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Menstrual health and influence of the menstrual cycle on performance and recovery in football

by Georgia A Brown

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the degree of

Doctor of Philosophy

under the supervision of Professor Rob Duffield, Professor Hugh H K Fullagar and Fabian Ehrmann

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Certificate of Authorship and Originality of Thesis

I, Georgia Brown, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abbreviations and Symbols

Abbreviation/Symbol/Unit	Word/Phrase
%	Percentage
Δ	Delta difference
±	Plus or minus
<	Less than
>	Greater than
AU	Arbitrary Units
CI	Confidence interval
cm	Centimetres
count·s^2	Count per second squared
CV	Coefficient of variation
ES	Effect size
GPS	Global positioning system
h	Hours
HC	Hormonal contraceptives
HMB	Heavy menstrual bleeding
Hz	Hertz
IQR	Interquartile range
kg	Kilograms
km	Kilometres
km·h^{-1}	Kilometres per hour
LH	Luteinising hormone
m	Metres
m·s^2	Metres per second squared
MD	Match day
MD+1	The day following match day
MD+2	The day two days following match day
min, mm	Minutes
mlU·mL^{-1}	Milli-international units per millilitre
MN	Match night
MN-1	The night prior to a match
MN+1	The night following a match
MSS	Menstrual symptom severity
OR	Odds ratio
PdG	Pregnanediol-3-glucorinide
PRS	Perceived Recovery Status
REDs	Relative Energy Deficiency in Sport
SD	Standard deviation
SE	Sleep efficiency
SOL	Sleep onset latency
THSRD	Total high-speed running distance
TST	Total sleep time
µg·mL^{-1}	Microgram per millilitre
WASO	Wake after sleep onset
y	years

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Abstract

This thesis explored the menstrual health, and the influence of menstrual phase and symptoms on performance, recovery and sleep for professional footballers. Study 1 described the menstrual health and perceived effects of the menstrual cycle for national team and first-team domestic league professional football players in Australia. For Studies 2, 3 and 4, prospective longitudinal data was collected from four domestic first-division teams to determine the influence of menstrual phase and symptoms on match running performance, recovery and sleep, respectively. Players tracked their menstrual cycle for up to four consecutive cycles using urinary hormone tests alongside calendar-based counting to determine menstrual status and menstrual phases (early-follicular, late-follicular, luteal). Players also reported menstrual symptom severities on match day and the following two days. Performance (match running via global positioning systems [GPS]), recovery (perceptual measures) and sleep (via actigraphy) were measured concurrent to menstrual data.

Study 1 examined the menstrual health, symptomatology and perceived effects of the menstrual cycle for football players within Australia. The prevalence of menstrual abnormalities was 0.5% primary amenorrhea, 2% secondary amenorrhea, 19% oligomenorrhea and 11% heavy menstrual bleeding (HMB). Eighteen percent of players used hormonal contraceptives (HCs). Ninety seven percent experienced one or more menstrual symptoms, with an average of 5 symptoms per player. The menstrual cycle was perceived to disrupt training and/or competition by 40% of players, with menstruation identified as the most disruptive phase. Increasing number of menstrual symptoms ($p <$

0.001), HMB ($p < 0.001$), and pelvic pain ($p < 0.001$) increased the likelihood of perceiving the menstrual cycle to disrupt performance.

Study 2 assessed the influence of menstrual phase and symptoms on match running. Separate linear mixed effect models were performed for menstrual phase and menstrual symptoms for each GPS measure. Greater relative total and high-speed running distances were reported during the late-follicular phase compared to early-follicular phase ($p = 0.04$ – 0.012) and luteal phase ($p = 0.007$). Menstrual phase did not significantly affect relative very-high speed running, peak speed, relative acceleration count or relative deceleration count ($p > 0.05$). Accelerations declined with increasing menstrual symptom severity (MSS; $p = 0.021$). Menstrual symptom severity did not affect relative total distance, relative high-speed running distance, relative very-high speed running distance, peak speed or relative deceleration count ($p > 0.05$).

Study 3 explored the relationship between menstrual phase and perceptual responses around matches, as well as menstrual phase and the timeline of perceptual recovery following matches. Linear mixed effect models were performed for each perceptual measure. Day relative to the match (match day [MD], day after match day [MD+1], two days after match day [MD+2]) and total high-speed running distance (THSRD) were included in the analyses to examine the timeline of recovery and to provide a measure of the fatiguing stimulus respectively. A significant interaction effect existed for Day x THSRD on perceived recovery status (PRS; $p < 0.001$), total wellness ($p<0.001$), fatigue ($p = 0.047$), soreness ($p < 0.001$) and stress ($p = 0.044$). During the early-follicular phase, moderate effect sizes (ESs) were reported for worse PRS on MD and MD+2 ($p = 0.07$ - 0.28), and better sleep quality on MD+2 ($p = 0.13$), though no significant differences existed between menstrual phases for any perceptual measure on MD, MD+1 or MD+2. All perceptual measures, except stress, were significantly different between Days ($p < 0.05$), representing a timeline of post-match recovery. Accordingly, perceptual recovery timelines differed based on THSRD and to a lesser extent menstrual phase.

Study 4 assessed the association between menstrual phase and symptoms on sleep prior to matches (MN-1), night of matches (MN) and night following matches (MN+1). Objective sleep was measured using actigraphy, and subjective sleep via a questionnaire. Bedtime was significantly later for MN ($p < 0.001$), waketime was significantly earlier for MN+1 ($p < 0.001$) and total sleep time (TST) was significantly longer for MN-1 ($p < 0.001$). Menstrual phase was not associated with any sleep variable ($p > 0.05$). Increased MSS score was associated with increased (longer) TST ($p = 0.03$) and increased (later) waketime ($p = 0.03$).

In summary, menstrual abnormalities and a high presence of menstrual symptoms were identified in professional players. Additionally, many football players within Australia perceived a negative effect of the menstrual cycle on training and competition. Menstrual phase, and to a lesser extent menstrual symptoms, affected match running, though high individual variability existed. Differences in the recovery time-course of perceptual measures existed between menstrual phases, though without consistently impaired or improved recovery in any phase. Menstrual phase was not associated with perceptual responses or sleep around matches. However, longer sleep durations and later waketimes were associated with higher symptom severities. As such, this thesis highlighted the need to monitor player menstrual health, and provided support for monitoring menstrual phase and symptoms with respect to performance and recovery.

Chapter 1: Introduction

1.1 Overview

Professional women's football (soccer) has seen significant growth in recent years (Culvin, 2021; Williams et al., 2022), with more demanding training and competition schedules and expectations (FIFPRO, 2023). Practitioners aiming to optimise female footballers' health, performance and well-being have ongoing concerns regarding female athlete-specific issues, including the menstrual cycle's impact on player health, performance and recovery (Emmonds et al., 2019). However, female athlete research is lacking (Kirkendall & Krustrup, 2022; Okholm Kryger et al., 2021), which has resulted in limited understanding of female-specific concerns, including the menstrual cycle. Within football, understanding the potential impact of the menstrual cycle on player performance and recovery has become increasingly important due to the growing demands and professionalisation of football. Included within these concerns are the respective effects of menstrual health-associated conditions, menstrual symptoms, and the varying phases of the menstrual cycle on player health, performance and recovery (Ihalainen et al., 2024a; McNulty et al., 2020; Oester et al., 2024; Romero-Parra et al., 2021; Taim et al., 2023; Vannuccini et al., 2020).

The menstrual cycle involves cyclical fluctuations of the female sex hormones, oestrogen and progesterone, regulating reproductive function, and resulting in menstruation when pregnancy does not occur (Thiyagarajan et al., 2021). A normal menstrual cycle begins between ages 11-14 years, lasts 21-35 days, includes 4-7 days of menstruation and 30-60 mL of blood loss (FPHI, 2020). Abnormalities related to the menstrual cycle, for example absence of menstruation (i.e., amenorrhea) and HMB, can affect health, wellbeing and athletic performance (Ihalainen et al., 2024a; Klingenberg, 2022; Mountjoy et al., 2018; Vannuccini et al., 2020). Given the potential health and performance consequences associated with menstrual abnormalities, knowledge of the prevalence of such conditions in football players is crucial to supporting player health and performance.

From a health perspective, concerns are heightened by the higher prevalence of menstrual dysfunctions, like amenorrhea, as well as normalisation of these issues and taboo surrounding menstruation, in athletic populations (De Souza et al., 2009; Gimunová et al., 2022; Verhoef et al., 2021). The reported prevalence of menstrual abnormalities varies widely between studies on athletic populations, including those involving football players. For example, the prevalence of secondary amenorrhea and irregular cycle lengths ranges from 3% to 30% amongst football players (Dasa et al., 2024; Matsumoto et al., 2023; Mkumbuzi et al., 2021; Molnár et al., 2016; Paludo et al., 2023; Parker et al., 2022). This variability may be attributed to differences in competition levels, socioeconomic and cultural contexts, and methodologies or questionnaires used in these studies. Consequently, generalising findings across football populations, including those in Australia, is challenging and highlights the need for further research.

Athlete's often report a perceived negative effect of the menstrual cycle, including menstrual symptoms, on performance and recovery (Oester et al., 2024). Among footballers, 24 to 100% of players report a negative perception of the menstrual cycle on performance (Matsumoto et al., 2023; Mkumbuzi et al., 2021; Paludo et al., 2023; Read et al., 2021). Additionally, 74 to 100% of footballers experience menstrual symptoms (Dupuit et al., 2023; Parker et al., 2022; Read et al., 2021). Whilst menstrual symptoms are common and often manageable, severe symptoms can cause significant physical or mental impairment (Biggs & Demuth, 2011; Taim et al., 2023) and may result in athletes missing training and competition (Dupuit et al., 2023; Ekenros et al., 2023; Parker et al., 2022). However, the acute effects of menstrual symptoms on athletic performance are not well understood. Hence, further research examining the influence of menstrual symptoms on objective measures of performance and recovery is required to inform menstrual symptom management strategies. Furthermore, understanding athletes' perceptions of menstrual effects is necessary to provide tailored support for athletes across their menstrual cycle and for guiding future research.

Variations in physical performance and recovery across the menstrual cycle may also be related to changes in the female sex hormones, oestrogen and progesterone (Elliott-Sale et al., 2020; McNulty et al., 2020). The primary function of oestrogen and progesterone is to control the menstrual cycle; however, these hormones also affect several physiological functions such as the cardiovascular system, neuromuscular control and energy system substrate utilisation (Bernstein & Behringer, 2023; D'Souza et al., 2023; Janse de Jonge, 2003; Oosthuyse et al., 2023). As such, the fluctuations in oestrogen and progesterone across the menstrual cycle are suggested to have ensuing effects on performance and recovery (Bernstein & Behringer, 2023; D'Souza et al., 2023; Janse de Jonge, 2003; Oosthuyse et al., 2023). The hormonal fluctuations create several contrasting hormonal profiles across a cycle, resulting in classification of menstrual sub-phases (Janse de Jonge et al., 2019). A healthy menstrual cycle commences with low oestrogen and progesterone during the early-follicular or menstruation phase, oestrogen rises to a peak through the late-follicular phase, then drops during the early-luteal phase, which is followed by a secondary but smaller rise in oestrogen and peak progesterone in the mid-luteal phase, and lastly a rapid decline in both hormones to end the cycle in the late-luteal or premenstrual phase (Bruinvels et al., 2022; Janse de Jonge et al., 2019). Changes in athletic performance and recovery are therefore frequently examined in relation to phase of the menstrual cycle due to differences in oestrogen and progesterone concentrations and/or ratios (McNulty et al., 2020; Meignie et al., 2021; Romero-Parra et al., 2021).

As context to the performance of football players, the physical work performed by a player during a match is one of several common indicators used by coaches and sports scientists to inform match demands and performance (Teixeira et al., 2021). Football is a high-intensity intermittent team sport consisting of two 45-minute halves, for which female players cover approximately 10km total distance per match (Griffin et al., 2020; Scott et al., 2020; Trewin et al., 2018a). Many high intensity actions are performed during matches including high-speed running, sprinting, accelerating and changes of direction (Griffin et al., 2020; Scott et al., 2020; Trewin et al., 2018a). High intensity actions are often associated with important match situations like goal scoring opportunities, defensive scenarios and attacking plays (Martinez-Hernandez et al., 2023; Rhodes et al., 2021; Schulze et al., 2022). Therefore, managing factors that affect physical performance during matches is a key concern for practitioners, yet research on the influence of the menstrual cycle on match running performance in football is limited.

Two studies have explored the influence of menstrual phase on football physical match performance (Igonin et al., 2022; Julian et al., 2017). Julian et al. (2020) reported that very high-speed running distance per minute (individualised threshold, 16.69 ± 1.09 – 19.94 ± 0.88m·min^{-1}) may be lower in the follicular compared to luteal phase, although there was large match-to-match variation (39.5%). In contrast, Igonin et al. (2022) reported less distance at moderate (7-14km·h^{-1}) and high (14-19km·h^{-1}) velocities during the early-follicular than late-follicular and mid-luteal phases, plus less total distance and sprints during the early-follicular than late-follicular phase. The lack of hormonal testing to classify menstrual phases in these studies increases the risk of comparing heterogenous hormonal profiles, which could have influenced the findings (Elliott-Sale et al., 2021; Janse de Jonge et al., 2019). Additionally, a total of 23 players were examined across the two studies, highlighting the limited research that exists. A systematic review and meta-analysis of 51 studies reported exercise performance (i.e., strength, endurance, power) may be trivially reduced during the early-follicular phase compared to all other phases (McNulty et al., 2020). However, the review lacks specificity to football, and the authors highlighted concerns regarding the low-quality of many studies due to the accuracy of methods to identify and verify menstrual phase. Further research with more robust menstrual phase classification measures is required to improve our understanding of the menstrual cycle's effects on football physical match performance.

The physical work, along with the cognitive demand of football induces match-related fatigue, which is suggested to require ≈72h to recover for female players (Goulart et al., 2022). Incomplete or suboptimal recovery may impede subsequent performance (Julian et al., 2021), and both training and matches are often scheduled within this recovery window in professional football (FIFPRO, 2023). Understanding factors that affect recovery, including the potential influence of the menstrual cycle, is therefore important for practitioners in the women's game (Bernstein & Behringer, 2023; Romero-Parra et al., 2021). A systematic review and meta-analysis reported increases in delayed onset muscle soreness and strength losses during the early-follicular phase when oestrogen levels are low, suggestive of impaired recovery during menstruation (Romero-Parra et al., 2021). However, most included studies examined only one phase, about half of the studies included hormone measurements and high heterogeneity regarding studied outcome variables was present. Few studies have examined the association between menstrual phase and perceptual recovery responses for football players (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024). The studies suggests minimal influence of menstrual phase on daily perceptual responses following matches (Abbott et al., 2024; Scott et al., 2024) and weekly mean perceptual responses (Juillard et al., 2024). However, each of these studies estimated menstrual phase using self-reporting of menstruation only (i.e., a low accuracy method) and the time-course of recovery for perceptual measures was not examined. As such, further high-quality investigations into the influence of menstrual phase on post-match recovery timelines in football are necessary.

Lastly, sleep is an important part of optimal preparation for, and recovery from, matches for players (Fullagar et al., 2015a; Fullagar et al., 2015b). However, sleep is often disrupted around competition due to evening schedules (Costa et al., 2021), nervousness the night prior to competition (Erlacher et al., 2011), and high cognitive arousal (Sim et al., 2023). Practitioners therefore aim to understand and manage risk factors for disturbed sleep to minimise subsequent harmful performance and recovery effects. Thus, understanding the relationship between the menstrual cycle and sleep may provide a more comprehensive understanding of the menstrual cycle's influence on football player performance and recovery. Studies with non-athletic populations suggest equivocal effects of menstrual phase on objective measures of sleep, whilst subjective sleep quality appears worse during the premenstrual and menstruation phases (Alzueta & Baker, 2023). This is likely in part due to the presence of menstrual symptoms, which appear to negatively affect sleep (Alzueta & Baker, 2023). Research within athletic populations is limited and shows varying effect of menstrual phase on sleep (Power et al., 2024), though no studies have been conducted with football players. Additionally, only one study has explored the relationship between menstrual symptoms and sleep among footballers, which found increased number of menstrual symptoms was associated with increased sleep duration, time in bed and wake after sleep onset (WASO) (Halson et al., 2024). Nonetheless, research examining the relationship between the menstrual cycle and sleep for athletes is yet to consider competition schedules, despite the importance of sleep for athletes around competition (Fullagar et al., 2015a; Fullagar et al., 2015b). Knowledge of menstrual-related changes to sleep around matches for football players may provide practical strategies to enhance player preparation and recovery.

1.2 Thesis Aims

This thesis aims to explore the menstrual health of football players, as well as investigate the relationships between menstrual phase and symptoms with football match running, recovery and sleep.

There are four overall aims for the thesis:

1. Understand the menstrual health, dysfunction, symptomatology and perceived effects of the menstrual cycle on performance in elite junior and senior football players (Study 1).
2. Explore the effects of menstrual cycle phase and symptoms on physical match performance in elite football players (Study 2).
3. Explore the influence of menstrual cycle phase on perceptual measures and recovery timeline of perceptual measures in elite football players around matches (Study 3).

