake of just 0.9 g/h (Tarnowski et al., 2022). In comparison, average group intakes of 32 g/h and 17 g/h have been observed during competitive matches in male English Premier League players (Anderson et al., 2017; Kasper et al., 2024). Possible explanations for the low intakes in female players may be the fear, or actual experience, of gastrointestinal problems during matches. Largely due to their smaller stomachs (Cox, 1945), females are likely to exhibit greater postprandial fullness and frequency and/or severity of gastrointestinal symptoms following consumption of a given food volume (Tiller et al., 2021). However, female athletes accustomed to feeding during exercise are able to tolerate greater intakes of food and fluid during training and competition (Martinez et al., 2023). Accordingly, implementing targeted nutrition 'training' of the gut (Jeukendrup, 2017), by ensuring repeated exposure to CHO intake in training and matches, may help improve tolerance and optimise fuelling practices during matches in this population.

Differences in substrate storage between males and females

On the day prior to a match ("MD-1"), a strategy known as "CHO loading" that targets CHO intakes as high as 6 to 8 g/kg body mass (BM) is recommended to elevate glycogen stores in skeletal muscle and liver (Collins et al., 2021) (**Table 1**). These guidelines are suggested to be applicable for both male and female soccer players, but no study has yet investigated the impact of CHO loading on muscle glycogen concentrations or performance in female soccer players (McManus et al., 2025), although CHO loading is generally recognised to benefit exercise performance more broadly (Larrosa et al., 2025). A difference between sexes in the ability to store muscle glycogen when following a CHO loading protocol was previously reported (Tarnopolsky et al., 1995). After 3 days of CHO loading, which increased CHO intake from 55% to 75% of habitual energy intake (equating to an average CHO intake of 6.6 g/kg in females and 8.4 g/kg in males during the protocol), a ~150 mmol/kg dw difference in glycogen concentration in the vastus lateralis muscle of the thigh was observed between male (565 mmol/kg dw) and female (409 mmol/kg dw) athletes (Tarnopolsky et al., 1995). However, the same authors later demonstrated that when the males and females consumed a similar absolute quantity of CHO (males: 600 g CHO equating to 8 g/kg BM vs. females: 540 g CHO equating to 9 g/kg BM), no differences in muscle glycogen concentration were evident (Tarnopolsky et al., 2001). Furthermore, when using a higher intake of CHO, muscle glycogen concentrations were found to increase to a similar extent in both males (~68% increase) and females (~79% increase) following a 3 day CHO loading protocol (12 g/kg lean body mass, equating to ~10.5 g/kg BM for males and ~ 9.9 g/kg BM for females) (James et al., 2001). Overall, these findings suggest that the capacity to store glycogen is not different between the sexes once the intake of CHO is sufficient, with 8-10 g/kg BM of CHO often being referred to as the “CHO loading threshold” (Bergström et al., 1967; Burke & Hawley, 1999; Wismann & Willoughby, 2006). These interpretations should, however, be considered in light of there being a limited number of studies, generally small sample sizes, and the general lack of standardisation or monitoring of menstrual cycle phase in these studies.

Nonetheless, if such a threshold exists, it remains uncertain whether CHO intakes on the lower end of the MD-1 CHO guidelines for soccer (i.e. 6 to 8 g/kg BM) would be sufficient to achieve the ergogenic benefits of CHO loading in female players. In studies examining the effects of CHO loading in male soccer players, all protocols have included a daily intake of at least 7 g/kg BM of CHO (Abt et al., 1998; Balsom et al., 1999; Bangsbo et al., 1992; Hiromatsu et al., 2023; Kazemi et al., 2023; Souglis et al., 2013). Furthermore, the majority of CHO loading studies to date have used 2 to 4 day protocols under controlled conditions with limited exercise, a pattern that does not reflect the typical training and fuelling protocols in professional soccer players (Anderson et al., 2022; McHaffie et al., 2024; Morehen et al., 2022). For example, match-day preparations in soccer often involve only one day of high CHO intake

(Anderson et al., 2022). Observations in female soccer players show markedly lower pre-match resting muscle glycogen concentrations (~400 mmol/kg dw) (Krustrup et al., 2022) compared to values previously reported in extended CHO loading studies in well-trained females, even when CHO intake has only been moderate e.g. ~600 mmol/kg dw after 4.7 g/kg/d for 4 days (Walker et al., 2000). Whether the short duration increase in CHO intake undertaken by soccer players in practice would result in meaningfully different pre-match muscle glycogen concentrations between male and female players is unknown.

In male soccer players, CHO loading strategies have been shown to delay fatigue and enhance the capacity for intermittent high-intensity exercise in some studies (Balsom et al., 1999; Bangsbo et al., 1992; Kazemi et al., 2023; Souglis et al., 2013), though not all have reported such benefits (Abt et al., 1998; Hiromatsu et al., 2023). A key limitation of several CHO loading studies in male soccer is the absence of a standardised pre-exercise meal. Given the established impact of pre-exercise CHO intake on performance (Burke & Hawley, 1999), absence of a standardised meal or major differences in CHO content of the pre-exercise meal introduces a confounder and a question whether any effects observed from these studies can be attributed to the CHO loading protocol alone. Furthermore, none of the existing CHO loading studies in soccer reported including CHO ingestion during exercise (Abt et al., 1998; Balsom et al., 1999; Bangsbo et al., 1992; Hiromatsu et al., 2023; Kazemi et al., 2023; Souglis et al., 2013), despite UEFA guidelines recommending 30 to 60 g of CHO immediately before and during soccer performance (Collins et al., 2021). Notably, a previous study in cycling (100 km time trial) reported negligible performance differences following a CHO loading protocol (9 vs. 6 g/kg/d for 3 days; muscle glycogen, 572±107 vs. 485±128 mmol/kg dw) when participants consumed CHO during exercise (1 g/kg BM), suggesting that CHO intake during exercise may mitigate the effects of commencing exercise with lower pre-exercise glycogen concentrations, or alternatively that the difference in muscle glycogen achieved with 9 g/kg/d compared 6 g/kg/d was not enough to impact performance (Burke et al., 2000). Taken together, these observations highlight the need for better-controlled CHO loading studies in soccer across both sexes.

One issue when determining the CHO requirements of female soccer players around competition is the lack of studies investigating the contribution of muscle glycogen to energy provision during soccer match-play or simulated soccer protocols in this population. Furthermore, the glycogen cost of soccer match-play has not yet been directly compared between male and female players. However, results from separate investigations demonstrate similar reductions in muscle glycogen concentrations between pre and post-match in males and females (Δ194 mmol/kg dw vs. Δ173 mmol/kg dw, respectively), with largely similar resting glycogen concentrations observed (449±22 vs 409±62 mmol/kg dw) (Krustrup et al., 2022; Krustrup et al., 2006). Although previous investigations have reported lower resting muscle glycogen concentrations in females compared to males (~300 vs. ~500 mmol/kg dw) (Impey et al., 2020), albeit not in soccer players specifically, this difference likely reflects the lower habitual CHO intakes in female athletes (~3 to 4 vs. ~4 to 6 g/kg BM/d) (de Sousa et al., 2022; García-Rovés et al., 2014). In studies that control for daily CHO intake and physical activity levels, similar resting muscle glycogen concentrations have been observed between sexes (James et al., 2001; Tarnopolsky et al., 2001). Furthermore, the lack of between-sex differences in GLUT-4, hexokinase and glycogen synthase expression and activities also suggests limited differences in muscle glucose delivery and storage between the sexes (Lundsgaard & Kiens, 2014).