4. Explore the relationship of menstrual cycle phase and symptoms with objective and subjective measures of sleep for elite football players around matches (Study 4).

1.3 Significance of Thesis

The menstrual health and influence of the menstrual cycle on performance and recovery for football players is a concern for practitioners, players and coaches, yet research to support player health and performance across their menstrual cycle is lacking in football.

Menstrual abnormalities are associated with known negative health and performance consequences (Ihalainen et al., 2024a; Klingenberg, 2022; Mountjoy et al., 2018; Vannuccini et al., 2020). However, the prevalence of these abnormalities varies widely among athletic populations, including football players (Dasa et al., 2024; Matsumoto et al., 2023; Mkumbuzi et al., 2021; Molnár et al., 2016; Paludo et al., 2023; Parker et al., 2022), making it difficult to generalise findings to other football teams, leagues and federations. Currently, the prevalence of menstrual abnormalities among football players in Australia remains unknown. Knowledge of player menstrual health can guide health screening processes, education and management strategies for female football practitioners. Addressing this gap is important, as optimising player menstrual health can play a valuable role in supporting their overall health, performance, and recovery.

Athletes, including football players, may refrain from training or competition due to menstrual-related symptoms (Ekenros et al., 2022; Pinel et al., 2022). However, research examining athlete menstrual symptomatology and the impact of menstrual symptoms on football performance and recovery is limited. Understanding the influence of menstrual symptoms offers a practical approach to monitoring and managing the menstrual cycle for all football players. This is particularly important given the high prevalence of menstrual disturbances among exercising women (De Souza et al., 2009), which may limit the applicability of phase-based analyses of performance and recovery (Elliott-Sale et al., 2021; McNulty et al., 2020). Therefore, research is required to inform strategies for symptom monitoring, management, and education, to minimise any negative effects of menstrual symptoms on players performance and recovery.

The effect of the menstrual cycle on performance and recovery is often attributed to menstrual phase-related hormonal fluctuations, though findings remain largely equivocal, with limited football-specific research (McNulty et al., 2020; Romero-Parra et al., 2021). Although many studies have explored the relationship between menstrual phases and physical performance, few have examined these effects in real-world sports settings, such as football matches. Furthermore, few football studies have explored post-match perceptual responses across menstrual phases, with limited differences observed (Abbott et al., 2024; Scott et al., 2024). Importantly, the time course of post-match recovery across menstrual phases has not been studied. Understanding whether the menstrual cycle exacerbates fatigue or impairs recovery could identify scenarios or deepen understanding of context to help practitioners adapt recovery strategies based on menstrual phase when necessary. Additionally, no research has examined the influence of menstrual phases on football players' sleep around matches. Understanding whether menstrual phases impact sleep is essential for managing potential menstrual-related effects on performance and recovery. As such, insights from this thesis could inform targeted interventions to enhance football player performance and recovery across the menstrual cycle.

Overall, the findings from this thesis will contribute to the growing body of evidence regarding athlete menstrual health, and influence of menstrual phase and symptoms on performance and recovery. Specifically, the research will aid practitioners working with female football players to guide screening, education, monitoring and management practices with respect to the menstrual cycle, to support football player health, performance and recovery.

1.4 Limitations

Several limitations are present within the thesis:

- The focus of Studies 2, 3 and 4 were menstrual cycle related changes in performance and recovery around matches. Data was collected during a professional season, therefore match schedules were fixed and player selection for matches was beyond the control of the researchers (e.g., coach decisions). Timing of menstrual phases was also not controllable. The number of observations per player in Studies 2, 3 and 4 were therefore limited by match schedules, player selection and individual timing of menstrual phases.
- Some participants were excluded from menstrual phase data analyses (Studies 2, 3 and 4) due to the presence of abnormal menstrual cycles (i.e., cycles which did not meet the specified menstrual phase criteria).
- The research was conducted with different professional football clubs, so it was not possible to control factors such as nutrition, recovery strategies, playing times.
- Accuracy of menstrual phase classification was limited to calendar-based counting and urinary hormone tests. The suggested gold tier method of including serum hormone testing was not possible due to the wide geographical spread of participants.

1.5 Delimitations

- This study is delimited to highly trained and professional female football players, thus is not generalisable to other sports or competition levels.
- Studies 2, 3 and 4 were conducted with non-HC users only, therefore the findings are not generalisable to HC users.
- Football performance was indicated by match running, which does not encompass all aspects of football match performance. Tactical and technical performance were not explored.
- Recovery was indicated by perceptual measures as each of the clubs involved used the same questionnaire. Recovery is multi-factorial and perceptual recovery does not entirely capture athlete recovery.
- Three menstrual phases were classified, though acknowledging the menstrual cycle can be subclassified into up to seven phases.

Chapter 2: Literature Review

2.1 Overview

This narrative review of literature aims to discuss the current understanding of the menstrual health of football players, as well as the influence of menstrual cycle phases and symptoms on physical match performance, recovery and sleep. Given the limited research that exists specifically with football populations on this topic, this literature review will be supplemented by studies with other athletic populations to provide a wider context. The review will commence with a background of the menstrual cycle before delving into the effects of the menstrual cycle on athlete performance, recovery and sleep. More specifically, menstrual cycle physiology will be explained, followed by a discussion of menstrual health, menstrual abnormalities and menstrual symptomology as related to footballers (soccer). Literature surrounding athletes' perceived effects of the menstrual cycle on training and competition will be explored, followed by the effects of the menstrual cycle on objective measures of performance and recovery. The objective effects of the menstrual cycle will be introduced with a broad overview of the menstrual cycle's effect on physical performance, with a subsequent review of the menstrual cycle's influence on football players' physical capacities and physical match performance (i.e., match running). Following exploration of the menstrual cycle's effects on performance, literature surrounding the menstrual cycle, fatigue and recovery for athletes will be examined. Lastly, to provide further insights to potential changes in performance and recovery across the menstrual cycle, literature on the relationship between the menstrual cycle and sleep will be reviewed, with a particular focus on athletic populations.

2.2 Methods

This narrative review of literature provides an overview of menstrual health and the influence of the menstrual cycle on athletic performance and recovery, with a sharpening focus on these topics specific to football populations. An online literature search was conducted to ensure all relevant football population articles were reviewed. Three online databases (PubMed, SPORTDiscus, Scopus) were searched using the following search string (menstrua* OR menses OR follicular OR luteal) AND (football OR soccer). A total of 383 articles were retrieved, and following removal of duplicates (n = 150), the title and abstract for 233 articles were reviewed using the following inclusion criteria: full-text available, English language, experimental or observational design, conducted with football (soccer) players, and addressed football players' perceived impact of the menstrual cycle, or explored the menstrual cycle in relation to physical performance, recovery, or sleep. Accordingly, 36 studies were included. The search results are outlined in the PRISMA flow diagram below (see Figure 2.1).

2.3 The Menstrual Cycle

Prior to reviewing the research on the effects of the menstrual cycle on performance, recovery and sleep, it is pertinent to review current literature describing the physiology, phases and symptoms of the menstrual cycle. Understanding menstrual physiology and the normal menstrual hormonal profile is necessary to better understand the measurement of phases (outlined in next section), menstrual abnormalities and their ensuing effects (discussed in Menstrual health and abnormalities) and the theoretical underpinnings behind phase-based changes in performance and recovery (discussed in Relationship between Menstrual Cycle and Performance and Relationship between Menstrual Cycle and Recovery). This first section of the literature review will provide background context to these aspects of the menstrual cycle.

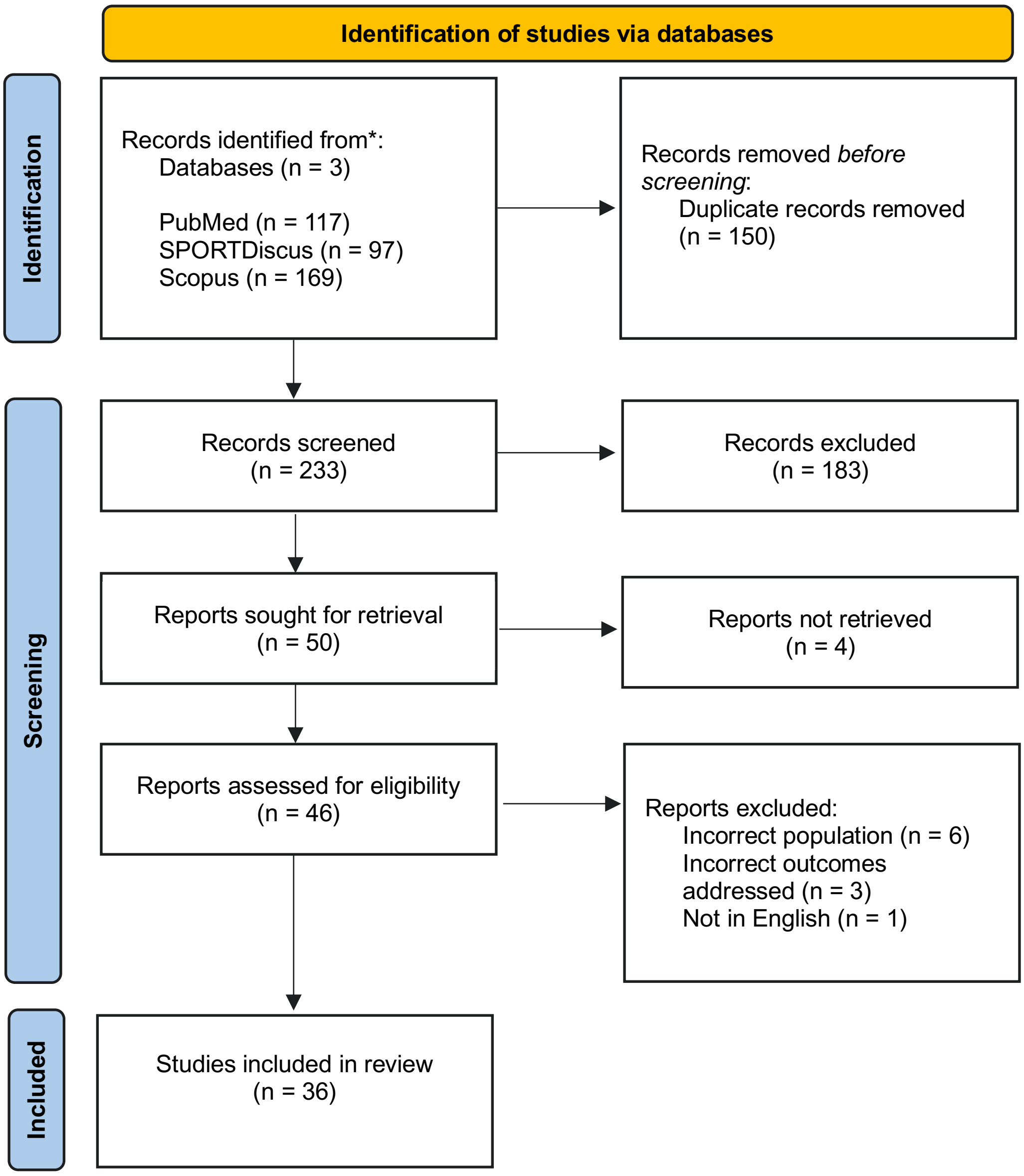

Figure 2.1 Representation of the literature review process by PRISMA flowchart.

2.3.1 Menstrual cycle physiology

The menstrual cycle involves recurring changes in hormones (as depicted by Figure 2.2) approximately every 28 days which prepares a female for ovulation and possible pregnancy (Thiyagarajan et al., 2021). When fertilisation and pregnancy does not occur, the uterine lining is shed and bleeding (menstruation, menses or period) ensues (Thiyagarajan et al., 2021). A normal menstrual cycle is characterised by menarche (a female's first menstrual period) occurrence around 11-14 years old and a healthy female will experience approximately 450 menstrual cycles in her life until she reaches menopause around the age of 49 ± 4 years (Chavez-MacGregor et al., 2008).

The menstrual cycle commences when gonadotropin releasing hormone is secreted from the hypothalamus, which stimulates the anterior pituitary gland to secrete follicular stimulating hormone and luteinising hormone (LH), which signals to the ovaries to produce the female sex hormones, oestrogen and progesterone (Buffet et al., 1998). As an overview, these five hormones interact through positive and negative feedback systems to grow a follicle, release an egg, prepare the uterus for implantation and shed the uterine lining if pregnancy does not occur (Buffet et al., 1998).

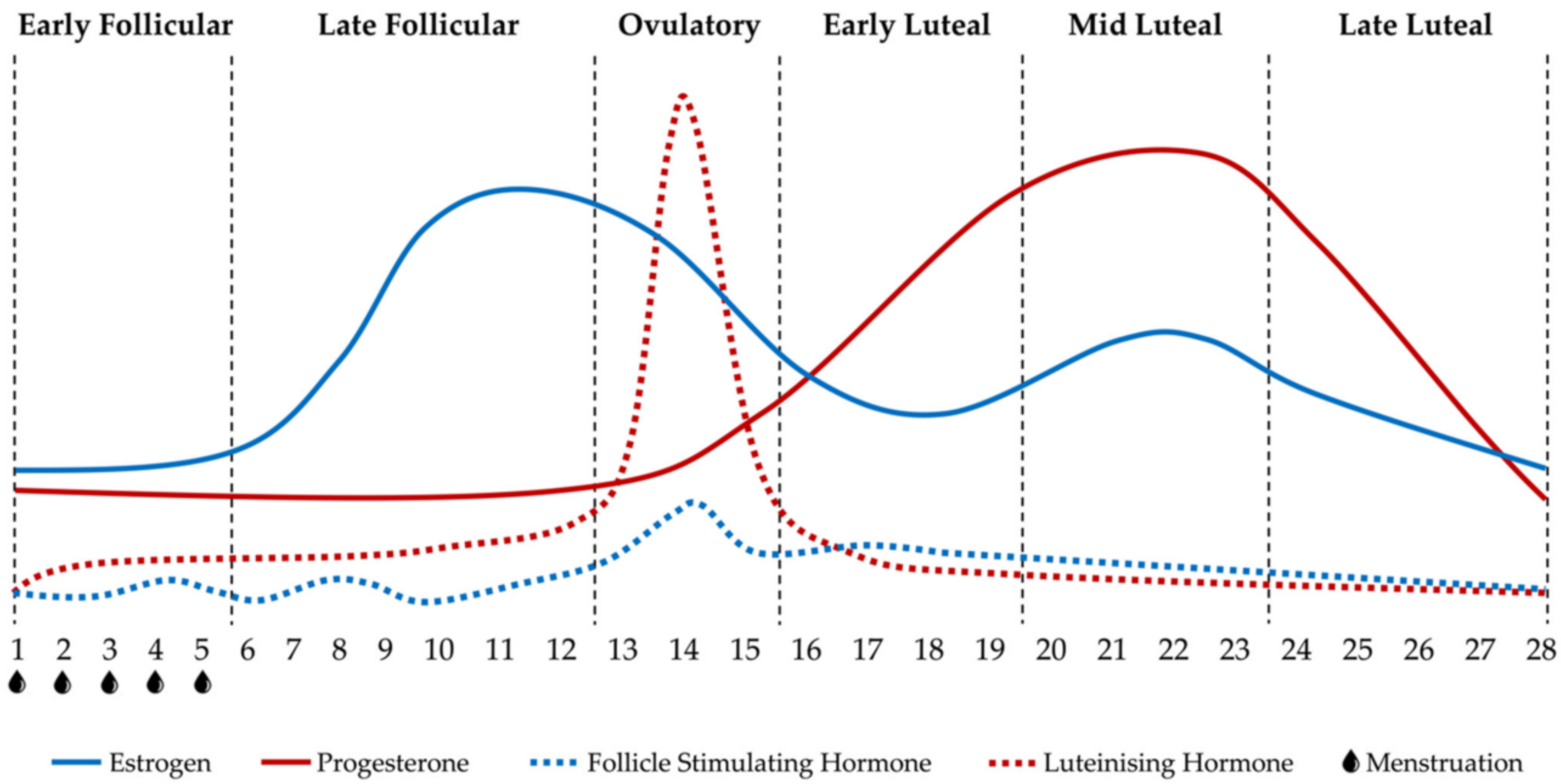

Figure 2.2 Ovarian hormone profile for a normal menstrual cycle over an idealised 28 days

(Carmichael et al., 2021b)

The specific regulation of the menstrual cycle involves increasing follicular stimulating hormone concentrations at the end of one menstrual cycle and in the first week of menstruation (start of the next cycle) leading to the recruitment and maturation of ovarian follicles (Reed & Carr, 2000; Thiyagarajan et al., 2021). This phase is often termed the follicular or proliferative phase (see days 1 to 12 in Figure 2.2). Follicular stimulating hormone acts on granulosa cells of the ovarian follicles which converts androgens to oestrogen under the presence of aromatase enzyme (Silberstein & Merriam, 2000). Increasing concentrations of oestrogen due to follicle growth and increasing number of granulosa cells leads to a decline in follicular stimulating hormone (negative feedback) and an increase of LH concentrations (positive feedback) (Reed & Carr, 2000; Thiyagarajan et al., 2021). Luteinising hormone receptors are primarily located on theca cells of the ovarian follicles which stimulates androgens that are transported to granulosa cells. Increasing concentrations of oestrogen promotes growth (proliferation) of the uterus' endometrial layer (Silberstein & Merriam, 2000). When oestrogen concentrations reach 200 picograms per millilitre of plasma, follicular stimulating hormone increases again and LH concentrations surge (via positive feedback; see days 13 to 14 in Figure 2.2) (Reed & Carr, 2000; Thiyagarajan et al., 2021). The LH surge stimulates luteinisation of granulosa and theca cells as well as the secretion of progesterone.

Following these events, ovulation occurs whereby an oocyte is released from the mature follicle which initiates the luteal phase or secretory phase (see days 16 to 28 in Figure 2.2). A corpus luteum forms from the remaining luteinised ovarian follicle cells (granulosa and theca cells) and stroma (connective tissues), which secretes oestrogen and progesterone (Reed & Carr, 2000). The endometrium continues to undergo changes (e.g., increasing vascular supply and mucous secretions) in the presence of progesterone in preparation for fertilisation of the oocyte (Borman et al., 2004). If fertilised, the oocyte becomes an ovum, is implanted in the endometrium and the corpus luteum continues to secrete oestrogen and progesterone (Thiyagarajan et al., 2021). If no fertilisation occurs the corpus luteum atrophies, oestrogen and progesterone decline, arterioles constrict and recoil leading to tissue ischemia and prostaglandins are released causing contraction of uterine muscle and shedding of the endometrial tissue (Buffet et al., 1998). This physiological process occurs during a normal, healthy menstrual cycle, also referred to as a eumenorrheic cycle.

2.3.2 Menstrual cycle phases

Menstrual cycle phases are defined by their differing oestrogen and progesterone hormonal profiles, as demonstrated in Figure 2.2 (phases labelled on the top y axis). Figure 2.2 represents approximate timings of hormonal fluctuations and phases as based on a typical 28-day cycle. However, the timings of hormonal fluctuations and phases is highly variable within and between individuals (Bull et al., 2019; Fehring et al., 2006; McKay et al., 2023), thus measuring hormones is required to accurately identify menstrual cycle phases. This is an important point, as changes in athletic performance or recovery due to the menstrual cycle are most frequently studied in relation to a phase of the menstrual cycle due to differences in oestrogen and progesterone concentrations and/or ratios (McNulty et al., 2020; Meignie et al., 2021; Romero-Parra et al., 2021). For this thesis, ensuring athletes have a normal menstrual cycle and accurate identification of menstrual phases is required to relate changes in athletic performance or recovery to the different menstrual phases, theoretically representing differences in oestrogen and progesterone. Hence, measuring the menstrual cycle phases provides an understanding of the menstrual health of athletes and improves the accuracy of phase-based comparisons.

Based on the presence of a normal menstrual cycle and hormonal profile (as presented in Figure 2.2), the menstrual cycle is categorised into the phases described above: follicular, ovulatory and luteal. The follicular and luteal phases can be further subclassified as early-, mid- or late-, depending on the volume and ratio of oestrogen and progesterone (as demonstrated in Figure 2.2), which results in the classification of two (follicular vs luteal) to seven phases (Elliott-Sale et al., 2021). The early-follicular phase, also known as menstruation, is characterised by low oestrogen and low progesterone. The mid-follicular phase is characterised by the rising of oestrogen and low progesterone. The late-follicular phase is indicated by peak (high) oestrogen levels and low progesterone. During the early-luteal phase, oestrogen drops whilst progesterone rises but both remain low. The mid-luteal phase is characterised by a secondary but smaller peak in oestrogen and peak progesterone. Finally, the late-luteal phase, also referred to as the pre-menstrual phase, is when oestrogen and progesterone sharply decline. Of note, the menstrual phase terminology used often differs between research articles, and this is reflected throughout the thesis whereby the terminology changes based on the referenced papers.

2.3.2.1 Measuring menstrual cycle phases

To explore and relate performance changes to menstrual phases, and therefore changes in oestrogen and progesterone, accurately determining menstrual phases is necessary. Intra- and inter- individual variability in menstrual cycle length, menstruation length, menstrual phase timing (i.e., timing of ovulation and hormonal fluctuations) exists, as well as variation in the ratio and concentrations of hormones (Bull et al., 2019; Dam et al., 2022), which creates challenges to accurately estimate menstrual phases. The menstrual cycle, its phases and sub-phases can be estimated, measured, and confirmed via a range of methods. Indirect methods to estimate menstrual phases include calendar-based counting, basal body temperature tracking and urinary LH testing (Allen et al., 2016; Schaumberg et al., 2017). Direct measures of menstrual phases include testing oestrogen and progesterone via urine, saliva or blood samples, as well as sonography (Allen et al., 2016; Schaumberg et al., 2017).

At the most basic level, menstrual cycle length can be determined using *calendar-based counting,* which refers to individuals self-reporting onset of menses, which is used to determine menstrual cycle length (i.e., number of days from onset of menses, until the day prior to the next onset of menses) (Schmalenberger et al., 2021). Forward-counting (prospectively) or backward-counting (retrospectively) from onset of menses can then be used to estimate menstrual phases, whereby ovulation timing is estimated (Allen et al., 2016; Schmalenberger et al., 2021). This method is low cost and low burden to participants, however, assumes the occurrence and timing of ovulation and a normal hormonal profile, thus increasing the likelihood of misclassification of phases (Allen et al., 2016). However, calendar-based counting is required to determine menstrual cycle length, which can be used in combination with some of the following methods to improve accuracy of menstrual phase classification.

Ovulation can be predicted using *basal body temperature* and *urinary LH. Basal body temperature* increases slightly (≈0.3°C) in the days following ovulation, thus daily measures can be used to estimate ovulation, and therefore categorising the menstrual cycle into follicular and luteal phases (Allen et al., 2016; Su et al., 2017). The cost and burden of basal body temperature is relatively low, however, basal body temperature is influenced by factors such as illness, room temperature, sleep disruption and alcohol consumption (Su et al., 2017). *Urinary LH* can be measured to prospectively predict ovulation, and therefore identify the timing of the end of the follicular and start of the luteal phases (Allen et al., 2016; Schaumberg et al., 2017). At home test kits can be used to test urine to detect the surge in LH. There is a moderate cost and burden for urinary LH testing, though accurate prediction (but not confirmation) of ovulation is beneficial (Allen et al., 2016; Schaumberg et al., 2017).

Oestrogen and progesterone can be measured via urine, saliva or blood samples to provide the most accurate confirmation of all menstrual phases and sub-phases. Recently at home test kits have been developed to detect an increase in, or measurement of, *urinary oestrogen* (estrone-3-glucoronide) *and progesterone* (pregnanediol-3-glucoronide [PdG]) (Bouchard et al., 2023; Leiva et al., 2019). Similar to the LH test kits, this a moderate cost and burden method, though the cost and burden accumulates when requiring individuals to test the three hormones (luteinising, oestrogen and progesterone). The validity of at home tests must also be considered as whilst most have conducted internal validity testing, published data in peer-reviewed articles is often lacking (Bouchard et al., 2023). *Saliva* measures are non-invasive, which may be collected and stored by individuals at home then sent to a laboratory for analysis, whereas *blood* samples are invasive and require frequent laboratory/clinic visits or expertise from a qualified practitioner (Allen et al., 2016). However, both methods are higher burden and high cost, as well as impractical due to the need for laboratory analysis and retrospective confirmation. *Sonography* can be used to identify all menstrual phases and sub-phases, though is high impractical, and has very high costs and participant burden (Allen et al., 2016). A summary of the menstrual phase determination methods is provided in Table 2.1

Table 2.1 Menstrual phase determination methods

	Method	Burden	Cost	Accuracy
Indirect	Calendar counting	Very low	Very low	Low
	Ovulation testing – basal body temperature	Low	Low	Moderate
	Ovulation testing – luteinising hormone	Moderate	Moderate	Moderate
Direct	Urine – oestrogen and progesterone	Moderate	Moderate	Moderate-high
	Saliva – oestrogen and progesterone	Moderate-high	High	High
	Blood – oestrogen and progesterone	High	High	High
	Sonography	Very high	Very high	Very high

A combination of methods are suggested to accurately determine the phases of the menstrual cycle (Allen et al., 2016; Elliott-Sale et al., 2021; Janse de Jonge et al., 2019; Schaumberg et al., 2017). Menstrual cycle phase classification is most accurately achieved using the three-step method:

1. Calendar-based tracking to report onset of menses and determine menstrual cycle length.
2. Urinary luteinising testing to predict ovulation, and therefore the end of the follicular and start of the luteal phase.
3. Serum (blood) sex hormone analysis to determine oestrogen and progesterone concentrations and ratios, to confirm menstrual phases.

Despite this three-step method being recommended to determine and confirm menstrual phases (Schaumberg et al., 2017), biochemical confirmation of sex hormones requires frequent blood samples, which may be difficult to implement in some practical research settings, such as in real-world sports settings with elite athletes. Regardless, accurate menstrual phase classification is important to research aiming to detect a difference between menstrual phases given the phases are distinguished by their hormonal profile.

Inaccurate measurement and classification of menstrual phases is believed to have contributed to inconsistent research findings in sport and exercise science research assessing the influence of menstrual phases on athletic performance and recovery (Janse de Jonge et al., 2019; McNulty et al., 2020). For example, without measurement of progesterone individuals with luteal phase defect, a condition characterised by low progesterone levels in the luteal phase, cannot be excluded from study participation, thus creating comparisons between individuals with differing hormonal profiles within the luteal phase. The high prevalence of luteal phase deficient and anovulatory cycles in exercising women (50%) highlights the importance of hormonal testing in studies with athletic populations, though it is recognised this study included a range of recreational to competitive athletes (De Souza et al., 2009). Additionally, misclassification of phases may occur if relying on calendar-based counting only and assuming ovulation occurs on day 14 of the cycle or 14 days prior to next menses, as studies have shown variation follicular phase length (16.9 days, 95% CI 10 - 30) (Bull et al., 2019).

In addition to concerns regarding accuracy of menstrual phase classification, comparisons between the follicular and luteal phases (i.e., pre- and post-ovulation) may be deemed inappropriate given the differing volumes and ratios of oestrogen and progesterone within each phase. As an example, this is indicated by the hormonal profile during the first few days of the follicular phase (low oestrogen and progesterone) being starkly different to the latter two thirds (rising oestrogen); thus, including all subphases under the one "follicular phase" may mask possible effects of the menstrual cycle (Janse de Jonge et al., 2019). Future studies comparing performance and recovery between phases should look to include hormonal measures to increase the accuracy of menstrual phase classification, though acknowledging limitations exist in real-word sport settings.

Overall, the menstrual phases are differentiated by their hormonal profiles in a normal, healthy menstrual cycle. Athletic performance or recovery may differ between phases due to the contrasting hormone profiles (McNulty et al., 2020; Romero-Parra et al., 2021). Whilst comparing performance and recovery between specific menstrual phases is important, acknowledging and understanding the day-to-day hormonal fluctuations, and the times between points where hormone levels or ratios are most contrasting is just as important, as athletes need to be supported throughout their entire menstrual cycle

(Bruinvels et al., 2022). Some menstrual phases, as represented by their concentrations and ratios of oestrogen and progesterone, do not exist for individuals with menstrual dysfunction whereby the hormonal profile is altered (discussed further in the next section on Menstrual Health).

In summary, accurate measurement and classification of menstrual phases is therefore necessary for exploring phase-related changes in athletic performance and recovery, in association with changes in oestrogen and progesterone. However, in real-world sport settings frequent and long-term urine and blood tests may not be feasible, thus alternate methods may be required. For example, monitoring menstruation and the days prior to menstruation as windows of concern, though phases which are not necessarily distinguished by their hormonal profile (Allen et al., 2016; Beato et al., 2024). Measuring the menstrual cycle can also provide insights to the menstrual health of, and menstrual abnormalities experienced by, athletes which can guide practitioner care. Currently, little is known about the menstrual health specifically of football players within Australia, though menstrual abnormalities are common in athletes and can negatively affect health and performance.

2.4 Menstrual Health

2.4.1 Menstrual health and abnormalities

Prior to exploring the influence of players' menstrual phases on performance and recovery, a healthy menstrual cycle must be ensured as menstrual abnormalities can pose significant risk to player health, athletic performance, and recovery (Ihalainen et al., 2024a; Klingenberg, 2022; Mountjoy et al., 2018; Vannuccini et al., 2020). Additionally, though of less importance, if players do not have a "healthy" menstrual cycle, hormone-related phase-based changes in performance and recovery may not be able applicable, due to the disrupted hormonal milieu caused by certain menstrual dysfunctions. Indeed, the need to care for and understand player menstrual health must precede exploration of menstrual phases for performance. The concern for athlete menstrual health is compounded by the normalisation of menstrual dysfunction and historically taboo nature of discussing menstruation in athletic environments (Verhoef et al., 2021). As such, key menstrual abnormalities and their impact on athletic performance and recovery will be discussed.

As background, a normal menstrual cycle is characterised by menarche occurrence around 11-14 years old, menstrual cycle length of 21-35 days, 4-7 days of menstruation, 30-60 mL of blood loss (FPHI, 2020) and a normal menstrual cycle hormonal profile as illustrated by the fluctuations of oestrogen and progesterone in Figure 2.2. Presentation of menstrual characteristics outside the aforementioned values are often a sign or symptom of a menstrual abnormality. Menstrual abnormalities, which are problems that affect or are related to the menstrual cycle, are relatively common for a female to experience (Taim et al., 2023). Varying terminology exists within the literature, including menstrual disorders, irregularities, functions, though for the current thesis, menstrual abnormalities will be used as an umbrella term referring to menstrual issues related to abnormal uterine bleeding (frequency and volume) and symptom related disorders. Descriptions of various menstrual abnormalities are outlined in Table 2.2 to provide context to some of the menstrual abnormalities that will be discussed throughout the literature review and thesis. Of concern, menstrual abnormalities can interfere with an individual's health, athletic performance and recovery (Elliott-Sale et al., 2020; Klingenberg, 2022; Mountjoy et al., 2018).

Table 2.2 Definitions of menstrual abnormalities

Category	Menstrual abnormality	Description
Abnormal uterine bleeding (frequency)	Primary amenorrhoea	Absence of menstruation when 15 years or older
	Secondary amenorrhoea	Absence of menstruation for >3 months following menarche in females who previously had regular menstrual cycles, or >6 months in females who previously had irregular menstrual cycles
	Oligomenorrhoea	Menstrual cycle length >35 days and <90 days, also known as long menstrual cycles
	Luteal phase defect	Cycles characterised by insufficient production of progesterone, or luteal phase <10 days
	Anovulation	Menstrual cycle where an egg is not released from the ovaries (ovulation does not occur)
	Polymenorrhoea	Menstrual cycle length <21 days, also known as short menstrual cycles
	Metrorrhagia	Bleeding between cycles, also known as intermenstrual bleeding
Abnormal uterine bleeding (volume)	Hypomenorrhoea	Light menstrual bleeding
	Menorrhagia	Heavy menstrual bleeding
Symptom-related	Dysmenorrhoea	Painful menstruation characterised by menstrual cramps
	Pre-menstrual syndrome	Physical and emotional symptoms in the week prior to and during menstruation
	Premenstrual dysphoric disorder	A severe form of premenstrual syndrome classified as a depressive disorder

(FPHI, 2020; Munro et al., 2022; "Practice Bulletin No. 128: Diagnosis of Abnormal Uterine Bleeding in Reproductive-Aged Women," 2012)

Several of the abnormal uterine bleeding menstrual abnormalities outlined in Table 2.2 are categorised as menstrual dysfunctions, specifically hypothalamic reproductive suppression dysfunction. Amenorrhea (primary and secondary) is the most severe hypothalamic reproductive suppression dysfunction, which is preceded in severity by oligomenorrhea, anovulation and luteal phase defect (Reed et al., 2015). These menstrual dysfunctions are associated with abnormal hormone levels thus preventing hormone-related phase-based comparison, though this issue is secondary to the health and performance consequences associated with menstrual dysfunction. Amongst athlete, menstrual dysfunction is often caused by "problematic low energy availability", where there is prolonged and/or severe imbalance between energy intake and energy expenditure, resulting in Relative Energy Deficiency in Sport (REDs) and inadequate energy for optimal physiological and psychological functioning (Mountjoy et al., 2023). Impaired reproductive function (i.e., menstrual dysfunction) is a key symptom of REDs. The consequences of REDs extend to various negative health, wellbeing, performance, and injury risk consequences (Mountjoy et al., 2023). Some consequences of REDs are directly associated with menstrual dysfunction, for example low oestrogen is directly linked to low bone mineral density which can increase an athlete's risk of fractures (Nazem & Ackerman, 2012). Other REDs impairments like reduced athletic performance and diminished training adaptations (Woods et al., 2017) because of low energy availability may not be linked to menstrual dysfunction (and the associated hormonal changes), but menstrual dysfunction may act as a surrogate marker (Mountjoy et al., 2018).