Lastly, an important question specific to female players is whether the capacity to store muscle glycogen is altered during specific phases of the menstrual cycle. Previous studies suggest that females can supercompensate muscle glycogen consequent to CHO loading in either phase of the menstrual cycle, at least when CHO is high (>8 g/kg BM) (McLay et al., 2007; Nicklas et al., 1989), but resting glycogen concentration has been observed to be lower during the follicular phase compared to the luteal phase (443 vs. 391 mmol/kg dw, respectively) (Hackney, 1990). Practically, this observation may mean that female players should aim to ingest the upper limits of recommendations (~8 g/kg BM) prior to matches, and pay particular attention to doing so during the follicular phase of their menstrual cycle (Moore et al., 2022), but this suggestion is tentative based on limited investigations to date as well the lack of evidence for or against the performance benefits of CHO loading in female soccer players. Similar recommendations may also be relevant for oral contraceptive pill users, particularly during the 'inactive' pill phase, which is typically 4 to 7 days of pills without active hormones that are taken following a 21 day course of 'active' pills, when circulating oestrogen and progesterone concentrations resemble those of the early follicular phase (Cano et al., 2022).

Differences in proportion of body mass as fat-free mass between males and females

While evidence suggests minimal between-sex differences in the muscle's capacity to store a given amount of glycogen per unit of muscle mass (James et al., 2001; Lundsgaard & Kiens, 2014), one consideration could be whether variations in FFM as a proportion of total BM could influence CHO requirements between male and female soccer players. CHO recommendations for exercise are often expressed as grams per kilogram of BM (Collins et al., 2021; Thomas et al., 2016). However, because FFM incorporates the lean tissue mass in the form of skeletal muscle as the primary user of CHO during exercise, and in the form of skeletal muscle and liver as the main storage sites for CHO, requirements for CHO intake could be more closely related to FFM than to overall BM. By analogy, there is increasing discussion of protein requirements being expressed on a per kg FFM basis (Dekker et al., 2022; Geisler et al., 2016).

Dual-energy X-ray absorptiometry (DXA) is a widely-accepted and reliable non-invasive method of estimating FM and FFM (Tewari et al., 2018). Average values for %FM and FFM in elite male soccer players by DXA typically range from ~8% to ~13% and ~55 kg to ~71 kg, respectively (Milanese et al., 2015; Milsom et al., 2015; Sebastiá-Rico et al., 2023). Data on elite female soccer players are more scarce, but average values for %FM and FFM of between ~14.5% to ~22% and ~42.5 kg to ~49.5 kg, respectively, have been observed using a combination of skinfold and bioelectrical impedance analysis methods (Petri et al., 2024; Randell et al., 2021), while values of ~18% to ~23% and ~47 kg to ~49 kg were reported using DXA (Morehen et al., 2023; Moss et al., 2020; Savolainen et al., 2023). Theoretically, the lower proportion of BM as FFM in female players, on average, suggests reduced CHO requirements in this population when expressed relative to BM.

Table 2 illustrates this concept by considering the requirements applied to players with BM of 60 and 80 kg, and %FM of 10%, 17.5% and 25%. The analysis suggests that compared to a male of 10%FM, a female of 25%FM who consumes the same target of 7 g/kg BM of CHO will consume 20% more CHO per kg FFM (7.8 vs. 9.3 g/kg FFM). If instead the target CHO intake is based on g/kg FFM, that same female would only require 5.8 g/kg BM in order to match the 7.8 g/kg FFM provided by the 7 g/kg BM.

These calculations illustrate that CHO requirements expressed per kg of BM may overestimate the needs of female players relative to their glycogen storage capacity, and support the rationale for using FFM-based requirements to more accurately individualise nutrition strategies across sexes. Yet, in practical terms, the change in the example above would mean consuming 348 g rather than 420 g of CHO as an absolute amount, with the 72 g difference being the equivalent of a large CHO-based snack, or small CHO-based meal. Therefore, whether these differences are physiologically-meaningful, or practically-actionable would warrant further exploration, such that when combined with the inherent inaccuracies in estimating %FM, there may be limited added value in routinely applying FFM-based recommendations over the more practical BM-based recommendations when working with female players.

Table 2. Sample calculations illustrating differences in carbohydrate requirements relative to body mass and fat-free mass as a function of different levels of body fat

Body mass (kg)	Fat mass (%)	FFM (kg)	CHO (g/kg BM)	CHO (g)	CHO (g/kg FFM)
60	10.0	54.0	7.0	420	7.8
60	17.5	49.5	7.0	420	8.5
60	25.0	45.0	7.0	420	9.3
60	25.0	45.0	5.8	348	7.7
80	10.0	72.0	7.0	560	7.8
80	17.5	66.0	7.0	560	8.5
80	25.0	60.0	7.0	560	9.3
80	25.0	60.0	5.8	464	7.7

Note: The value of 7 g/kg BM is based on the recommendation that for the day prior to a match (MD-1), CHO intake should be at least 6 to 8 g/kg BM to elevate muscle and liver glycogen stores (Collins et al., 2021). Abbreviations: BM, body mass; FFM, fat-free mass; CHO, carbohydrate.

Differences between males and females in physical performance and running demands of soccer match-play

The question of whether CHO requirements differ between male and female soccer players is intrinsically linked to potential differences in the physical demands of match-play between men’s and women’s soccer. Efforts to quantify the metabolic demands of soccer match-play, particularly those related to CHO metabolism, are constrained by the limitations of existing measurement technologies. The most commonly reported metrics used to assess physical demands include total distance covered and distance covered within fixed speed or velocity zones derived from wearable tracking technologies such as global positioning systems (GPS) technology, or from semi-automated optical tracking technologies used at the elite level (Harkness-Armstrong et al., 2022; Miguel et al., 2021).

Across international and domestic competitions, elite women's soccer players cover on average ~9,500 to 9,900 m per match, or ~103 to 110 m/min (Harkness-Armstrong et al., 2022; Pérez Armendáriz et al., 2024). Compared to men's soccer, female players cover less total distance during elite competition at both international and domestic levels (Bradley et al., 2014; Ju et al., 2025). While these differences are statistically significant, the effect sizes (ES) are small-to-moderate (ES=0.5-0.8), equating to an average difference of ~400 m over 90 minutes, or ~4.4 m/min (~0.26 km/h). Interpreted solely as average speed, total distance suggests a relatively low overall movement intensity. However, the physiological demands of match-play are not captured by average speed alone, but rather by how this distance is accumulated, through repeated high-speed efforts, accelerations, decelerations, and directional changes, which collectively underpin the metabolic demands and CHO requirements of match-play (Paul et al., 2015).

One common issue in the comparison of the high-speed activity between men's and women's soccer is the application of identical absolute speed zones to both male and female players, despite well-documented sex differences in maximal running speed (Djaoui et al., 2017; Hallam & Amorim, 2022; Haugen et al., 2012; Ju et al., 2025; McClelland & Weyand, 2022). As male players generally achieve higher average maximal running speeds by ~8 to 10% (Bradley & Vescovi, 2015; Ju et al., 2025), males are more likely to accumulate greater distances in higher speed categories. This method skews the interpretation of high-speed efforts in favour of male players, irrespective of relative exercise intensity (Bradley & Vescovi, 2015; Gualtieri et al., 2023). To address this, some studies have implemented downward-adjusted thresholds for female players (Harkness-Armstrong et al., 2022). These adjusted thresholds are often arbitrarily selected, and there is currently no standardised or validated framework for this approach (Gualtieri et al., 2023). As a result, speed zone definitions vary widely across studies, limiting both cross-study and between-sex comparisons (Gualtieri et al., 2023; Harkness-Armstrong et al., 2022). When adjusted thresholds are applied, the proportion of total distance categorised as high speed is largely similar between men's and women's soccer (Bradley et al., 2014; Ju et al., 2025). The integration of acceleration and deceleration metrics into match-play analyses remains limited by inconsistent definitions, poor inter-unit reliability, and variability introduced by differing proprietary data processing methods (Harkness-Armstrong et al., 2022; Malone et al., 2017; Sweeting et al., 2017; Thornton et al., 2019; Whitehead et al., 2018). These issues must be addressed before firmer conclusions as to the differences in the physical demands of men's and women's soccer can be made.

Assessing the metabolic demands of soccer match-play and the implications for carbohydrate requirements

While GPS-derived metrics are useful for general quantification of running demands, they provide only a partial representation of the physical work performed (Bourdon et al., 2017). Specifically, these metrics fail to capture the complex, multidirectional movement patterns characteristic of soccer, including jumping, landing, rapid changes of direction and high-intensity actions embedded within gameplay scenarios such as physical duels or pressing (Malone et al., 2017; Reilly, 1997). Although most modern player tracking technologies are technically capable of differentiating movement types, particularly GPS that incorporate inertial measurement units (Beato et al., 2018; Whitehead et al., 2018), most analyses do not distinguish between biomechanically distinct movement types, such as forward, lateral, and backward running, each of which likely imposes different energetic demands (Flynn et al., 1994). As a result, analyses based solely on linear, speed-based thresholds may underestimate the true metabolic demands of match-play.

Accurately quantifying substrate utilisation, particularly CHO oxidation, during soccer remains a methodological challenge. Indirect calorimetry, a gold standard for assessing energy expenditure and substrate utilisation in steady-state exercise, is unsuitable in soccer due to the intermittent and stochastic nature of match-play. The dynamic variation in movement intensity, combined with the frequent transitions between low- and high-speed activity, precludes steady-state conditions required for accurate calorimetric measurement (Jeukendrup & Wallis, 2005). Indirect calorimetry also lacks the temporal sensitivity to capture the brief, high-intensity bursts of activity that often exceed the velocity of $\dot{V}O_2max$, which are an inherent part of elite-level match-play. These methodological constraints limit the capacity to measure real-time energy expenditure and, by extension, the specific contribution of CHO oxidation during key phases of performance.

Alternative methods commonly used to assess the demands of match-play, such as heart rate monitoring and blood lactate sampling, also lack the sensitivity to differentiate between movement types or accurately quantify energetic cost. Heart rate remains elevated for much of match-play in both men’s and women’s soccer, typically averaging 80 to 90% of maximal heart rate across both halves, even during periods of relatively low physical work (Bangsbo et al., 2006; Krustrup et al., 2006). As a result, heart rate offers limited insight into the variability of physical work or the intensity of discrete movement patterns. Similarly, blood lactate concentration is a poor proxy for the metabolic demands of match-play, as measurements are highly dependent on the intensity and type of activity performed immediately prior to sampling (Bangsbo et al., 2006). This temporal limitation likely contributes to the wide range of values reported at the end of playing halves (i.e. 1 to 12 mmol/L), making it an unreliable indicator of the overall metabolic demands of match-play (Bangsbo et al., 2006; Krustrup et al., 2010).

While muscle biopsy studies have demonstrated substantial reductions in glycogen content across both type I and II fibres by the end of match-play in men’s and women’s soccer (Krustrup et al., 2022; Krustrup et al., 2006), it remains unclear to what extent these reductions impair soccer performance (Bangsbo et al., 2006). In women’s soccer, declines in sprint performance were significantly correlated to reductions in muscle glycogen (Krustrup et al., 2022), whereas no association was found in men’s soccer despite similar reductions in muscle glycogen content (Krustrup et al., 2006). Match-tracking data often show that high-speed running and sprint outputs are greater during the first half of match-play (Di Salvo et al., 2009), with the most demanding periods also occurring in the early stages of a game (Bradley & Noakes, 2013; Harkness-Armstrong et al., 2022). This temporal decline in physical output is often interpreted as fatigue, though this view likely oversimplifies the underlying causes, which may also reflect other factors such as tactical pacing, substitution patterns, or in-game nutrition practices (Carling, 2013). Without real-time markers of substrate utilisation, it is difficult to isolate the role of CHO availability from other performance determinants.

Further complicating this picture is the lack of in vivo data on hepatic glucose output and the limited understanding of glycogen compartmentalisation within the skeletal muscle. Glycogen pools localised near mitochondria or sarcoplasmic reticulum may serve functional roles beyond general energy provision, particularly in maintaining excitation-contraction coupling during prolonged or repeated efforts (Vigh-Larsen et al., 2021). However, current methodologies do not allow for the in-field assessment of these mechanisms, leaving a critical gap in our understanding of the local metabolic environment within working muscle during match-play. Collectively, the above limitations underscore the need for more nuanced and context-sensitive tools to assess metabolic demands in soccer. Without methodologies capable of capturing the true energetic cost of movement, particularly with respect to CHO utilisation, our understanding of fuelling strategies, fatigue mechanisms, and recovery processes remains incomplete.