The altered hormonal profiles displayed by individuals with menstrual dysfunction are depicted in Figure 2.3. Amenorrhea (primary and secondary) occurs as a result of a disruption to the hypothalamic-pituitary-ovarian axis whereby there's a reduction in the gonadotropin releasing hormone pulsatility, followed by a reduction in LH and follicular stimulating hormone pulsatility, and consequently a reduction of oestrogen and progesterone levels (Gordon et al., 2017), as demonstrated by the "Amenorrhea" plot in Figure 2.3. Anovulation (absence of ovulation) occurs when there's an insufficient rise in oestrogen during the follicular phase resulting in LH failing to rise mid-cycle (De Souza et al., 2009), as depicted by the "Anovulatory" plots in Figure 2.3. Luteal phase defect is characterised by insufficient progesterone during the luteal phase or a luteal phase less than 10 days (De Souza et al., 2009), as demonstrated by the "LPD" plot in Figure 2.3. Anovulation and luteal phase defect are often referred to as subtle menstrual disturbances as individuals may present with a "normal" cycle length (21-35days), though they do not display a normal hormonal profile ("Ovulatory" compared to "LPD" and "Anovulatory" plots in Figure 2.3), thus without hormonal testing these menstrual disturbances remain undetected.

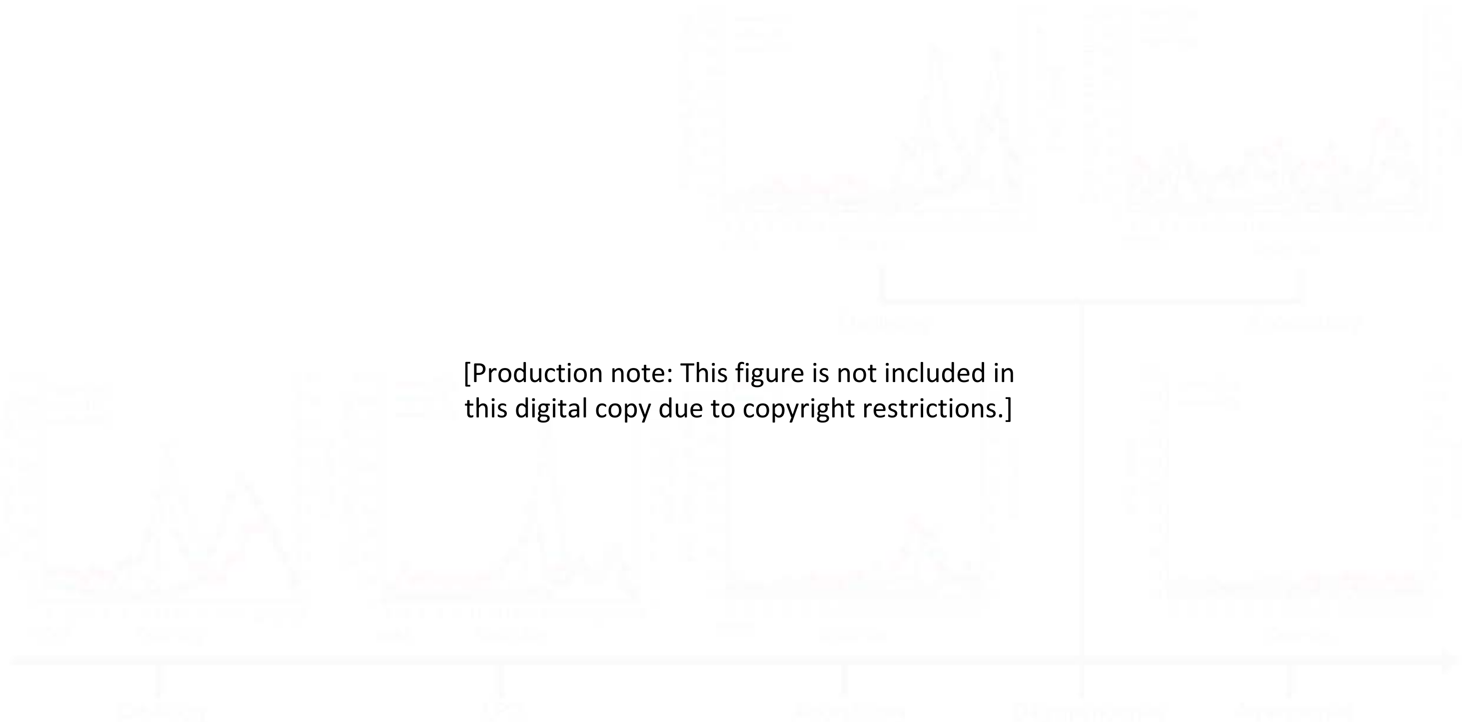

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Figure 2.3 Hormonal profile across a menstrual cycle for various hypothalamic reproductive suppression dysfunctions of increasing severity associated with energy deficiency.
(Allaway et al., 2016)

In addition to the discussed menstrual dysfunctions, menstrual abnormalities such as menorrhagia (herein referred to as HMB) can impact athlete performance. Various definitions of HMB exist, including excessive menstrual blood loss that interferes with quality of life (Sharp et al., 2017), and >80ml of blood loss per cycle (Higham et al., 1990), for which diagnosis is often subjective via a pictorial assessment (Higham et al., 1990). Heavy menstrual bleeding can negatively impact performance due to the increased risk of iron deficiency and anaemia (Bruinvels et al., 2016; Hinton, 2014). Iron is critical to oxidative metabolism due to its role in oxygen transport and the electron transport chain (Hinton, 2014), therefore, HMB increases the risk of impaired submaximal and maximal endurance performance (Bruinvels et al., 2016; Hinton, 2014). Additionally, concerns regarding flooding and bleeding through uniforms (Armour et al., 2020; Findlay et al., 2020) may be heightened by HMB, resulting in anxiety, worry and distraction for athletes. Further, amongst athletes HMB has been associated with increased stress and decrease perceived wellbeing (Vannuccini et al., 2020).

Menstrual abnormalities, such as amenorrhea and HMB, can negatively impact athlete performance, thus it’s essential to consider the menstrual health of athletes when discussing the influence of the menstrual cycle on athlete performance and recovery. Secondly, the altered hormonal profiles related to menstrual dysfunctions means individuals with menstrual dysfunction do not display some, or any, of the typical hormone-differentiated menstrual phases (Figure 2.2), creating challenges for exploring phase-related athletic performance and recovery variations.

2.4.1.1 Prevalence of menstrual abnormalities amongst athletes

Understanding the prevalence of menstrual abnormalities amongst athletes is important to contextualise the magnitude of menstrual health issues, particularly given the known associated health and performance consequences (Elliott-Sale et al., 2020; Klingenberg, 2022; Mountjoy et al., 2018). This information can help guide the development of menstrual health monitoring, education, and management strategies for female athlete practitioners and researchers. Most research exploring the prevalence of menstrual abnormalities amongst athletes have been mixed-sport studies, or small cohort single sport studies making generalisations challenging. A recent review found the prevalence of menstrual irregularities (primary amenorrhoea, secondary amenorrhoea, oligomenorrhoea) ranged from 0 to 61% across professional individual and team sport athletes (Gimunová et al., 2022). In a study of 186 elite Danish athletes from various sports (including 29 football players), 51% (n = 41/80) of non-HC users reported menstrual disturbances (menstrual cycle length <25 days or >35 days), including one athlete with primary amenorrhoea and 13 (16%) with secondary amenorrhoea (Oxfeldt et al., 2020). Similarly, secondary amenorrhea was reported by 10% (n = 40/407) of Swedish and Norwegian athletes from various sports including football players (Ekenros et al., 2022). Further, research with exercising women found subtle menstrual disturbances (LPD or anovulation as determined with hormonal testing) amongst 50% (n = 60/120) of participants compared to 4% of sedentary participants (De Souza et al., 2009), though this was not specific to athletes.

The prevalence of menstrual abnormalities amongst football players has been explored in several studies as outlined in Table 2.3. In a study of professional football players in England, 11% (n = 6/54) and 15% (n = 8/54) were amenorrhoeic and oligomenorrheic respectively (Parker et al., 2022). For African national team players, irregular cycles were reported by 26% (n = 11/42) of players and missing cycles by 10% (n = 4/42) of players (Mkumbuzi et al., 2021). In Japan, 23% (n = 26/115) of trained to professional players reported currently and/or previously having secondary amenorrhea, with no difference between competition levels (Matsumoto et al., 2023). In Norway, 30% (n = 8/60) of players from the top two domestic leagues were classified as amenorrhoeic (Dasa et al., 2024). This compares to an Under 18 Cyprian team which found 1/19 players were amenorrhoeic (Paludo et al., 2023). Additionally, 0%, 3% (n = 2/65) and 14% (n = 9/65) of first and second division Hungarian National Championship players reported a history of primary amenorrhea, secondary amenorrhea and oligomenorrhea respectively (Molnár et al., 2016). Amongst retired elite and professional football players from the United States, 22% (n = 115/560) experienced secondary amenorrhea during their career (Ling et al., 2023). Whilst 19% (n = 28/145) of United States football players (national youth team, NCAA Division 1 University team, professional team) reported some form of menstrual dysfunction (Prather et al., 2016).

Table 2.3 Prevalence of menstrual abnormalities amongst football players

Author/s (Year)	Participants (n)	Age (y)	Competition level	Country	Outcomes (n)	Current or previous menstrual dysfunction
Dasa et al., (2024)	60	23 ± 4	National to international	Norway	30% amenorrhoea (8)	Current
Ling et al., (2023)	560	34 ± 9	Retired trained to international	United States	22% secondary amenorrhea (115)	Previous
Matsumoto et al., (2023)	115	20 ± 4	Trained to professional	Japan	23% secondary amenorrhea (26)	Current or previous
Mkumbuzi et al., (2021)	42	24 ± 4	International	Africa	10% missing cycles (4) 26% irregular cycles (11) 12% heavy periods (5)	Current
Molnár et al., (2016)	65	23 ± 5	National	Hungary	0% primary amenorrhea (0) 3% secondary amenorrhea (2) 14% oligomenorrhea (9)	Current or previous
Paludo et al., (2023)	19	15 ± 1	Developmental	Cyprus	5% amenorrhea (1)	Current
Parker et al., (2022)	54	24 (IQR 20, 27)	National	England	11% amenorrhea (6) 15% oligomenorrhea (8)	Current
Prather et al., (2016)	145	15 - 30	Developmental to Professional	United States	19% menstrual dysfunction (28)	Current

As perhaps expected, the more severe menstrual dysfunctions (amenorrhea) are less prevalent than the less severe (oligomenorrhea), though it's difficult to ascertain the overall prevalence due to the different terminology (i.e., irregular vs oligomenorrhea), timing (i.e., historical vs current menstrual dysfunction) and some studies using an umbrella category of "menstrual dysfunction" rather than reporting on the individual dysfunctions. Broadly, the prevalence of, and historical experience of, menstrual dysfunction appears to range between 10 and 30% amongst football players, though no studies have been conducted for football players within Australia. Further, the prevalence of subtle menstrual disturbances (anovulation and luteal phase defect) amongst footballers is unknown, though 24% (n = 8/33) of football players were excluded from a study assessing menstrual phase effects on match running due to anovulation or insufficient progesterone increases (Julian et al., 2020).

Whilst the prevalence of severe menstrual dysfunction has been relatively well reported, the prevalence of other menstrual abnormalities such as HMB are less well known. Amongst the general population, 27% of women experienced two or more HMB symptoms (Fraser et al., 2015). Heavy menstrual bleeding has been reported by 14% (n = 26/186) of Danish athletes from various sports, including football (Oxfeldt et al., 2020). A higher prevalence of HMB has been reported amongst competitive Australian athletes (Armour et al., 2020), as well as British track and field athletes (Jones et al., 2024) (30% [n = 37/124] and 31% [n = 40/128] respectively). In a study of Australian Olympic and Paralympic athletes, 11% (n = 22/195) and 3% (n = 6/195) of athletes reported "heavy flow" and period duration > 7days respectively (McNamara et al., 2022). Only one study specific to football players has examined the prevalence of HMB, where "heavy periods" were reported by 12% (n = 5/42) of African national team players (Mkumbuzi et al., 2021). Similar to menstrual dysfunction reports, HMB prevalence appears to range from 10 to 30%, with the varied prevalence attributed to in part by the differing definitions and terminology that exists.

A wide range in the prevalence of menstrual abnormalities (10 - 30%) exists between studies, including those specific to football populations. Applying current findings to other athlete groups may therefore be inappropriate and challenging. Additionally, the prevalence of menstrual abnormalities for football players within Australia is currently unknown and could guide player education and support. Furthermore, contextual factors such as differences in access to health care, sociocultural attitudes towards menstruation, and perhaps unique training environments, may influence menstrual health (Ciccia et al., 2023; Hall, 2021; McNamara et al., 2022). Coupling the unknown prevalence of menstrual abnormalities, the contextual differences between countries and the known negative impacts of menstrual abnormalities on health, wellbeing and performance, necessitates further research into the menstrual health (and abnormalities) of football players within Australia. As such, Study 1 of this thesis will aim to understand the prevalence of menstrual health and menstrual dysfunction of football players within Australia.

2.4.2 Menstrual symptomatology

Menstrual symptomatology refers to the range of symptoms experienced by an individual as related to the menstrual cycle (Bruinvels et al., 2021). A health component of menstrual symptomatology exists, whereby menstrual symptoms that cause significant impairment during the premenstrual and menstruation phases indicate menstrual abnormalities such as dysmenorrhea, premenstrual syndrome and premenstrual dysphoric disorder (Taim et al., 2023). However, many females also experience mild to moderate symptoms that are not related to menstrual abnormalities. Menstrual symptoms can be experienced by individuals with normal and abnormal hormonal profiles (i.e., menstrual dysfunctions like luteal phase defect), as well as those using HCs or naturally menstruating (i.e., non-HC users who experience regular menstruation) (McNulty et al., 2023; Taim et al., 2023). Monitoring menstrual symptoms provides an alternative method to monitoring and managing the menstrual cycle which supports individuals regardless of their hormonal profile or HC use, in addition to in environments where hormonal testing for accurate menstrual phase classification is not feasible.

Menstrual-related symptoms include both physical and psychological symptoms that are primarily experienced in the week prior to and during menstruation (Biggs & Demuth, 2011). Examples of physical symptoms include abdominal cramps, backpain, bloating, breast tenderness and headaches, whilst some psychological symptoms include cravings, irritability, anxiety, difficulty concentrating and depressed mood/mood swings (Taim et al., 2023). Individual variability in menstrual symptoms type, timing, and severity exists, which may be associated with diagnosable menstrual abnormalities. Premenstrual syndrome and the more severe premenstrual dysphoric disorder are diagnosable menstrual conditions characterised by repetitive, cyclical menstrual symptoms causing significant personal, interpersonal or functional impairment (Biggs & Demuth, 2011). Dysmenorrhea, which is painful menstruation characterised by abdominal cramps, can be regarded as a menstrual abnormality as well as a menstrual symptom ("ACOG Committee Opinion No. 760: Dysmenorrhea and Endometriosis in the Adolescent," 2018).

Traditionally, menstrual cycle research has examined the interaction between menstrual cycle phases, in relation to specific sex hormone levels and ratios, or menstrual dysfunction, in relation to low energy availability, with performance and recovery (Bruinvels et al., 2022; Nattiv et al., 2007). The influence of menstrual symptoms on performance and recovery has therefore largely been inferred or indirectly explored within menstrual phase research, with suggestions that impaired performance during menstruation could in part be attributed to the presence of menstrual symptoms (McNulty et al., 2023). Menstrual symptoms may, but not always, be associated with hormonal changes and menstrual phases symptoms (McNulty et al., 2023), thus it would be beneficial to directly explore the impact of menstrual symptoms independent of menstrual phase. The need for such research is reinforced by the perceived negative effect of menstrual symptoms on performance (Armour et al., 2020; Bruinvels et al., 2021; Findlay et al., 2020), and even reports of athletes refraining from training due to menstrual pain and symptoms (Ekenros et al., 2022). However, consideration is also required for the beneficial effects of exercise on menstrual symptoms and pain (Armour et al., 2019; Pearce et al., 2020), thus acknowledging the bidirectional association between exercise and/or training and the menstrual cycle.

The etiopathogenesis of menstrual symptoms is complex and multifactorial. One known mechanism is linked to the increase and subsequent rapid decline of oestrogen and progesterone during the luteal phase (Modzelewski et al., 2024). For example, oestrogen's influence on chemicals in the brain and its interaction with serotonin is known to affect mood, anxiety and depression (Gudipally & Sharma, 2024; Walf & Frye, 2006). Impaired sensitivity between allopregnanolone (progesterone metabolite) and gamma-aminobutyric acid (inhibitory neurotransmitter) interactions in the central nervous system is also suggested to play a role (Rapkin & Akopians, 2012). However, individuals using HCs, whereby endogenous fluctuations of oestrogen and progesterone are suppressed by the presence of synthetic hormones, may still report experiencing menstrual symptoms (McNulty et al., 2023). Further, menstrual symptoms can be experienced by individuals with menstrual dysfunction where an altered hormonal profile is displayed (Bann et al., 2022), thus highlighting the complex pathophysiology of menstrual symptoms. As an example, dysmenorrhea may be due to abnormal pelvic pathology (e.g., as related to endometriosis), or caused by the increased prostaglandin levels which stimulate uterine contraction and restrict uterine blood flow ("ACOG Committee Opinion No. 760: Dysmenorrhea and Endometriosis in the Adolescent," 2018).