Concluding remarks

There have been increasing calls to develop, or at least systematically evaluate, the need for female-specific nutrition guidelines for soccer (Holtzman & Ackerman, 2021; Martinho et al., 2024; Moore et al., 2022). While such efforts have the potential to support player health and performance, it must be acknowledged that, in practice, elite players have been consistently reported to not adhere to the existing evidence-based recommendations (Morehen et al., 2022; Renard et al., 2021). For example, average CHO intakes around training and match play that have been reported in female soccer players (3-4 g/kg BM) (Gravina et al., 2022; Martinho et al., 2024; Morehen et al., 2022) are well below current recommendations (6-8 g/kg BM) (Collins et al., 2021). Of relevance are recent data from elite youth female players in England that indicate that higher CHO consumption is often perceived as contributing to increases in fat mass and negative body image (McHaffie et al., 2022), which highlights a need to better understand the psychosocial and environmental determinants of dietary behaviours in female soccer players more broadly. From a practitioner perspective, challenges in eliciting behavioural change among players, uncertainty regarding the scientific basis of existing CHO guidelines, limited time and support, and a lack of autonomy over the nutrition service provision, were all identified as barriers to implementing nutrition recommendations in elite men’s soccer (Costello et al., 2025). Similar research involving practitioners in the women’s game is necessary, particularly given that effective implementation of CHO guidelines requires coordinated efforts between players, coaching staff, and nutritionists.

Although some between-sex differences in physiology, metabolism, and running demands among soccer players exist, the currently-available evidence, although somewhat limited, does not suggest that CHO-based requirements differ between male and female players in obvious ways that would translate into practically-meaningful differences in fuelling strategies being employed. However, variations in FFM as a proportion of total BM and its potential implications for CHO storage and intake may warrant further investigation as an influencing factor. Nonetheless, on the basis of the current evidence, we consider it premature to suggest that female players will require sex-specific guidelines in relation to CHO-based fuelling strategies for performance in soccer. Because of the inter-individual variability that exists regardless of biological sex, an individualised approach to fuelling remains the cornerstone to sports nutrition practice. However, given the dearth of sports nutrition research in female athletes, intervention studies in female players investigating CHO-based fuelling studies before and during soccer match-play or simulated soccer protocols are warranted.

REFERENCES

Abt, G., Zhou, S., & Weatherby, R. (1998). The effect of a high-carbohydrate diet on the skill performance of midfield soccer players after intermittent treadmill exercise. *J Sci Med Sport*, *1*(4), 203-212. https://doi.org/10.1016/s1440-2440(09)60003-7

Anderson, L., Drust, B., Close, G. L., & Morton, J. P. (2022). Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization. *Journal of Sports Sciences*, *40*(9), 1000-1019. https://doi.org/10.1080/02640414.2022.2044135

Anderson, L., Orme, P., Naughton, R. J., Close, G. L., Milsom, J., Rydings, D., O'Boyle, A., Di Michele, R., Louis, J., Hambly, C., Speakman, J. R., Morgans, R., Drust, B., & Morton, J. P. (2017). Energy Intake and Expenditure of Professional Soccer Players of the English Premier League: Evidence of Carbohydrate Periodization. *Int J Sport Nutr Exerc Metab*, *27*(3), 228-238. https://doi.org/10.1123/ijsnem.2016-0259

Balsom, P. D., Wood, K., Olsson, P., & Ekblom, B. (1999). Carbohydrate intake and multiple sprint sports: with special reference to football (soccer). *International Journal of Sports Medicine*, *20*(1), 48-52. https://doi.org/10.1055/s-2007-971091

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, *24*(7), 665-674. https://doi.org/10.1080/02640410500482529

Bangsbo, J., Nørregaard, L., & Thorsøe, F. (1992). The effect of carbohydrate diet on intermittent exercise performance. *International Journal of Sports Medicine*, *13*(2), 152-157. https://doi.org/10.1055/s-2007-1021247

Beato, M., Coratella, G., Stiff, A., & Iacono, A. D. (2018). The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. *Frontiers in Physiology*, *9*, 1288. https://doi.org/10.3389/fphys.2018.01288

Bergström, J., Hermansen, L., Hultman, E., & Saltin, B. (1967). Diet, muscle glycogen and physical performance. *Acta Physiol Scand*, *71*(2), 140-150. https://doi.org/10.1111/j.1748-1716.1967.tb03720.x

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance*, *12*(s2), S2-161-S162-170. https://doi.org/10.1123/ijspp.2017-0208

Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., & Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Human Movement Science*, *33*, 159-171. https://doi.org/10.1016/j.humov.2013.07.024

Bradley, P. S., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? *Journal of Sports Sciences*, *31*(15), 1627-1638. https://doi.org/10.1080/02640414.2013.796062

Bradley, P. S., & Vescovi, J. D. (2015). Velocity Thresholds for Women's Soccer Matches: Sex Specificity Dictates High-Speed-Running and Sprinting Thresholds—Female Athletes in Motion (FAiM). *International Journal of Sports Physiology and Performance*, *10*(1), 112-116. https://doi.org/10.1123/ijspp.2014-0212

Burke, L. M., & Hawley, J. A. (1999). Carbohydrate and exercise. *Curr Opin Clin Nutr Metab Care*, *2*(6), 515-520. https://doi.org/10.1097/00075197-199911000-00015

Burke, L. M., Hawley, J. A., Schabort, E. J., St Clair Gibson, A., Mujika, I., & Noakes, T. D. (2000). Carbohydrate loading failed to improve 100-km cycling performance in a placebo-controlled trial. *J Appl Physiol (1985)*, *88*(4), 1284-1290. https://doi.org/10.1152/jappl.2000.88.4.1284

Campbell, S. E., & Febbraio, M. A. (2001). Effect of ovarian hormones on mitochondrial enzyme activity in the fat oxidation pathway of skeletal muscle. *American journal of physiology. Endocrinology and metabolism*, *281*(4), E803–E808. https://doi.org/10.1152/ajpendo.2001.281.4.E803

Cano, A., Ventura, L., Martinez, G., Cugusi, L., Caria, M., Deriu, F., & Manca, A. (2022). Analysis of sex-based differences in energy substrate utilization during moderate-intensity aerobic exercise. *European Journal of Applied Physiology*, *122*(1), 29-70. https://doi.org/10.1007/s00421-021-04802-5

Carling, C. (2013). Interpreting Physical Performance in Professional Soccer Match-Play: Should We be More Pragmatic in Our Approach? *Sports Medicine*, *43*(8), 655-663. https://doi.org/10.1007/s40279-013-0055-8

Carter, S. L., Rennie, C., & Tarnopolsky, M. A. (2001). Substrate utilization during endurance exercise in men and women after endurance training. *Am J Physiol Endocrinol Metab*, *280*(6), E898-907. https://doi.org/10.1152/ajpendo.2001.280.6.E898

Chenevière, X., Borrani, F., Sangsue, D., Gojanovic, B., & Malatesta, D. (2011). Gender differences in whole-body fat oxidation kinetics during exercise. *Appl Physiol Nutr Metab*, *36*(1), 88-95. https://doi.org/10.1139/h10-086

Collins, J., Maughan, R. J., Gleeson, M., Bilsborough, J., Jeukendrup, A., Morton, J. P., Phillips, S. M., Armstrong, L., Burke, L. M., Close, G. L., Duffield, R., Larson-Meyer, E., Louis, J., Medina, D., Meyer, F., Rollo, I., Sundgot-Borgen, J., Wall, B. T., Boullosa, B.,…McCall, A. (2021). UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. *Br J Sports Med*, *55*(8), 416. https://doi.org/10.1136/bjsports-2019-101961

Costello, N., Roe, S., Backhouse, S. H., & Bentley, M. R. N. (2025). Barriers and enablers to implementing the UEFA Consensus Statement on Nutrition: insights from sport nutrition practitioners in the English Premier League. *Sci Med Footb*, 1-14. https://doi.org/10.1080/24733938.2025.2517055

Cox, A. J. (1945). Variations in Size of the Human Stomach. *Cal West Med*, *63*(6), 267-268.

D'Eon, T. M., Sharoff, C., Chipkin, S. R., Grow, D., Ruby, B. C., & Braun, B. (2002). Regulation of exercise carbohydrate metabolism by estrogen and progesterone in women. *Am J Physiol Endocrinol Metab*, *283*(5), E1046-1055. https://doi.org/10.1152/ajpendo.00271.2002

Datson, N., Drust, B., Weston, M., Jarman, I. H., Lisboa, P. J., & Gregson, W. (2017). Match Physical Performance of Elite Female Soccer Players During International Competition. *Journal of Strength and Conditioning Research*, *31*(9), 2379-2387. https://doi.org/10.1519/jsc.0000000000001575 de Sousa, M. V., Lundsgaard, A. M., Christensen, P. M., Christensen, L., Randers, M. B., Mohr, M., Nybo, L., Kiens, B., & Fritzen, A. M. (2022). Nutritional optimization for female elite football players-topical review. *Scand J Med Sci Sports*, *32 Suppl 1*, 81-104. https://doi.org/10.1111/sms.14102

Dekker, I. M., van Rijssen, N. M., Verreijen, A., Weijs, P. J., de Boer, W. B. E., Terpstra, D., & Kruizenga, H. M. (2022). Calculation of protein requirements; a comparison of calculations based on bodyweight and fat free mass. *Clin Nutr ESPEN*, *48*, 378-385. https://doi.org/10.1016/j.clnesp.2022.01.014

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of High Intensity Activity in Premier League Soccer. *International Journal of Sports Medicine*, *30*(3), 205-212. https://doi.org/10.1055/s-0028-1105950

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal Sprinting Speed of Elite Soccer Players During Training and Matches. *Journal of Strength and Conditioning Research*, *31*(6), 1509-1517. https://doi.org/10.1519/jsc.0000000000001642

Elliott-Sale, K., & Hicks, K. (2018). Hormonal-based contraception and the exercising female. In: Forsyth J, Roberts CM, editors. The exercising female: science and its application. Routledge: Taylor and Francis.

Esbjörnsson-Liljedahl, M., Bodin, K., & Jansson, E. (2002). Smaller muscle ATP reduction in women than in men by repeated bouts of sprint exercise. *J Appl Physiol (1985)*, *93*(3), 1075-1083. https://doi.org/10.1152/japplphysiol.00732.1999

Esbjörnsson-Liljedahl, M., Sundberg, C. J., Norman, B., & Jansson, E. (1999). Metabolic response in type I and type II muscle fibers during a 30-s cycle sprint in men and women. *J Appl Physiol (1985)*, *87*(4), 1326-1332. https://doi.org/10.1152/jappl.1999.87.4.1326

Flynn, T. W., Connery, S. M., Smutok, M. A., Zeballos, R. J., & Weisman, I. M. (1994). Comparison of cardiopulmonary responses to forward and backward walking and running. *Medicine and Science in Sports and Exercise*, *26*(1), 89-94.

Friedlander, A. L., Casazza, G. A., Horning, M. A., Usaj, A., & Brooks, G. A. (1999). Endurance training increases fatty acid turnover, but not fat oxidation, in young men. *J Appl Physiol (1985)*, *86*(6), 2097-2105. https://doi.org/10.1152/jappl.1999.86.6.2097

García-Rovés, P. M., García-Zapico, P., Patterson, A. M., & Iglesias-Gutiérrez, E. (2014). Nutrient intake and food habits of soccer players: analyzing the correlates of eating practice. *Nutrients*, *6*(7), 2697-2717. https://doi.org/10.3390/nu6072697

Geisler, C., Prado, C. M., & Müller, M. J. (2016). Inadequacy of Body Weight-Based Recommendations for Individual Protein Intake-Lessons from Body Composition Analysis. *Nutrients*, *9*(1). https://doi.org/10.3390/nu9010023

Gravina, L., Ruiz, F., Diaz, E., Lekue, J. A., Badiola, A., Irazusta, J., & Gil, S. M. (2012). Influence of nutrient intake on antioxidant capacity, muscle damage and white blood cell count in female soccer players. *Journal of the International Society of Sports Nutrition*, *9*(1). https://doi.org/10.1186/1550-2783-9-32

Gualtieri, A., Rampinini, E., Dello Iacono, A., & Beato, M. (2023). High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review. *Frontiers in Sports and Active Living*, *5*(1116293). https://doi.org/10.3389/fspor.2023.1116293

Hackney, A. C. (1990). Effects of the menstrual cycle on resting muscle glycogen content. *Horm Metab Res*, *22*(12), 647. https://doi.org/10.1055/s-2007-1004994

Haizlip, K. M., Harrison, B. C., & Leinwand, L. A. (2015). Sex-based differences in skeletal muscle kinetics and fiber-type composition. *Physiology (Bethesda)*, *30*(1), 30-39. https://doi.org/10.1152/physiol.00024.2014

Hallam, L. C., & Amorim, F. T. (2022). Expanding the Gap: An Updated Look Into Sex Differences in Running Performance. *Frontiers in Physiology*, *12*(804149). https://doi.org/10.3389/fphys.2021.804149

Harger-Domitrovich, S. G., McClaughry, A. E., Gaskill, S. E., & Ruby, B. C. (2007). Exogenous carbohydrate spares muscle glycogen in men and women during 10 h of exercise. *Medicine and Science in Sports and Exercise*, *39*(12), 2171-2179. https://doi.org/10.1249/mss.0b013e318157a650

Hargreaves, M., & Spriet, L. L. (2020). Skeletal muscle energy metabolism during exercise. *Nat Metab*, *2*(9), 817-828. https://doi.org/10.1038/s42255-020-0251-4

Harkness-Armstrong, A., Till, K., Datson, N., Myhill, N., & Emmonds, S. (2022). A systematic review of match-play characteristics in women's soccer. *PLOS ONE*, *17*(6), e0268334. https://doi.org/10.1371/journal.pone.0268334