2.4.2.1 Prevalence of menstrual symptoms amongst footballers

Athletes often perceive a negative effect of menstrual symptoms on performance (Armour et al., 2020; Bruinvels et al., 2021; Findlay et al., 2020), including in some cases refraining from training (Ekenros et al., 2022). Such perceptions and actions are reasonable given the potential severity of symptoms such as cramps, backpain and headaches. Knowledge of the prevalence of menstrual symptoms experienced by athletes may therefore aid practitioners in developing strategies to monitor and manage symptoms to minimise the negative impact of menstrual symptoms on athlete availability and performance.

The prevalence of menstrual symptoms experienced by athletes varies significantly between studies. A recent scoping review reported from 18 studies that 24 - 100% of athletes experience negative menstrual symptoms (Oester et al., 2024). Most included studies were cross-sectional in nature (surveys and semi-structured interviews), with fewer longitudinal studies. Reporting of menstrual symptoms via surveys and semi-structured interviews involves several limitations including recall bias, influence of the most recent menstrual cycle on answers provided and risk of unauthentic responses with non-anonymous surveys/interviews (Althubaiti, 2016; Oester et al., 2024). Additionally, the authors noted a wide range of symptoms were investigated, and athlete demographics varied in terms of age, HC use, competition level and type of sport, though no sub-group analyses were performed by the authors (Oester et al., 2024). The large variability in symptom prevalence may be attributed to the differing methodologies, symptoms investigated and participant demographics. Where future studies include participants of heterogenous demographics, reporting results by sport, competition level and HC use would be beneficial to improve generalisability of findings. Longitudinal studies would also be beneficial to minimise limitations associated with cross-sectional research (e.g., recall bias), and to explore menstrual symptoms in further depth (e.g., timing, type, severity, intra-individual variability).

Several studies have examined menstrual symptoms amongst elite football players. A survey-based study conducted with six professional English clubs found 74% of non-HC users (n = 40/54) experienced negative menstrual symptoms and 4% were unable to train due to symptoms, whilst fewer HC users (40%, n = 8/21) experienced negative menstrual symptoms (Parker et al., 2022). This compares to semi-structured interviews conducted with 15 professional players in England, which found 93% (n = 14/15) of players experienced symptoms in the pre-menstrual phase and 100% during menstruation (Read et al., 2021). Further, African national team players reported experiencing abdominal cramps, headaches, mood swings, irritability and breast tenderness during menses and the week prior, primarily reported as mild, though the total number of players who experienced symptoms was not reported (Mkumbuzi et al., 2021). Only one longitudinal study exists where a national league second division French football team were monitored for one season and found 95% (n = 18/19) of players reported at least one menstrual symptom per cycle, averaging four symptoms per cycle (Dupuit et al., 2023). Thus, menstrual symptom prevalence appears high amongst football players, though no studies exist exploring symptom prevalence amongst football players in Australia, nor concurrent to performance and recovery variables for footballers.

The prevalence of premenstrual syndrome ranges from 9 - 60% in athletic populations (Taim et al., 2023), though diagnosis of premenstrual syndrome and assessment of symptom severity lacks consensus (Kwan & Onwude, 2015). Hence, this lack of consensus often leads to premenstrual syndrome and premenstrual symptoms being incorrectly used interchangeably and contributes to the wide ranging prevalence (Oester et al., 2024). In contrast the prevalence of premenstrual dysphoric disorder ranges 2 - 10% in the general population (Bhatia & Bhatia, 2002) and similarly 1 – 13% in athletic populations (Taim et al., 2023), with less variation likely due to the stricter diagnosis in accordance with the DSM-5 criteria. Almost 60% (n = 31/52) of professional Brazilian players were categorised as having premenstrual syndrome, as identified via a questionnaire completed daily for three months (Foster et al., 2017; Foster et al., 2019). In this group of players premenstrual syndrome was shown to influence inflammatory markers related to stress hormones and mood states, though an effect on performance or recovery was not explored. Such a high prevalence warrants menstrual symptom monitoring in other populations, and exploration of the effect on performance and recovery. The prevalence and types of menstrual symptoms experienced by football players within Australia will be explored in Study 1 of this thesis, whilst the influence of symptoms on performance and recovery will be examined within Studies 2 to 4.

2.4.3 Hormonal contraceptives

Whilst HC users are not the focus population of the thesis, context as to why HC users are considered a separate population is valuable. This distinction is particularly important given the prevalence of HC use, with 43% of Australian women aged 18–39 reportedly using HCs (Skiba et al., 2019). The natural fluctuations of endogenous oestrogen and progesterone during a menstrual cycle are suppressed by HCs which introduce exogenous (synthetic) hormones into the body (Sims & Heather, 2018). Therefore, the ovarian hormonal profiles of HC users differs to naturally menstruating individuals and the downregulation of endogenous hormones with simultaneous upregulation of exogenous hormones may have different effects on physiological systems (Sims & Heather, 2018). Additionally, given menstrual cycle phases are depicted by different levels and ratios of oestrogen and progesterone, HC users do not experience the same menstrual phases. In fact, the hormonal profile experienced by HC users differs depending on the type of HC which vary in dosage, potency, androgenicity and ratios of hormones (Sims & Heather, 2018) as demonstrated by two forms of the oral contraceptive pill in Figure 2.4.

a.

b. [Production note: This figure is not included in this digital copy due to copyright restrictions.]

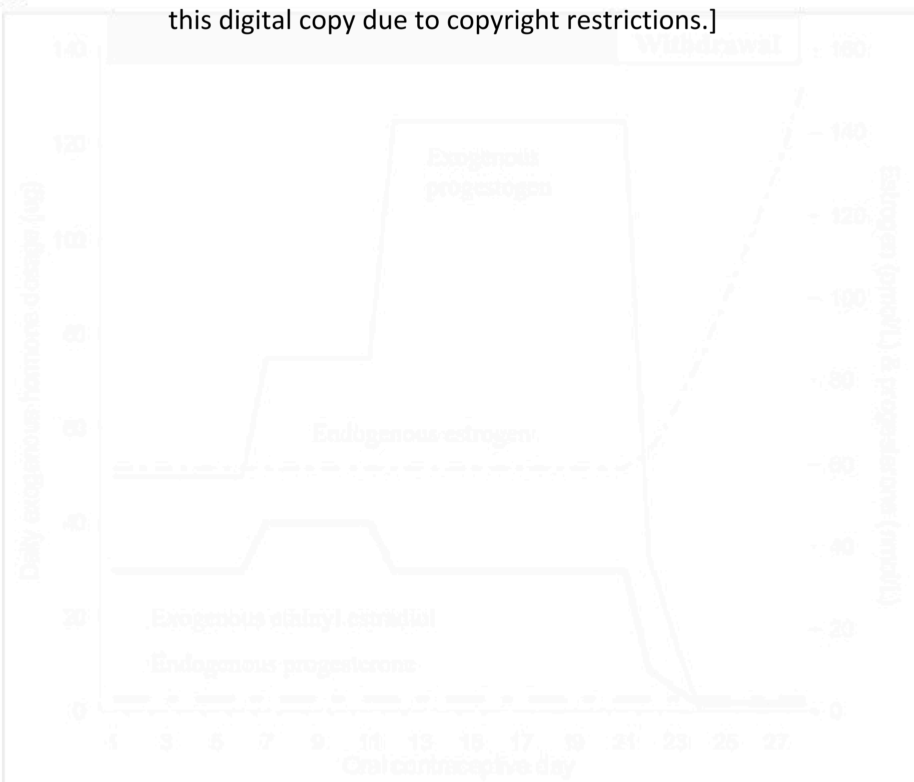

Figure 2.4 Endogenous and exogenous hormonal profile displayed by oral contraceptive users of a) monophasic pill and b) triphasic pill.
(Rechichi et al., 2009).

Hormonal contraceptives are used by athletes for a range of reasons including contraception, reducing menstrual-related symptoms (e.g., pain, bleeding, migraines) and controlling the menstrual cycle (Oxfeldt et al., 2020), though this has not specifically been explored in football players. It should be noted however that HC use may mask, and therefore is not advised as treatment for, oligomenorrhoea and amenorrhoea (Cheng et al., 2021). For mixed-sport studies with elite and sub-elite athletes, HC use is reported as 50 - 61% (Ekenros et al., 2022; Martin et al., 2018; McNamara et al., 2022; Oxfeldt et al., 2020). The prevalence of HC use for footballers has been reported as 8% (n = 3/42) for African National Team players (Mkumbuzi et al., 2021), 28% (n = 21/75) for professional footballers in England (Parker et al., 2022) and 77% (n = 240/312) for Swedish and Norwegian elite and sub-elite players (Ekenros et al., 2023). Mkumbuzi et al. (2021) attributed the lower HC use amongst African players to religious, cultural and socioeconomic differences. Additionally, HC use may differ between sports (Ekenros et al., 2023) and competition levels (Ekenros et al., 2022). In summary, the prevalence of, types of, and reasons for, HC use amongst football players in Australia is currently unknown, thus will be examined in Study 1 which will be beneficial in guiding the menstrual health care and education of players.

2.5 Relationship between Menstrual Cycle and Performance

The menstrual cycle may affect athletic performance and recovery via three main mechanisms, including menstrual abnormalities, menstrual phases and menstrual symptoms. As an overview, menstrual dysfunction is frequently associated with low energy availability and REDs in athletes which can reduce athlete performance and recovery (Mountjoy et al., 2023). Heavy menstrual bleeding is another menstrual health consideration which may harm endurance performance, as well as cause distraction and stress in athletes (Bruinvels et al., 2016; Hinton, 2014; Vannuccini et al., 2020). Additionally, performance and recovery may differ between menstrual phases as related to differing hormonal profiles, for example low oestrogen and progesterone during the early-follicular phase (menstruation) compared to peak oestrogen and low progesterone during the late-follicular phase (McNulty et al., 2020; Meignie et al., 2021; Romero-Parra et al., 2021). Lastly, menstrual symptoms are suggested to influence performance and recovery, particularly given athlete reports of symptoms effects on performance, recovery and ability to train (Armour et al., 2020; Bruinvels et al., 2021; Ekenros et al., 2022; Findlay et al., 2020). Collectively, an understanding of the effect of menstrual cycle on physical performance and recovery is of importance for female athletes.

Optimising athlete menstrual health will aid in optimising athlete performance and recovery. As a secondary but lesser issue, it's not possible to explore the effect of some menstrual phases (as related to differing hormone concentrations) in individuals with menstrual dysfunction and disrupted hormonal profiles, thus a normal menstrual cycle (and hormonal profile) must be ensured. However, the remainder of the literature review will primarily focus on the effects of menstrual phase, with a secondary focus on the effects of menstrual symptoms due to the limited symptoms research that exists, though menstrual phase and symptoms effects are not mutually exclusive. This is evidenced by menstrual symptoms typically occurring during the pre-menstrual and menstrual phases (Martin et al., 2018; Parker et al., 2022). Thus, any changes in performance or recovery between menstrual phases must take into consideration the potential symptoms effects. Exploring both perceived and objectively measured menstrual phase and symptoms effects are important in supporting female footballers' performance and health.

2.5.1 *Athlete perceived effects of the menstrual cycle on performance*

Exploring whether athletes perceive there to be an effect of the menstrual cycle on performance is necessary to support athletes, guide research as well as menstrual monitoring and management practices. Recently a number of studies have explored athletes' perceived effects of the menstrual cycle, including the effects on their training and competition performance through surveys and semi-structured interviews (Armour et al., 2020; Bruinvels et al., 2016; Ekenros et al., 2022; Martin et al., 2018; McNamara et al., 2022; Mkumbuzi et al., 2021; Oxfeldt et al., 2020; Parker et al., 2022; Read et al., 2021). The percentage of athletes that feel their menstrual cycle impacts their performance varies greatly. This is evidenced by a scoping review including 39 studies which found 3 - 100% of recreational to world class athletes report a negative impact of the menstrual cycle on athletic performance (Oester et al., 2024).

Based on the above, football players are no exception and as reported through surveys; 24% (n = 10/42) of African National Team players and 67% (n = 13/19) of an Under 18 Cyprian team perceived a negative effect of the menstrual cycle (Mkumbuzi et al., 2021; Paludo et al., 2023), whilst 86% (n = 99/115) of Japanese trained to professional football players perceived changes in performance due to menstruation (Matsumoto et al., 2023). As based on semi-structured interviews, 100% (n = 15) of football players from two professional English teams perceived a negative impact on performance (Read et al., 2021). In a group of amateur UK football players, 83% of players (n = 105/127) reported menstruation limited their football playing sometimes, rarely or always (Pinel et al., 2022). Overall, 24 to 100% of footballers appear to perceive a negative effect of the menstrual cycle on performance. Differing methodologies (e.g., questionnaires vs surveys) and question wording (e.g., impact of menstruation vs menstrual cycle) may contribute to the different results. Additionally, social, economic, cultural and competition level differences may affect how football players perceive the menstrual cycle to affect their performance (Mkumbuzi et al., 2021; Oester et al., 2024), limiting generalisability of the current findings to other football teams and leagues. Hence, Study 1 will survey the perceived effects of the menstrual cycle on performance for football players within Australia.

Whilst social, economic, cultural and competition level factors may account for some group level differences in perceived effects of the menstrual cycle, the presence and severity of menstrual symptoms experienced by individuals may also contribute to an athlete's perceived impact of the menstrual cycle. Indeed, a study of Paralympic and Olympic athletes (not including footballers) reported those experiencing three or more symptoms were twice as likely to report their performance being negatively affected by their menstrual cycle (McNamara et al., 2022). Similarly, endurance athletes experiencing menstrual pain are more likely to report a negative menstrual cycle impact on performance (Ekenros et al., 2022). Most often menstruation is the phase perceived to affect training and performance, followed by the days prior to menstruation (Armour et al., 2020; Ekenros et al., 2022; Martin et al., 2018; Solli et al., 2020), which coincides with the timing of menstrual symptoms (Martin et al., 2018; Parker et al., 2022). Heavy menstrual bleeding may also contribute to this finding, as athletes with HMB are more likely to report the menstrual cycle impacts their training and performances (69% vs 39%) (Bruinvels et al., 2016). Even athletes without HMB identify menstrual bleeding as inconvenient and report a distraction for fear of leaking (Brown et al., 2021; Pinel et al., 2022). Whether such findings exist in professional football populations, particularly on match day, is unknown and could aid in the development of targeted interventions to improve player performance, or perception of performance, across the menstrual cycle.

Whether an athlete perceives a negative effect of the menstrual cycle on performance varies between populations (Oester et al., 2024). However, there appears to be consensus regarding the timing of the menstrual cycle's disruption to performance, with athletes reporting whilst menstruating or during the premenstrual phase as most disruptive (Armour et al., 2020; Ekenros et al., 2022; Martin et al., 2018; Solli et al., 2020). Additionally, the aspects of training and competition disrupted by the menstrual cycle as reported by athletes varies. For example, negative impacts to fatigue and energy levels (Armour et al., 2020), strength and aerobic fitness (Ekenros et al., 2022), confidence and focus (Read et al., 2021) as well as recovery (Read et al., 2021) have been reported by athletes. Elite footballers also identified their sleep, appetite and psychological readiness are negatively impacted by their menstrual cycle which may affect match preparation or recovery (Read et al., 2021). Therefore, football players perceive various aspects of performance and recovery to be negatively impacted by the menstrual cycle, though as discussed in the following sections, our current understandings on the menstrual cycle's influence on athletic performance, recovery and sleep are equivocal and limited in football specific populations.

2.5.2 Athletic performance and the menstrual cycle

Menstrual health, phases and symptoms may collectively and independently affect athletes physically, cognitively, behaviourally and perceptually (Ihalainen et al., 2024a; McNulty et al., 2020; Oester et al., 2024; Taim et al., 2023). The potential consequent (negative) influence of the menstrual cycle on athlete performance, and particularly competition performance, is of concern for practitioners and players (Beato et al., 2024; Carmichael et al., 2024; Oester et al., 2024). Athlete performance can encompass physical, tactical, technical and cognitive performance (Bangsbo, 2015; Gomez-Ruano et al., 2020; Impellizzeri & Marcora, 2009). Understanding if and how the menstrual cycle influences each of these aspects of athlete performance is necessary to optimise female performance (Carmichael et al., 2021b; Read et al., 2021). Whilst acknowledging the important contribution each has to an athlete's sport specific performance, the influence of the menstrual cycle on physical performance, with respect to physical capacity tests (e.g., strength, speed, power, endurance) and during match play, will be focussed on within this literature review. Physical capacities are often related to physical competition performance (Aquino et al., 2020; Redkva et al., 2018), thus if physical capacities are impaired in relation to the menstrual cycle, then theoretically physical competition performance may subsequently be affected. However, physical competition performance is multifaceted and not reliant purely on discrete physical capacities (Impellizzeri & Marcora, 2009), thus the influence of the menstrual cycle on physical performance should also be explored during competition.