Haugen, T. A., Tønnessen, E., & Seiler, S. (2012). Speed and Countermovement-Jump Characteristics of Elite Female Soccer Players, 1995–2010. *International Journal of Sports Physiology and Performance*, *7*(4), 340-349. https://doi.org/10.1123/ijspp.7.4.340

Hiromatsu, C., Kasahara, N., Lin, C. A., Wang, F., & Goto, K. (2023). Continuous Monitoring of Interstitial Fluid Glucose Responses to Endurance Exercise with Different Levels of Carbohydrate Intake. *Nutrients*, *15*(22). https://doi.org/10.3390/nu15224746

Holtzman, B., & Ackerman, K. E. (2021). Recommendations and Nutritional Considerations for Female Athletes: Health and Performance. *Sports Medicine*, *51*(Suppl 1), 43-57. https://doi.org/10.1007/s40279-021-01508-8

Ijaz, A., Collins, A. J., Moreno-Cabañas, A., Bradshaw, L., Hutchins, K., Betts, J. A., Podlogar, T., Wallis, G. A., & Gonzalez, J. T. (2024). Exogenous Glucose Oxidation During

Exercise Is Positively Related to Body Size. *International journal of sport nutrition and exercise metabolism*, *35*(1), 12–23. https://doi.org/10.1123/ijsnem.2024-0097

Impey, S. G., Jevons, E., Mees, G., Cocks, M., Strauss, J., Chester, N., Laurie, I., Target, D., Hodgson, A., Shepherd, S. O., & Morton, J. P. (2020). Glycogen Utilization during Running: Intensity, Sex, and Muscle-Specific Responses. *Medicine and Science in Sports and Exercise*, *52*(9), 1966-1975. https://doi.org/10.1249/mss.0000000000002332

James, A. P., Lorraine, M., Cullen, D., Goodman, C., Dawson, B., Palmer, T. N., & Fournier, P. A. (2001). Muscle glycogen supercompensation: absence of a gender-related difference. *European Journal of Applied Physiology*, *85*(6), 533-538. https://doi.org/10.1007/s004210100499

Jeukendrup A. E. (2010). Carbohydrate and exercise performance: the role of multiple transportable carbohydrates. *Current opinion in clinical nutrition and metabolic care*, *13*(4), 452–457. https://doi.org/10.1097/MCO.0b013e328339de9f

Jeukendrup A. E. (2017). Training the Gut for Athletes. *Sports medicine (Auckland, N.Z.)*, *47*(Suppl 1), 101–110. https://doi.org/10.1007/s40279-017-0690-6

Jeukendrup, A. E., & Wallis, G. A. (2005). Measurement of Substrate Oxidation During Exercise by Means of Gas Exchange Measurements. *International Journal of Sports Medicine*, *26*, S28-S37. https://doi.org/10.1055/s-2004-830512

Ju, W., Kim, B., Lee, J., & Choi, S.-H. (2025). Gender disparities in match performance at FIFA World Cups: more direct play, less off-ball movement, and less pressing in women’s matches. *International Journal of Performance Analysis in Sport*, 1-16. https://doi.org/10.1080/24748668.2025.2523700

Kasper, A. M., Allan, J., Hodges, D., Catterson, P., Mason, L., Fitzpatrick, J., Grantham, N., Morton, J. P., Hearris, M. A., & Close, G. L. (2024). Nutritional habits of professional team sport athletes: An insight into the carbohydrate, fluid, and caffeine habits of English Premier League football players during match play. *Journal of Sports Sciences*, *42*(17), 1589-1596. https://doi.org/10.1080/02640414.2024.2402137

Kazemi, A., Racil, G., Ahmadi Hekmatikar, A. H., Behnam Moghadam, M., Karami, P., & Henselmans, M. (2023). Improved physical performance of elite soccer players based on GPS results after 4 days of carbohydrate loading followed by 3 days of low carbohydrate diet. *J Int Soc Sports Nutr*, *20*(1), 2258837. https://doi.org/10.1080/15502783.2023.2258837

Krustrup, P., Mohr, M., Nybo, L., Draganidis, D., Randers, M. B., Ermidis, G., Ørntoft, C., Røddik, L., Batsilas, D., Poulios, A., Ørtenblad, N., Loules, G., Deli, C. K., Batrakoulis, A., Nielsen, J. L., Jamurtas, A. Z., & Fatouros, I. G. (2022). Muscle metabolism and impaired sprint performance in an elite women's football game. *Scand J Med Sci Sports*, *32 Suppl 1*, 27-38. https://doi.org/10.1111/sms.13970

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. *Medicine and Science in Sports and Exercise*, *38*(6), 1165-1174. https://doi.org/10.1249/01.mss.0000222845.89262.cd

Krustrup, P., Zebis, M., Jensen, J. M., & Mohr, M. (2010). Game-Induced Fatigue Patterns in Elite Female Soccer. *Journal of Strength and Conditioning Research*, *24*(2), 437-441. https://doi.org/10.1519/JSC.0b013e3181c09b79

Larrosa, M., Gil-Izquierdo, A., González-Rodríguez, L. G., Alférez, M. J. M., San Juan, A. F., Sánchez-Gómez, Á., Calvo-Ayuso, N., Ramos-Álvarez, J. J., Fernández-Lázaro, D., Lopez-Grueso, R., López-León, I., Moreno-Lara, J., Domínguez-Balmaseda, D., Illescas-Quiroga, R., Cuenca, E., López, T., Montoya, J. J., Rodrigues-de-Souza, D. P., Carrillo-Alvarez, E.,…Domínguez, R. (2025). Nutritional Strategies for Optimizing

Health, Sports Performance, and Recovery for Female Athletes and Other Physically Active Women: A Systematic Review. *Nutr Rev*, *83*(3), e1068-e1089. https://doi.org/10.1093/nutrit/nuae082

Lundsgaard, A. M., & Kiens, B. (2014). Gender differences in skeletal muscle substrate metabolism - molecular mechanisms and insulin sensitivity. *Front Endocrinol (Lausanne)*, *5*, 195. https://doi.org/10.3389/fendo.2014.00195

M'Kaouar, H., Péronnet, F., Massicotte, D., & Lavoie, C. (2004). Gender difference in the metabolic response to prolonged exercise with [13C]glucose ingestion. *European Journal of Applied Physiology*, *92*(4-5), 462-469. https://doi.org/10.1007/s00421-004-1122-5

Malone, J. J., Lovell, R., Varley, M. C., & Coutts, A. J. (2017). Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), S218-s226. https://doi.org/10.1123/ijspp.2016-0236

Martinez, I. G., Mika, A. S., Biesiekierski, J. R., & Costa, R. J. S. (2023). The Effect of Gut-Training and Feeding-Challenge on Markers of Gastrointestinal Status in Response to Endurance Exercise: A Systematic Literature Review. *Sports Medicine*, *53*(6), 1175-1200. https://doi.org/10.1007/s40279-023-01841-0

Martinho, D. V., Field, A., Naughton, R., Ribeiro, A. S., Rebelo, A., Gouveia É, R., & Sarmento, H. (2024). Nutritional perspectives in female soccer: a scoping review. *J Int Soc Sports Nutr*, *21*(1), 2366427. https://doi.org/10.1080/15502783.2024.2366427

McClelland, E. L., & Weyand, P. G. (2022). Sex differences in human running performance: smaller gaps at shorter distances? *Journal of Applied Physiology*, *133*(4), 876-885. https://doi.org/10.1152/japplphysiol.00359.2022

McHaffie, S. J., Langan-Evans, C., Strauss, J. A., Areta, J. L., Rosimus, C., Evans, M., Waghorn, R., Grant, J., Cuthbert, M., Hambly, C., Speakman, J. R., & Morton, J. P. (2024). Energy expenditure, intake and availability in female soccer players via doubly labelled water: Are we misrepresenting low energy availability? *Exp Physiol*. https://doi.org/10.1113/ep091589

McLay, R. T., Thomson, C. D., Williams, S. M., & Rehrer, N. J. (2007). Carbohydrate loading and female endurance athletes: effect of menstrual-cycle phase. *Int J Sport Nutr Exerc Metab*, *17*(2), 189-205. https://doi.org/10.1123/ijsnem.17.2.189

McManus, L., Faria, V. S., Scriney, M., & Egan, B. (2025). Less than 4% of participants in studies of carbohydrate-based fuelling strategies for soccer performance have been female: results from an audit of her representation. *Sci Med Footb*, 1-12. https://doi.org/10.1080/24733938.2025.2501809

Melanson, E. L., Sharp, T. A., Seagle, H. M., Horton, T. J., Donahoo, W. T., Grunwald, G. K., Hamilton, J. T., & Hill, J. O. (2002). Effect of exercise intensity on 24-h energy expenditure and nutrient oxidation. *J Appl Physiol (1985)*, *92*(3), 1045-1052. https://doi.org/10.1152/japplphysiol.00706.2001

Miguel, M., Oliveira, R., Loureiro, N., García-Rubio, J., & Ibáñez, S. J. (2021). Load Measures in Training/Match Monitoring in Soccer: A Systematic Review. *International Journal of Environmental Research and Public Health*, *18*(5), 2721. https://doi.org/10.3390/ijerph18052721

Milanese, C., Cavedon, V., Corradini, G., De Vita, F., & Zancanaro, C. (2015). Seasonal DXA-measured body composition changes in professional male soccer players. *Journal of Sports Sciences*, *33*(12), 1219-1228. https://doi.org/10.1080/02640414.2015.1022573

Milsom, J., Naughton, R., O'Boyle, A., Iqbal, Z., Morgans, R., Drust, B., & Morton, J. P. (2015). Body composition assessment of English Premier League soccer players: a comparative DXA analysis of first team, U21 and U18 squads. *Journal of Sports Sciences*, *33*(17), 1799-1806. https://doi.org/10.1080/02640414.2015.1012101

Montero, D., Madsen, K., Meinild-Lundby, A. K., Edin, F., & Lundby, C. (2018). Sexual dimorphism of substrate utilization: Differences in skeletal muscle mitochondrial volume density and function. *Exp Physiol*, *103*(6), 851-859. https://doi.org/10.1113/ep087007

Moore, D. R., Sygo, J., & Morton, J. P. (2022). Fuelling the female athlete: Carbohydrate and protein recommendations. *Eur J Sport Sci*, *22*(5), 684-696. https://doi.org/10.1080/17461391.2021.1922508

Morehen, J. C., Rosimus, C., Cavanagh, B. P., Hambly, C., Speakman, J. R., Elliott-Sale, K. J., Hannon, M. P., & Morton, J. P. (2022). Energy Expenditure of Female International Standard Soccer Players: A Doubly Labeled Water Investigation. *Medicine and Science in Sports and Exercise*, *54*(5), 769-779. https://doi.org/10.1249/mss.0000000000002850

Moss, S. L., Randell, R. K., Burgess, D., Ridley, S., ÓCairealláin, C., Allison, R., & Rollo, I. (2021). Assessment of energy availability and associated risk factors in professional female soccer players. *European journal of sport science*, *21*(6), 861–870. https://doi.org/10.1080/17461391.2020.1788647

Nicklas, B. J., Hackney, A. C., & Sharp, R. L. (1989). The menstrual cycle and exercise: performance, muscle glycogen, and substrate responses. *International Journal of Sports Medicine*, *10*(4), 264-269. https://doi.org/10.1055/s-2007-1024913

Oosthuyse, T., & Bosch, A. N. (2012). Oestrogen's regulation of fat metabolism during exercise and gender specific effects. *Current opinion in pharmacology*, *12*(3), 363–371. https://doi.org/10.1016/j.coph.2012.02.008

Paul, D. J., Bradley, P. S., & Nassis, G. P. (2015). Factors Affecting Match Running Performance of Elite Soccer Players: Shedding Some Light on the Complexity. *International Journal of Sports Physiology and Performance*, *10*(4), 516-519. https://doi.org/10.1123/ijspp.2015-0029

Pérez Armendáriz, M. L., Spyrou, K., & E. Alcaraz, P. (2024). Match demands of female team sports: a scoping review. *Biology of Sport*, *41*(1), 175-199. https://doi.org/10.5114/biolsport.2024.129476

Petri, C., Pengue, L., Bartolini, A., Pistolesi, D., & Arrones, L. S. (2024). Body Composition Changes in Male and Female Elite Soccer Players: Effects of a Nutritional Program Led by a Sport Nutritionist. *Nutrients*, *16*(3). https://doi.org/10.3390/nu16030334

Pettersson, S., Edin, F., Bakkman, L., & McGawley, K. (2019). Effects of supplementing with an 18% carbohydrate-hydrogel drink versus a placebo during whole-body exercise in -5 °C with elite cross-country ski athletes: a crossover study. *J Int Soc Sports Nutr*, *16*(1), 46. https://doi.org/10.1186/s12970-019-0317-4

Randell, R. K., Clifford, T., Drust, B., Moss, S. L., Unnithan, V. B., De Ste Croix, M. B. A., Datson, N., Martin, D., Mayho, H., Carter, J. M., & Rollo, I. (2021). Physiological Characteristics of Female Soccer Players and Health and Performance Considerations: A Narrative Review. *Sports Medicine*, *51*(7), 1377-1399. https://doi.org/10.1007/s40279-021-01458-1

Reilly, T. (1997). Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences*, *15*(3), 257-263. https://doi.org/10.1080/026404197367263

Renard, M., Kelly, D. T., Chéilleachair, N. N., & Catháin, C. (2021). How Does the Dietary Intake of Female Field-Based Team Sport Athletes Compare to Dietary

Recommendations for Health and Performance? A Systematic Literature Review. *Nutrients*, *13*(4). https://doi.org/10.3390/nu13041235