2.5.3 Menstrual phase effects on physical performance

The influence of menstrual phase on performance has been summarised across three review papers which explore exercise performance (McNulty et al., 2020), athletic performance (Meignie et al., 2021) and physical performance (Carmichael et al., 2021b), with the primary focus of each review being changes to physical capacities across menstrual phases. Hereafter the term physical performance will be used, despite the differing terminology between review papers. Exploration of changes in physical performance across the menstrual phases are underpinned by the changing concentrations of oestrogen and progesterone between phases (Elliott-Sale et al., 2020; McNulty et al., 2020). Menstrual phase related changes in performance may also be related to the presence of (heavy menstrual) bleeding (i.e., menstruation/early-follicular phase), and menstrual symptoms (i.e., primarily occurring during premenstrual and menstruation/early-follicular phases). As outlined next, current research surrounding the effect of menstrual cycle phase on physical performance is equivocal.

A recent systematic review and meta-analysis reported physical performance may be trivially reduced in the early-follicular phase (menstruation) when oestrogen and progesterone levels are low (McNulty et al., 2020). However, this research included participants from various sports, of all training levels (did not focus solely on athletes), a range of physical capacities/physical performance tests (i.e., strength, endurance, power) were used, there was inconsistency in menstrual phase classification and number of menstrual phases compared, and majority of studies (42%) were rated as low quality due to methodological issues. Exploration of menstrual phase effects on physical performance may require differentiation of the physical sub-properties (i.e., strength, endurance, power) due to the different potential mechanistic effects of the menstrual cycle on each property. An ensuing narrative review suggested that physical performance may be reduced during the late-luteal and early-follicular phases, again when oestrogen and progesterone levels are low (Carmichael et al., 2021b). Further, another systematic review on elite athletes, which included a total of seven studies, reported similar findings to McNulty et al. (2020), that the magnitude and direction of the effects of the menstrual cycle on physical performance are largely inconclusive (Meignie et al., 2021). These reviews were not specific to elite football populations, though relevant studies will be discussed in the ensuing section (2.5.6 Menstrual cycle effects on footballers' physical capacities).

There are many mechanisms by which the concentrations and/or ratios of oestrogen and progesterone may affect strength, power and endurance. Several of the potential mechanisms will be identified below to provide context to the possible effects of menstrual phases on physical performance, though a detailed discussion of all the mechanisms is beyond the scope of this narrative literature review.

2.5.3.1 Menstrual phase effects on strength and power

Theoretically, acute strength and power may be greater during the late follicular phase where oestrogen levels are high and progesterone levels are low, as oestrogen is postulated to have neuroexcitatory effects and progesterone neuroinhibitory effects (Ansdell et al., 2019). Additionally, oestrogen is suggested to aid strength given the importance of oestrogen to muscle strength in postmenopausal women and ovariectomised rodents (Lowe et al., 2010). Despite the theoretical mechanisms to support fluctuations in strength across the menstrual cycle, a systematic review and meta-analysis suggested strength is minimally affected by changes in oestrogen and progesterone, though most studies included had a small sample size and methodological issues related to menstrual phase identification and verification, poor control of confounders and lack of randomisation of trials (Blagrove et al., 2020). These findings are further supported by a recent umbrella review of five systematic reviews and meta-analyses which found inconsistent changes in acute strength across the menstrual cycle (Colenso-Semple et al., 2023). However, the authors suggested the equivocal findings are likely in part due to poor methodological practices such as menstrual phase identification and verification and heterogenous study outcomes (Colenso-Semple et al., 2023), thus further research on the influence of menstrual cycle phase on strength measures is required.

2.5.3.1 Menstrual phase effects on endurance

In terms of endurance performance, progesterone increases core body temperature and the thermoregulatory setpoint increasing cardiovascular strain, resulting in potentially worse prolonged (endurance) performance and a higher perceived effort/intensity particularly in hot and humid environments during the mid-luteal phase (Janse de Jonge, 2003). Additionally, oestrogen is suggested to have a glycogen sparing effect whilst progesterone promotes lipolysis, which may further impact endurance performance (Bernstein & Behringer, 2023). However, the menstrual cycle's influence on exercise metabolism appears to only affect performance in a state of energy depletion (Bernstein & Behringer, 2023), which is an unlikely scenario for most elite athletes. A systematic review and meta-analysis found no difference in aerobic capacity (VO_2max) between the early-follicular and luteal phases in physically active women (Schumpf et al., 2023), though other menstrual phases (e.g., late follicular phase) were not compared due to lack of data. Of concern, most included studies were classified as moderate to high risk of bias due to variations in phase determination methods and recommendations were provided for future research to use the three-step method of menstrual phase verification (outlined in section 2.3.2.1). Currently no systematic reviews exist for the effect of menstrual phase on aerobic power (e.g., time trial tests) and submaximal endurance performance. As such, there are a range of physiological systems that may be affected by oestrogen and progesterone which could have ensuing effects on athletic performance; however, there is a lack of conclusive evidence of an effect of menstrual cycle phases on physical performance.

2.5.4 Menstrual symptoms effects on athletic performance

In addition to the biological mechanisms discussed above, changes in physical performance across the menstrual cycle may be related to the presence of menstrual-related symptoms. Survey-based studies have highlighted an association between menstrual symptoms and perceived performance disruption (McNamara et al., 2022). However, few longitudinal studies exist which assess athletic performance concurrent to menstrual symptom tracking, thus our understanding is limited by subjective data and recall bias. A study of recreational to trained athletes found an association between daily tracked menstrual symptoms and perceived reduction in physical performance, though perceived performance was captured by a one-off survey (McNulty et al., 2023). Elite rowers were monitored for three to six months, and daily symptoms were found to be negatively correlated with self-reported daily training performance (Antero et al., 2023). Whilst the simultaneous reporting of daily symptoms and performance rating minimises concerns regarding retrospective surveys, subjective data is still limiting, which is highlighted by the lack of relationship found between self-reported symptoms and the coach performance evaluations in the same study (Antero et al., 2023). Furthermore, following seven months of monitoring elite skiers and rowers, a positive association was found between increased menstrual symptoms and likelihood of being in a "hard state" i.e., the load is higher than the adaptative capacity of the athlete (De Larochelambert et al., 2024). Whilst these studies provide longitudinal evidence, studies demonstrating objective performance changes in relation to menstrual symptoms are still missing.

Longitudinal studies monitoring menstrual symptoms concurrent to objective performance measures are required to address the current gap in literature.

2.5.5 Menstrual symptoms effects on player availability

Player availability refers to the availability of players to train and compete (Calleja-González et al., 2022). Injuries are the primary reason for player unavailability, whilst illness, national team duty and other reasons also exist (Ekstrand et al., 2021). Whilst menstrual symptoms are often manageable, they can negatively impact athlete training and competition availability (Dupuit et al., 2023; Ekenros et al., 2023; Parker et al., 2022), highlighting a potential effect on long-term athletic performance. Indeed, athletes report refraining from training, and to a lesser extent competition, due to various menstrual symptoms including menstrual pain, fatigue, nausea and mental-related symptoms (Ekenros et al., 2023; Ekenros et al., 2022).

Amongst footballers, 13% (n = 2/15) and 4% (n = 2/54) of professional football players in England reported missing training and/or competition due to severe symptoms (Parker et al., 2022; Read et al., 2021). Amongst amateur women footballers, physical symptoms were the most frequently reported barrier to playing football with 27% (n = 34/127) of players avoiding football for 1-8 days per month (Pinel et al., 2022). Additionally, 50% (n = 51/103) and 18% (n = 19/103) of sub-elite to elite footballers not using HCs report refraining from training and competition respectively due to menstrual pain and premenstrual syndrome (Ekenros et al., 2023). The same study reported a lower percentage of HC users report refraining from training (42%, n = 87/209) and competition (15%, n = 32/209) due to menstrual pain and premenstrual symptoms. From these few studies it appears fewer professional compared to sub-elite and amateur footballers miss training or competition due to menstrual symptoms. Martin et al. (2018) reported less athletes refrain from exercise than the general population, speculating internal and external pressures to perform at higher competitive levels contribute to this difference. However, a scoping review found no clear difference in the impact of menstrual symptoms on performance between competition levels, age groups or sports, though acknowledging only descriptive range of percentages were explored as opposed to statistical comparisons (Oester et al., 2024). Further research into the association between menstrual symptoms, performance and availability may improve menstrual symptom monitoring and management strategies to maximise athletic performance, and availability for training and competition.

Overall, the menstrual cycle may negatively impact athletic performance, in association with fluctuations of endogenous sex hormones between menstrual phases, or the presence of menstrual symptoms. Research on the effect of menstrual phase on physical performance is equivocal, with more high-quality research required to truly understand any performance related changes across the menstrual cycle. Evidently, menstrual symptoms affect player availability and perceived performance, though objective research is lacking, highlighting the need for further attention to the impact of menstrual symptoms for athletes.

2.5.6 Menstrual cycle effects on footballers' physical capacities

Football is a high-intensity intermittent sport consisting of sprinting, change of direction and a high level of endurance capacity (Griffin et al., 2020). Given the high physical load performed within a football match, changes to physical capacities across the menstrual cycle may affect football physical match performance, as evidenced by the correlation between performance in physical capacity tests and physical match performance (Aquino et al., 2020; Redkva et al., 2018). The systematic reviews discussed in the previous section (Section 2.5.3 Menstrual phase effects on physical performance) exploring the effects of the menstrual cycle on physical performance included athletes from various sports and examined various performance outcomes (McNulty et al., 2020; Meignie et al., 2021). Therefore, exploring the effect of menstrual phase on physical capacities specifically in football players may provide further insights to changes in performance across the menstrual cycle relevant to football performance. The association between menstrual phase and physical capacities performed by footballers is outlined in Table 2.4.

The intermittent nature of football results in a high portion of the match spent walking and jogging, interspersed with high intensity actions which rely on a high level of aerobic fitness to assist recovery (Datson et al., 2014; Vescovi et al., 2021). Given the prolonged intermittent high intensity nature of matches, football players' aerobic fitness is often assessed using the YoYo Intermittent Endurance or Recovery Tests (Datson et al., 2014). To date, few studies have examined the effect of menstrual phase on endurance performance in football populations. Tounsi et al. (2018) found no difference in YoYo Intermittent Recovery Test Level 1 performance between the early-follicular phase (day 2-4), late-follicular phase (day 7-9) and luteal phase (day 20-22) for 11 Tunisian high-level players. Comparatively, Julian et al. (2017) found worse YoYo Intermittent Endurance Test performance during the mid-luteal phase (day 21-22) compared to early-follicular phase (day 5-7) for seven out of nine German second league football players. Despite similar populations (i.e., high level football players) and both studies testing serum progesterone, the differing results could be attributed to the specific days/phases selected for testing, as well as the different tests used (YoYo Intermittent Recovery Test vs YoYo Intermittent Endurance Test). Given such little available research, further investigation is needed, including studies with larger sample sizes.

Power is important for football specific movements, such as accelerating, jumping for defensive plays and corner kicks, as well as kicking (Arnason et al., 2004; Young & Rath, 2011). Power is frequently examined via countermovement or vertical jump tests in football populations (Datson et al., 2014). No differences were found in countermovement jump between the early-follicular phase (day 2 of menstruation) and ovulatory phase (determined as 14 days later) within an Italian first division team (n = 20), though the authors reported worse flexibility during the early-follicular phase across two menstrual cycles (Campa et al., 2022). Trivial to unclear effects for countermovement jump and mean propulsive velocity for back squat were reported for 13 under 17 Chilean national team players between the follicular and luteal phases (Villaseca-Vicuña et al., 2024). No difference in hop tests or squat jump tests were found between menstruation, follicular and luteal phases for 12 youth players (Sánchez et al., 2022). Countermovement and squat jump performance also did not differ between menstrual phases (follicular, ovulation, luteal phase) for Spanish second division players (n = 14), though a higher eccentric-utilisation ratio was reported during ovulation (Aloy et al., 2024). Of note, the previous studies used calendar-based counting only to estimate menstrual phase. Studies which included serum oestrogen and/or progesterone testing (more accurate menstrual phase measuring methods) also found no difference in countermovement jump (Julian et al., 2017), vertical hump height (Igonin et al., 2024; Julian et al., 2017), or 5 stride jump test between menstrual phases (Tounsi et al., 2018). Thus, based on the current research there doesn't appear to be an influence of menstrual phase on jump performance which may be reassuring for players and practitioners.

Table 2.4 Menstrual phase and footballer's physical capacities.

Author (year)	Participants (n - competition level)	Age (y)	Menstrual phases (day of cycle)	Phase determination method	Outcomes
Aloy et al., (2024)	14 - national second division	18.5 ± 1.7	Follicular Ovulation Luteal	Calendar counting	⇔ countermovement jump height ⇔ squat jump ↑ elasticity index during ovulation phase
Campa et al., (2022)	20 - national first division	23.8 ± 3.4	Early-follicular (2) Ovulation (16)	Calendar counting	⇔ countermovement jump height ↓ sit-and-reach during early-follicular phase ⇔ 20m sprint time
Igonin et al., (2024)	11 - national second division	26.0 ± 3.7	Early-follicular (1-2) Late-follicular (11-12) Mid-luteal (21-22)	Calendar counting Serum oestrogen & progesterone	⇔ squat jump height ⇔ 15m agility test ↓ 10-, 20- and 30m sprint time during early-follicular than late-follicular phase and during mid-luteal than late-follicular phase ⇔ repeated sprint ability (7x34.2m sprint, 25s active recovery)
Julian et al., (2017)	9 - national second division	19 ± 4	Early-follicular (5-7) Mid-luteal (21-22)	Calendar counting Serum oestrogen & progesterone	↓ YoYo Intermittent Endurance Test during mid-luteal phase ⇔ countermovement jump ⇔ repeated sprint performance (3x30m, 2 min passive recovery)
Sánchez et al., (2022)	12 – youth regional team	16.2 ± 1.7	Menstruation Follicular Luteal phase	Calendar counting	⇔ 40m sprint time ⇔ change of direction speed ⇔ squat jump height
Somboonwong., et al (2015)	13 - national team	18.8 ± 1.3	Early-follicular (3-6) Mid-luteal (5-8	Calendar counting Basal body temperature	⇔ 40-yd sprint time

Table 2.4 continued.

Author (year)	Participants (n - competition level)	Age (y)	Menstrual phases (day of cycle)	Phase determination method	Outcomes
Tounsi et al., (2018)	11 - high-level	21.2 ± 3.2	Early-follicular (2-4) Late-follicular (7-9) Luteal phase (20-22)	Calendar counting Serum progesterone	⇔ YoYo Intermittent Recovery Test Level 1 ⇔ 5-stride jump test ⇔ repeated sprint ability (6x40m, 20s passive recovery)
Villaseca-Vicuña et al., (2024)	13 – youth national team	15.7 ± 0.5	Follicular (12-13) Luteal (24-25)	Calendar counting	⇔ countermovement jump ⇔ back squat velocity ↑ 10m sprint time during follicular phase

↓ = worse; ↑ = better; ⇔ = no difference

Speed is critical for football specific actions such a sprints and accelerations, which are associated with goal scoring opportunities (Martinez-Hernandez et al., 2023). Trivial to small differences in 10m sprint time between follicular (day 12-13) and luteal (day 24-25) phases were found amongst under 17 Chilean national team players (Villaseca-Vicuña et al., 2024). Further, no significant differences existed in 20m sprint performance between the early-follicular phase (day 2 of menstruation) and ovulatory phase (determined as 14 days later) for 20 Italian first division players (Campa et al., 2022). Similarly, no significant differences in 40m sprint time or change of direction speed were identified between menstruation, follicular and luteal phases for 12 youth players (Sánchez et al., 2022). Somboonwong et al. (2015) found rectal temperature to be higher at rest and during a warm-up during the mid-luteal phase (5-8 days after elevated basal body temperature) than the early-follicular phase (day 3-6), as was resting heart rate for 13 Thai national players. In this study, following the warm-up no differences were noted in temperature, heart rate or 40-yd sprint times; though no hormonal testing was conducted and sprint times were recorded using a stopwatch. In fact, no hormonal testing was conducted to confirm menstrual phases in any of these studies, as all relied on calendar-based counting, which could contribute to the lack of menstrual phase effect. Reliance on calendar-based counting alone to determine menstrual phases is an inaccurate phase determination method which increases the likelihood of phase misclassification and including participants with abnormal hormonal profiles, thus may mask any true effect of menstrual phase on performance (Allen et al., 2016; Elliott-Sale et al., 2021; Janse de Jonge et al., 2019; Schaumberg et al., 2017).

For a study which included serum oestrogen and progesterone testing, amongst 11 sub-elite French national league players, 10-, 20- and 30m sprint time was slower in the early-follicular than late-follicular and in the mid-luteal than late-follicular phases, though no difference in change of direction velocity was found between phases (Igonin et al., 2024). It is possible that the lack of hormonal testing in the majority of studies examining changes in sprint performance across the menstrual phase could have contributed to the lack of effect, compared to the effect of menstrual phase on sprint performance reported by Igonin et al. (2024). Future studies examining the influence of menstrual phase on sprint performance should therefore include more robust menstrual phase measures (e.g., urinary LH testing) to improve menstrual phase-based comparisons.

Repeated sprint ability is a critical component of football match performance, and testing repeated sprint ability provides an indication of anaerobic capacity and rate of fatigue (Gabbett et al., 2013). Amongst German second league players (n = 9), no difference in repeated sprint performance (3 x 30m, 2 min passive recovery) was reported between the early-follicular (day 5-7) and mid-luteal (day 21-22) phases (Julian et al., 2017). No difference in repeated sprint ability (7 x 34.2m sprint, 25s active recovery) was reported for 11 sub-elite French national league players, between the early-follicular (days 1-2), late-follicular (day 11-12) and in the mid-luteal (day 21-22) phases (Igonin et al., 2024). Similarly, no difference in repeated sprint ability (6 x 40m, 20s passive recovery) was reported between the early-follicular (day 2-4), late-follicular (day 7-9) and luteal (day 20-22) phases for 11 Tunisian high-level players (Tounsi et al., 2018). Regardless of the repeated sprint ability protocol employed (i.e., number of repetitions, distance, recovery duration and type), the current research suggests menstrual phase does not appear to affect the repeated sprint ability of football players. Although higher quality menstrual phase classification methods were used (i.e., serum oestrogen and/or progesterone measurements were conducted) which increases the confidence in the findings, more research is required to support these findings given only three studies exist with a total sample size of 31 football players, making robust conclusions difficult.

Given the issues with methodological quality to identify and confirm menstrual phases in the current literature, future studies should aim to conduct hormonal testing to ensure eumenorrheic participants are studied (e.g., exclusion of participants with anovulatory cycles) and for accurate phase classification (McNulty et al., 2020). The small number of studies and inconclusive influence of menstrual phase on physical capacities, particularly for speed (sprint performance) and endurance performance, in the research that does exist highlights the need for more high-quality studies to assess changes in physical capacities relevant to football. As previously discussed, there continues to be a reported perceived effect of the menstrual cycle on training and performance by some football players, yet whether there are objective measurable changes across menstrual phases remains unclear. Future studies should therefore examine changes in physical capacities not only in relation to oestrogen and progesterone levels or menstrual phase, but also the number and severity of menstrual symptoms, and on the individual not only group level. Exploring the effects of menstrual symptoms is particularly important as a high percentage of exercising women experience menstrual cycles that don't display a "normal" hormonal profile, despite having a regular menstrual cycle (21-35 days) (De Souza et al., 2009); thus, excluding them from hormone-related phase-based comparisons (Elliott-Sale et al., 2021).

2.5.7 Menstrual cycle effects on footballers' physical match performance

Performance in physical capacity tests provides an indication of the capacity for match running (Aquino et al., 2020; Redkva et al., 2018), though does not translate directly to physical match performance, which is multifaceted and influenced by other factors i.e., tactics, technical factors, opposition, position, weather (Impellizzeri & Marcora, 2009). Therefore, whether menstrual phase and symptoms influence physical match performance should be examined in ecologically valid contexts. The physical work performed by a football player in a match is referred to as the external load, and is most often measured by GPS, which measure distances covered at specific speed thresholds, accelerations and decelerations (Miguel et al., 2021).

There are a range of GPS variables that are often used by professional football teams, that report distances and classify as speed-derived variables (e.g., generic speed zones, individualised speed zones, peak speed, speed intensity), acceleration-derived variables (e.g., generic acceleration/deceleration zones, number of impacts, player loads) and composite variables (e.g., metabolic load, repeated high-intensity efforts) (Rago et al., 2020). Whilst the validity, reliability and limitations of 5Hz GPS units has previously been reviewed with concerns based on the sampling rate (Scott et al., 2016), 10Hz and 18Hz GPS units appear valid and reliable (Beato et al., 2018; Scott et al., 2016). As further rationale, match GPS data objectively quantifies the player movement patterns (Griffin et al., 2020), with key GPS metrics providing insight on match physical demands and performance (Martinez-Hernandez et al., 2023; Rago et al., 2020; Rhodes et al., 2021; Schulze et al., 2022).

Studies reporting GPS data in female football show that professional players typically cover 10,332m ± 877m at a match intensity of 109m/min ± 9m/min each match (Datson et al., 2014; Griffin et al., 2020; Vescovi et al., 2021). The distance covered at high or very-high speed is in part dependent on the speed thresholds used, therefore varies greatly between studies (Griffin et al., 2020; Vescovi et al., 2021). For example, using 10Hz GPS units and a high-speed threshold of >16.5 $km{\cdot}h^{-1}$, Trewin et al. (2018a) reported players covered 873m, compared to 2799m when a high-speed threshold of 12.5-22.5$km{\cdot}h^{-1}$ was used (Scott et al., 2020). Currently, there are no standardised speed thresholds, despite suggestions to standardise high-speed running and sprinting velocity thresholds (Bradley & Vescovi, 2014). Regardless, high-speed running is an important variable to monitor and train given most goals are scored from straight sprints (Faude et al., 2012), though it should also be noted that high-speed running is highly variable between matches and has a high coefficient of variation (CV; 33%) (Trewin et al., 2018a).

The majority of high and very-high-speed running efforts are between 5 and 10m (Datson et al., 2017), highlighting the importance of accelerations in female football. Accelerations and decelerations are usually represented as a count per match, as opposed to distance. Similar to speed-derived GPS variables, there are no standardised thresholds for acceleration and deceleration measurements (Griffin et al., 2020; Vescovi et al., 2021). In studies of international football matches, Meylan et al. (2016) reported approximately 162 accelerations using a threshold >2.26$m{\cdot}s^2$, whilst Ramos et al. (2019) reported 201-218 accelerations using a lower thresholds (>1 $m{\cdot}s^2$), and also reported 161-182 decelerations (>-1$m{\cdot}s^2$). Whilst the CV for accelerations are high (17%), there is less variation in this measure than high-speed running (33%) (Trewin et al., 2018a). Accelerations and decelerations have a higher metabolic cost (Osgnach et al., 2010) and mechanical load (Dalen et al., 2016) than running at a constant velocity, further emphasising the need to monitor these variables. Such high-intensity actions are often associated with decisive moments in matches, for example goal scoring opportunities, defensive actions and attacking play (Martinez-Hernandez et al., 2023; Rhodes et al., 2021; Schulze et al., 2022). Thus, monitoring accelerations and decelerations provides an indication of player's physical performance.

To date, limited menstrual cycle research exists specifical to football match performance, though as discussed earlier, there is potential for the menstrual to affect physical performance. Only two studies (Igonin et al., 2022; Julian et al., 2020) have analysed football match physical performance directly in relation to the phases of the menstrual cycle. The first study by Julian et al. (2020) used hormonal testing to establish a physiologically normal menstrual cycle in 15 elite football players, then tracked their cycle length (no further hormonal testing) and match running (via GPS) over four months. The authors reported that very high-speed running distance per minute (individualised threshold, 16.69 ± 1.09 – 19.94 ± 0.88m·min^{-1}) may be greater in the luteal phase, although large match-to-match variation (39.5%) was reported. Further, there were no large or meaningful relationships between the GPS measures and change in sex hormones. Match running distance per minute covered at all other speed thresholds analysed did not differ between the follicular and luteal phase. However, it should be noted the use of only two menstrual phases (follicular vs luteal), and therefore differing hormonal profiles within each phase could have masked any effects were subphases (e.g., early-follicular vs late-follicular) analysed instead.

The second study which explored changes in match running between menstrual phases was conducted with eight sub-elite football players (Igonin et al., 2022). Players tracked their menstrual cycle (calendar-based counting only) and wore an ankle inertial measurement unit during matches for three seasons. Igonin et al. (2022) found less distance was covered at moderate (7-14km·h^{-1}) and high (14-19km·h^{-1}) velocities during the early-follicular phase than late-follicular and mid-luteal phases. Additionally, total distance covered and number of sprints (one sprint equalled four or more strides >21km·h^{-1}) were lower during the early-follicular phase than late-follicular phase. Both studies used calendar-based counting to determine menstrual phase, thus potentially including abnormal cycles (i.e., players with anovulatory or luteal phase deficient cycles) given the frequency of inconsistent cycles in exercising women (De Souza et al., 2009), or resulting in phase misclassification given the intra-individual variability in cycle and phase length (Colenso-Semple et al., 2023). Future research should include hormonal measures to assess menstrual status and determine menstrual phases, in addition to analysing sub-phases of the menstrual cycle. Accordingly, Study 2 of this thesis will explore changes in match running across the early-follicular, late-follicular and luteal phases, with menstrual phase measures including urinary LH and PdG.

Physiological explanations of the above findings remain speculative, though theoretically, changes in substrate metabolism across the menstrual cycle may contribute to changes in match running between menstrual phases (Oosthuyse & Bosch, 2010). Oestrogen promotes glycogen sparing and fat utilisation (Oosthuyse & Bosch, 2010). Glycogen is the primary fuel source during football (de Sousa et al., 2022) and muscle glycogen stores are depleted during elite female football matches (Krustrup et al., 2021). Reductions in sprint performance are correlated with reductions in muscle glycogen levels in female football (Krustrup et al., 2021). Hence, when oestrogen levels are high (late-follicular and mid-luteal phases) there is potential for delayed onset of fatigue due to the glycogen sparing effect of oestrogen. However, nutritional strategies may negate the effects of oestrogen on gluconeogenesis thus minimising any differences between phases (Oosthuyse & Bosch, 2010). Oestrogen and progesterone levels may also affect exercise-induced fatiguability and consequently match running, though the current research is mixed (Pereira et al., 2020).

The lack of studies that have examined match running in relation to menstrual phase (Igonin et al., 2022; Julian et al., 2020), the mixed findings within these studies, and the unclear influence of menstrual phase on physical capacities amongst football players necessitates additional ecological studies to verify the effects of menstrual subphases on football players match running. The effect of menstrual symptoms on match running should also be studied given athletes report refraining from training or playing due to menstrual related symptoms (Ekenros et al., 2022; Pinel et al., 2022). Moreover, monitoring symptoms is logistically and feasibly more achievable than accurately measuring menstrual phase, particularly in real-word football team settings. Thus, Study 2 will also examine the influence of menstrual symptoms on match running. Further research would improve knowledge of whether the menstrual cycle influences physical match performance, which is necessary to implement strategies to manage or overcome any potential negative effects.

2.6 Relationship between Menstrual Cycle and Recovery

The match demands experienced by football players, including distances and high-speed efforts can result in both acute and residual fatigue responses, which then require players to recover from to manage training and prepare for competition (Carling et al., 2018; Thorpe et al., 2017). Fatigue is traditionally defined as “failure to maintain the required or expected force” (Edwards, 1981), though it is inherently more complex in field-based settings, and reflects a disturbed psychophysiological state from the physical and mental efforts. In turn, recovery refers to the restoration of a disturbed psychophysiological state over time (Kellmann et al., 2018; Nedelec et al., 2012). Thus, fatigue and recovery exist along a continuum, such that if inadequate recovery is coupled with high stress or fatigue, this increases a player's risk of under-recovery, overtraining, injury and illness (Kellmann et al., 2018). The recent increase in professionalism of women's football has resulted in increasing congested match schedules (multi-match weeks) (FIFPRO, 2023), heightening the importance of managing fatigue and recovery for female football players. Therefore, knowledge of the factors that influence fatigue and recovery, and how they are influenced by menstrual cycle function is a key concern for football players and practitioners.

2.6.1 Overview of fatigue and recovery

Fatigue involves both peripheral and central components, resulting in decreases in performance, physiological functioning and/or increased perceptions of fatigue to ensure preservation of homeostasis (Behrens et al., 2023; Tornero-Aguilera et al., 2022). Fatigue that occurs within and the immediate hours following a match is referred to as acute fatigue, whereas impairments in the days following a match (e.g., 72 h following) is residual fatigue (Hader et al., 2019). Several mechanism underly fatigue experienced by players during and following a football match, including muscular damage, substrate depletion, dehydration and central fatigue (Nedelec et al., 2012). For example, exercise induced muscle damage occurs due to the many eccentric muscle contractions players perform during matches such as decelerations (Rhodes et al., 2021), which results in decreased muscle function and delayed onset muscle soreness (Howatson & van Someren, 2008). Additional match-related stressors can also contribute to overall post-match fatigue, for example travel to and from competition (Janse van Rensburg et al., 2021), mental stressors from coaches and media (Coutts, 2016), and match outcomes (Fessi & Moalla, 2018).

The type and magnitude of fatigue experienced by athletes is influenced by many factors including the sport (e.g., duration, intensity, contraction type), gender, training status, psychological states (e.g., stress), environmental conditions (e.g., heat) and general stressors (e.g., family, media) (Kellmann et al., 2018; Sahlin, 1992; Tornero-Aguilera et al., 2022). As illustrated in Figure 2.5, balancing training and non-training stressors, the resultant fatigue and recovery is essential for improvements in performance or positive training adaptations (Meeusen et al., 2013). In contrast, the combination of overloaded training and non-training stress paired with insufficient recovery may lead to under-recovery, overtraining, injury and illness (Kellmann et al., 2018; Meeusen et al., 2013). As well as the magnitude of fatigue being influenced by several factors, the time-course of recovery is influenced by factors like fitness, age, gender (Janse van Rensburg et al., 2021), and potentially the menstrual cycle (Romero-Parra et al., 2021). Monitoring player fatigue and recovery status in football, particularly in the hours and days following matches, is therefore important to prepare for upcoming competition, whilst also reducing the risk of injury, illness and overtraining.

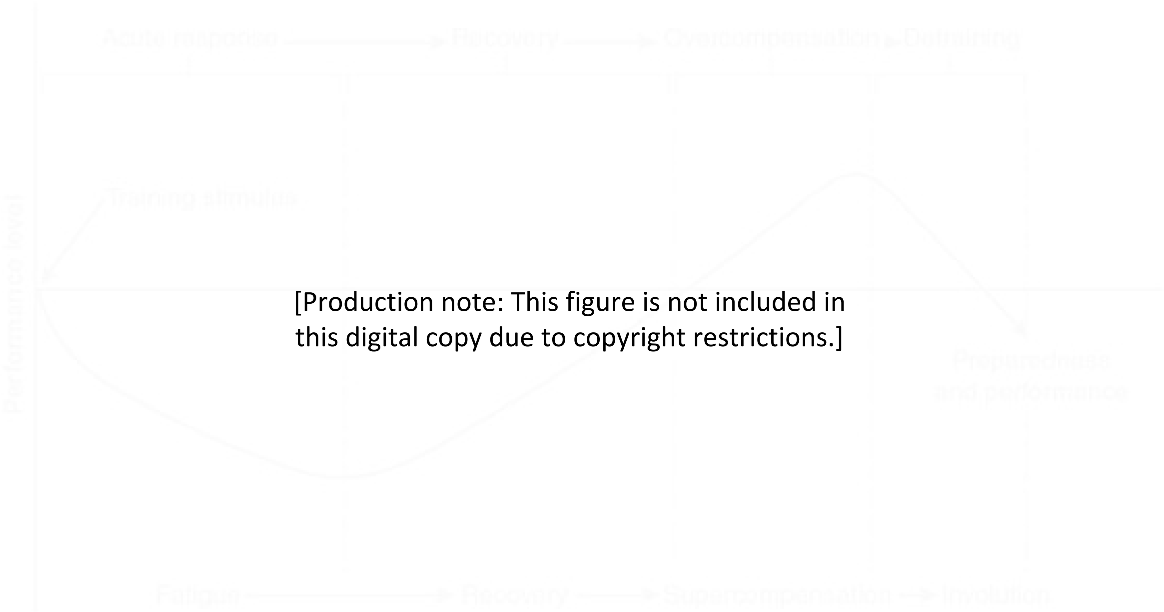

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Figure 2.5 Stimulus-Fatigue-Recovery-Adaptation model.
(Hoffman, 2012)

2.6.2 Monitoring fatigue and recovery in football

Fatigue and recovery are multifactorial in nature and as such can be monitored via many physiological and psychological measures. Physical performance tests, such as sprint, jump and strength tests, provide important information but may be deemed counterproductive due to their ability to contribute to further fatigue and delay recovery (Marqués-Jiménez et al., 2017; Nedelec et al., 2012). Autonomic measures related to heart rate, such as submaximal heart rate, heart-rate variability and heart rate recovery, can infer fatigue and recovery though their sensitivity to acute load changes in team sports (along with high variability) has been questioned (Thorpe et al., 2017). Biochemical markers may be used, such creatine kinase which is a muscle damage marker and interleukin-6 which is an inflammatory marker, however, they are costly, often require practitioner expertise to draw blood, and have time-consuming analyses which deem them impractical in football settings (Thorpe et al., 2017). Athlete self-reported measures provide subjective markers of fatigue and recovery, for example perceived soreness, as collected by questionnaires (Nedelec et al., 2012; Thorpe et al., 2017). Given the challenges and issues associated with physical tests, autonomic measures and biochemical markers, athlete self-reported measures are frequently used in applied sporting environments, including football, due to their practicality and non-fatiguing nature (Nedelec et al., 2012; Saw et al., 2016; Taylor et al., 2012).