Riddell, M. C., Partington, S. L., Stupka, N., Armstrong, D., Rennie, C., & Tarnopolsky, M. A. (2003). Substrate utilization during exercise performed with and without glucose ingestion in female and male endurance trained athletes. *Int J Sport Nutr Exerc Metab*, *13*(4), 407-421. https://doi.org/10.1123/ijsnem.13.4.407

Roepstorff, C., Thiele, M., Hillig, T., Pilegaard, H., Richter, E. A., Wojtaszewski, J. F., & Kiens, B. (2006). Higher skeletal muscle alpha2AMPK activation and lower energy charge and fat oxidation in men than in women during submaximal exercise. *J Physiol*, *574*(Pt 1), 125-138. https://doi.org/10.1113/jphysiol.2006.108720

Sarafian, D., Schutz, Y., Montani, J. P., Dulloo, A. G., & Miles-Chan, J. L. (2016). Sex difference in substrate oxidation during low-intensity isometric exercise in young adults. *Appl Physiol Nutr Metab*, *41*(9), 977-984. https://doi.org/10.1139/apnm-2016-0127

Sebastiá-Rico, J., Soriano, J. M., González-Gálvez, N., & Martínez-Sanz, J. M. (2023). Body Composition of Male Professional Soccer Players Using Different Measurement Methods: A Systematic Review and Meta-Analysis. *Nutrients*, *15*(5). https://doi.org/10.3390/nu15051160

Souglis, A. G., Chryssanthopoulos, C. I., Travlos, A. K., Zorzou, A. E., Gissis, I. T., Papadopoulos, C. N., & Sotiropoulos, A. A. (2013). The effect of high vs. low carbohydrate diets on distances covered in soccer. *Journal of Strength and Conditioning Research*, *27*(8), 2235-2247. https://doi.org/10.1519/JSC.0b013e3182792147

Sweeting, A. J., Cormack, S. J., Morgan, S., & Aughey, R. J. (2017). When Is a Sprint a Sprint? A Review of the Analysis of Team-Sport Athlete Activity Profile. *Frontiers in Physiology*, *8*, 432. https://doi.org/10.3389/fphys.2017.00432

Tarnopolsky, L. J., MacDougall, J. D., Atkinson, S. A., Tarnopolsky, M. A., & Sutton, J. R. (1990). Gender differences in substrate for endurance exercise. *J Appl Physiol (1985)*, *68*(1), 302-308. https://doi.org/10.1152/jappl.1990.68.1.302

Tarnopolsky, M. A. (2008). Sex differences in exercise metabolism and the role of 17-beta estradiol. *Medicine and Science in Sports and Exercise*, *40*(4), 648-654. https://doi.org/10.1249/MSS.0b013e31816212ff

Tarnopolsky, M. A., Atkinson, S. A., Phillips, S. M., & MacDougall, J. D. (1995). Carbohydrate loading and metabolism during exercise in men and women. *J Appl Physiol (1985)*, *78*(4), 1360-1368. https://doi.org/10.1152/jappl.1995.78.4.1360

Tarnopolsky, M. A., Zawada, C., Richmond, L. B., Carter, S., Shearer, J., Graham, T., & Phillips, S. M. (2001). Gender differences in carbohydrate loading are related to energy intake. *J Appl Physiol (1985)*, *91*(1), 225-230. https://doi.org/10.1152/jappl.2001.91.1.225

Tarnowski, C. A., Rollo, I., Carter, J. M., Lizarraga-Dallo, M. A., Oliva, M. P., Clifford, T., James, L. J., & Randell, R. K. (2022). Fluid Balance and Carbohydrate Intake of Elite Female Soccer Players during Training and Competition. *Nutrients*, *14*(15). https://doi.org/10.3390/nu14153188

Tewari, N., Awad, S., Macdonald, I. A., & Lobo, D. N. (2018). A comparison of three methods to assess body composition. *Nutrition*, *47*, 1-5. https://doi.org/10.1016/j.nut.2017.09.005

Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and Science in Sports and Exercise*, *48*(3), 543-568. https://doi.org/10.1249/mss.0000000000000852

Thornton, H. R., Nelson, A. R., Delaney, J. A., Serpiello, F. R., & Duthie, G. M. (2019). Interunit Reliability and Effect of Data-Processing Methods of Global Positioning Systems. *International Journal of Sports Physiology and Performance*, *14*(4), 432-438. https://doi.org/10.1123/ijspp.2018-0273

Tiller, N. B., Elliott-Sale, K. J., Knechtle, B., Wilson, P. B., Roberts, J. D., & Millet, G. Y. (2021). Do Sex Differences in Physiology Confer a Female Advantage in Ultra-Endurance Sport? *Sports Medicine*, *51*(5), 895-915. https://doi.org/10.1007/s40279-020-01417-2

Tremblay, J., Peronnet, F., Massicotte, D., & Lavoie, C. (2010). Carbohydrate supplementation and sex differences in fuel selection during exercise. *Medicine and Science in Sports and Exercise*, *42*(7), 1314-1323. https://doi.org/10.1249/MSS.0b013e3181cbba0b

Venables, M. C., Achten, J., & Jeukendrup, A. E. (2005). Determinants of fat oxidation during exercise in healthy men and women: a cross-sectional study. *J Appl Physiol (1985)*, *98*(1), 160-167. https://doi.org/10.1152/japplphysiol.00662.2003

Vigh-Larsen, J. F., Ørtenblad, N., Spriet, L. L., Overgaard, K., & Mohr, M. (2021). Muscle Glycogen Metabolism and High-Intensity Exercise Performance: A Narrative Review. *Sports Medicine*, *51*(9), 1855-1874. https://doi.org/10.1007/s40279-021-01475-0

Walker, J. L., Heigenhauser, G. J., Hultman, E., & Spriet, L. L. (2000). Dietary carbohydrate, muscle glycogen content, and endurance performance in well-trained women. *J Appl Physiol (1985)*, *88*(6), 2151-2158. https://doi.org/10.1152/jappl.2000.88.6.2151

Wallis, G. A., Dawson, R., Achten, J., Webber, J., & Jeukendrup, A. E. (2006). Metabolic response to carbohydrate ingestion during exercise in males and females. *Am J Physiol Endocrinol Metab*, *290*(4), E708-715. https://doi.org/10.1152/ajpendo.00357.2005

Whitehead, S., Till, K., Weaving, D., & Jones, B. (2018). The Use of Microtechnology to Quantify the Peak Match Demands of the Football Codes: A Systematic Review. *Sports Medicine*, *48*(11), 2549-2575. https://doi.org/10.1007/s40279-018-0965-6

Wismann, J., & Willoughby, D. (2006). Gender differences in carbohydrate metabolism and carbohydrate loading. *J Int Soc Sports Nutr*, *3*(1), 28-34. https://doi.org/10.1186/1550-2783-3-1-28