Athlete self-reported measures are a non-invasive, cost-effective and often time-efficient method of monitoring fatigue and recovery status (Thorpe et al., 2017). Several validated questionnaires exist, for example the Profile of Mood States and Acute Recovery Stress Scale for Athletes, though the time-consuming nature of these long questionnaires prevent their frequent use in sport and therefore practitioners often utilise adapted versions, or shorter questionnaires (Taylor et al., 2012). However, a systematic review of the risk of bias and measurement property quality for athlete reported outcome measures found most multiple-item questionnaires were acceptable, whilst single-item questions (e.g., wellness items) lack validity (Jeffries et al., 2020). The review suggests findings based on these single-item questionnaires should be interpreted with caution. Despite this, an earlier systematic review found subjective measures reflect changes in acute and chronic load with greater sensitivity and consistency than objective measures (Saw et al., 2016).

Athlete perceptual recovery is frequently monitored in football using single-item scales, for example wellness subscales. The Hooper questionnaire rates perceptual fatigue, soreness, stress and sleep on 7-point Likert-scales and sums the items to provide a "wellness" score (Hooper & Mackinnon, 1995). Amongst male football players, 35-40% worse fatigue, sleep and soreness scores were reported post-match compared to pre-match, which improved by 17-26% three days following a match (Thorpe et al., 2016). Further, fluctuations in perceptual fatigue are associated with fluctuations in total high intensity running distance for elite male football players (Thorpe et al., 2015). Moreover, Hooper Index (summed wellness score) was shown to be more useful than heart rate variability for monitoring post-match fatigue in male football players due to smaller typical error and increased signal-to-noise ratio (Rabbani et al., 2019). Despite the demonstrated applicability of perceptual fatigue and recovery measures in male football, limited research exists for changes in perceptual responses following female football matches (Goulart et al., 2022).

2.6.3 Female football post-match fatigue and recovery

Research examining the post-match fatigue response and time-course of recovery for female football players is lacking compared to research with males (Goulart et al., 2022). A systematic review and meta-analysis of 26 studies reported female football players experience acute fatigue immediately following a match, with residual fatigue demonstrated in the following days (Goulart et al., 2022). The review suggested female football players require more than 72h for complete physical, physiological and perceptual recovery from a football match (Goulart et al., 2022). Specifically, the review found physical performance markers such as sprint and jump performance were recovered within 72h following a match, whilst YoYo test performance was impaired immediately post-match though no studies exist with YoYo test data in the days following a match. Muscle soreness was recovered within 72h of a match, though no data existed for 48h following a match, whilst fatigue was increased, and vigour decreased 12h following a match, without data for any later time-points. Inflammatory markers (cytokines) were only impaired immediately post-match, whilst creatine reactive protein was impaired until 72h post-match. Lastly, muscle damage markers such as creatine kinase and lactate dehydrogenase remained significantly different from pre-match levels at 72h, suggesting incomplete recovery and that blood markers of muscle damage have the longest recovery time-course. Whilst perceptual markers of fatigue and recovery are most frequently employed in football settings as previously discussed, research examining changes in physical performance parameters and physiological parameters is more prevalent than perceptual parameters (Goulart et al., 2022).

In summary, the systematic review and meta-analysis by Goulart et al. (2022) provides a review of female football players post-match fatigue and recovery due to the analysis of official matches only. Of note, the review included studies with recreational to elite players, different match conditions (e.g., single match vs congested fixture) and at various times of the season (e.g., early, mid, late), which could have impacted the dose-response relationships between match load, fatigue and recovery, though the small number of studies prevented subgroup analyses. Furthermore, only 30% of the included studies reported menstrual cycle phase or HC use, whilst two studies controlled menstrual phase due to its potential effects. As such, more research investigating the post-match perceptual responses of female football players is required due to the scarcity of current studies coupled with practical applicability of findings.

2.6.4 Menstrual cycle associations with athlete perceptual fatigue and recovery

Understanding whether the menstrual cycle exacerbates athlete fatigue or slows recovery can assist practitioners in planning recovery and training prescription. A recent systematic review and meta-analysis examined athlete perceptual responses between menstrual phases and found most studies reported no significant differences (Paludo et al., 2022). However, the limited number of studies (n = 14) coupled with the many different sporting populations, outcome variables (not only perceived fatigue and recovery) and menstrual phase classifications methods, limits the ability to form generalisable conclusions. Of note, the review did not include data on training load or context of training schedules with respect to the perceptual responses, which should be accounted for when exploring the influence of the menstrual phase on fatigue and recovery responses.

Several studies have examined the perceptual responses of football players at given timepoints with respect to menstrual phases. When examining the dose-response relationship for 16 football players during a World Cup and preparatory camp, an increased perceived fatigue response was reported during the luteal phase than follicular phase 48h after a match, with no difference between four menstrual phases (menstrual, follicular, luteal, premenstrual) for perceived soreness or sleep, nor fatigue at 24 and 72h following a match (Scott et al., 2024). On average 1.5 cycles were monitored across 16 players, limiting repeated observations within the same phase per player and resulting in an underpowered study. Perceptual measures (soreness, sleep, stress, fatigue, mood) reported the day of and three days following matches did not differ between four menstrual phases (menstruation, follicular, ovulation, luteal) for 22 players in an English professional team (Abbott et al., 2024). Similarly, fatigue, stress, sleep, soreness and Hooper Index (summed score of the wellness subscales) did not differ between two menstrual phases (follicular vs luteal) for 18 elite academy players, although mean weekly scores were compared instead of daily scores (Juillard et al., 2024). Whilst there appears to be a limited effect of menstrual phase on football players' perceptual recovery and fatigue responses, the respective studies relied on calendar-based counting to estimate menstrual phase which could influence the results. Additionally, given the observational nature of the studies, the possibility of a bidirectional relationship between the menstrual cycle and recovery should be acknowledged. Future studies employing more rigorous menstrual phase classification methods are therefore required to examine the relationship between menstrual phase and post-match perceptual responses for football players.

In addition to the equivocal effect of menstrual phase on athlete perceptual responses, the influence of the menstrual cycle on athlete recovery (i.e., change in fatigue markers following exercise) is unclear. A recent systematic review and meta-analysis of recreationally active to professional athletes found the difference (baseline vs post-exercise) in delayed onset muscle soreness and strength losses as a result of exercise-induced muscle damage were greater in the early-follicular phase, where oestrogen levels are low, than the late follicular or mid-luteal phases (Romero-Parra et al., 2021). This may suggest longer recovery periods are required during the early-follicular phase. Such findings may be due to the purported effects of oestrogen having antioxidant and membrane stabiliser properties as well as anti-inflammatory effects, which may reduce inflammation, reduce exercise induced muscle damage and aid recovery (Enns & Tiidus, 2010; Kendall & Eston, 2002). The review (Romero-Parra et al., 2021) included 19 studies of various subject training status (sedentary to professional athletes) and exercise protocols, thus introducing methodological heterogeneity, and minimising the specificity to football populations. Additionally, few studies examined more than one phase, only 11/19 studies included sex hormone analysis and high heterogeneity of the outcome variables was present, thus the results should be interpreted with caution.

Currently no data exists on the effects of menstrual phase on footballers' post-match time-course of recovery. However, given oxidative stress and muscle damage occurs in females following football matches (Souglis et al., 2018), and the theoretically beneficial effects of oestrogen on recovery mechanisms (Enns & Tiidus, 2010; Kendall & Eston, 2002), the influence of the menstrual cycle phases, with respect to fluctuating sex hormones, on recovery in football players should be investigated. As such, Study 3 of this thesis will investigate the influence of menstrual cycle phase on perceptual measures and the recovery timeline of perceptual measures around matches. Such knowledge would help players and practitioners to adapt recovery strategies where appropriate as based on menstrual phase, as well as periodisation of strength and conditioning programs where possible. Finally, due to the strong interactive effects between recovery, sleep and subsequent athletic performance, to adequately explore the effects of the menstrual cycle on footballers' recovery, concurrent consideration of footballers' sleep should occur.

2.7 Relationship between Menstrual Cycle and Sleep

Sleep is a reversable neuro-behavioural process of reduced movement and response to stimulus, though altered brain activity, during the rest phase of the circadian rhythm (Daniel & Ana, 2015; Power et al., 2024). For athletes sleep is an important part of athlete preparation for, and recovery from, competition – as is evidenced by football practitioners ranking sleep as the most important post-match recovery strategy (Querido et al., 2022). Understanding and managing the risk factors for disturbed sleep is therefore essential for practitioners to minimise any subsequent harmful effects on performance and recovery, and for female players this also requires an understanding of the associations between the menstrual cycle and sleep.

2.7.1 Overview of Sleep

Sleep consists of two main stages: non-rapid eye movement sleep and rapid eye movement sleep, which are further divided into light sleep (non-rapid eye movement sleep stages 1 and 2) and deep sleep (non-rapid eye movement sleep stage 3), followed by rapid eye movement sleep (Walsh et al., 2021). The stages of sleep are classified according to electrical activity of the brain, breathing frequency, heart rate, eye movement and muscle tone (Okechukwu, 2022), with non-rapid eye movement often being referred to as slow-wave sleep whereas rapid eye movement sleep is characterised by an active brain and muscle atonia (Halson, 2014; Okechukwu, 2022). The stages of sleep are proposed to have distinct complementary functions, including roles such as motor learning and memory consolidation (Frazer et al., 2021), growth hormone release for tissue regeneration (Van Cauter & Plat, 1996) and immune function support (Besedovsky et al., 2012). Ultimately, sleep serves to recover from wakefulness and prepare for subsequent wake, which aligns with athletes requiring sleep for physical and mental recovery, in addition to preparation for performance (Daniel & Ana, 2015; Halson, 2014).

Current recommendations on sleep volume include adolescents to achieve 8-10 h of sleep per night, whilst adults should achieve 7-9 h of sleep per night (Hirshkowitz et al., 2015). Athletes are suggested to require more sleep than the general population to recover from their high physiological and psychological loads, as based on the restorative and energy conserving functions of sleep (Fullagar et al., 2015b; Walsh et al., 2021). Athletes report requiring 8.3 h ± 0.9 h of sleep to feel rested, though typically obtain 6.7 h ± 0.8 h of sleep (Sargent et al., 2021). The concern for players not achieving sufficient sleep is that poor sleep may negatively affect athlete performance and recovery. For example, reduced TST and restfulness was experienced by top division European male football players (n = 16) following night matches compared to day matches, with reduced perceived recovery reported the following mornings (Fullagar et al., 2016b). Additionally, 24 h of sleep deprivation compared to habitual sleep negatively affected continuous kicking test performance, though no other football skills were affected, for 19 junior male football players (Pallesen et al., 2017). However, partial sleep restriction compared with habitual sleep following night matches (5.37 h vs. 8.59 h) did not impair countermovement jump, wellbeing, or cognitive function for nine male division two English football players (Abbott et al., 2022). Overall, the effects of a night of total sleep deprivation (0 h sleep) are known to impair athlete performance and recovery (Skein et al., 2011), whilst the effects of a partially disrupted night of sleep appear to have equivocal effects (Fullagar et al., 2015a; Fullagar et al., 2015b). Although this is not an extensive review of the literature surrounding the influence of sleep impairments (disruption or deprivation) on football player performance and recovery, these examples have been discussed to provide context to the importance of sleep for football players, especially around matches.

Sleep may be negatively affected by sport-specific factors such as high training or competition loads (Dumortier et al., 2018), early morning training (Lastella et al., 2015), travel for competition (Janse van Rensburg et al., 2021), evening competition schedules (Costa et al., 2021), nervousness the night prior to competition (Erlacher et al., 2011) and cognitive arousal (Sim et al., 2023). Therefore, it's logical that partially disrupted sleep is common for athletes, particularly the night prior to and night following competition when sleep is of utmost importance (Fullagar et al., 2015a; Fullagar et al., 2015b). The combination of match schedules, high workloads, psychological stress and cognitive arousal associated with matches creates a worst-case scenario for poor sleep surrounding matches.

2.7.2 Measuring Sleep

The gold standard objective measurement of sleep is polysomnography where heart rate, breathing rate, oxygen saturation, electroencephalographic responses, eye movement and skeletal muscle activity are measured (Roomkham et al., 2018). The combination of physiological measures quantifies the different stages of sleep (rapid eye movement and non-rapid eye movement), however, is not cost-effective, nor practical within most real-world football environments given the need for a laboratory and/or skilled technicians to perform and interpret the results (Lehrer et al., 2022). Activity monitors, usually like a watch worn on the wrist are much more practical sleep measuring tools that detect movement and use an algorithm to determine sleep/wake schedules (Lehrer et al., 2022).

The most cost effective and easy to use sleep measuring tools are sleep diaries and questionnaires. Compared to polysomnography, sleep diaries often overestimate TST and sleep efficiency (SE), whilst underestimating sleep onset latency (SOL) and WASO (Lehrer et al., 2022). Activity monitors such as actigraphs are a more valid alternative to polysomnography whilst being relatively low burden (Lehrer et al., 2022) and can be used in combination with sleep diaries to improve accuracy.

In addition to the stages of sleep discussed, common measures of sleep are defined in Table 2.5 (Dietch & Taylor, 2021). Total sleep time provides a measure of sleep quantity, whilst SOL, SE and WASO provide an indication of sleep continuity and objective sleep quality (Hirshkowitz et al., 2015; Ohayon et al., 2017). The National Sleep Foundation recommend good sleep quality for young adults and adults is indicated by SOL <30mins, SE >85% and WASO <20min (Ohayon et al., 2017). Several validated subjective sleep quality questionnaires like the Pittsburgh Sleep Quality Index exist, which are frequently used to monitor sleep and sleep related medical disorders, though not validated amongst athletes (Fabbri et al., 2021). However, in applied sports practice these questionnaires are rarely used for long-term monitoring due to the length of the questionnaires. Hence, the most common measuring instruments used to report sleep amongst athletes are actigraphy and Likert Scales, followed by longer questionnaires such as the Pittsburgh Sleep Quality Index for screening sleep (João Gustavo et al., 2019; Simim et al., 2020).

Table 2.5 Sleep measure definitions.

Sleep measure	Units	Definition
Bedtime	hh:min	The self-reported clock time at which a participant went to bed to attempt to sleep.
Waketime	hh:min	The self-reported clock time at which a participant woke up and stopped attempting to sleep.
Total sleep time	h min	The total amount of sleep obtained during a sleep period.
Sleep onset latency	min	The period between bedtime and sleep onset time.
Sleep efficiency	%	The percentage of time in bed that was spent asleep.
Wake after sleep onset	min	The total amount of time spent awake during a sleep period.
Sleep quality	au	Subjective measurement of perceived quality of sleep usually rated on a Likert scale.

(Dietch & Taylor, 2021)

2.7.3 Female footballers' sleep before and after matches

As an overview of female footballers' sleep around competition, the following studies demonstrate the varying effects of match nights for female football players. Amongst Norwegian national team players reduced time in bed (1 h ± 8 min) and TST (55 min ± 7 min) but longer SOL (3 min) were reported the night after compared to the night prior to a match (Moen et al., 2021). Similarly, lower TST (49 – 65 min) the night after a match compared to training has been reported in professional players (Carriço et al., 2018; Thomas et al., 2021). In comparison, no difference in perceived sleep quality (Pexa et al., 2023), TST or SE (Barreira et al., 2024) the night after a match in college players and Portuguese national team players respectively were reported. Further, for high level players, TST was worse (1 h 28 min – 1 h 39 min) following evening training compared to match days and rest days (Costa et al., 2019a; Costa et al., 2021). It is unclear whether female footballers' sleep is worse following matches, with three studies demonstrating reduced TST after matches (Carriço et al., 2018; Moen et al., 2021; Thomas et al., 2021), one study demonstrating no change in TST (Barreira et al., 2024) and two studies reporting worse sleep following evening training instead of matches (Costa et al., 2019a; Costa et al., 2021). To optimise female footballers' sleep and ensure recovery, further studies exploring female football player sleep around matches is required.

The influence of various match-related factors on female footballers' sleep have also been explored, including match location, playing status and workload. Compared to home games, away games may induce sleep disruption, with later bed times (36 min, 95% CI 12-44 min), longer SOL (5 min, 95% CI 1-7 min) (Costa et al., 2019b) , though practically these differences may be considered small. In comparison, one study reported longer TST (36 min ± 31 min) for away matches than home matches (Carriço et al., 2018). No difference in sleep has been reported between starters and non-starters (Fernandes et al., 2021), nor those with high compared to low minutes played during a season (Pexa et al., 2023). Comparatively, Costa et al. (2021) found session-rating of perceived exertion (duration x rating of perceived exertion) was negatively correlated with TST and SE in high level players, though the study included training sessions as well as matches, suggesting perhaps differing effects of matches and training on sleep. Of concern, female football players often obtain less than the recommended 7 h sleep (Costa et al., 2019a; Costa et al., 2021; Moen et al., 2021). Whilst limited research exists for female footballers' sleep, there is some evidence for situations that may impair sleep though the influence of match location and training loads on sleep is equivocal. Additional studies would be beneficial to confirm the current evidence given the scarcity of female football specific sleep research around competition. Whether the menstrual cycle exacerbates any match-related impairments to players' sleep is also important to ensure females are supported across their menstrual cycle.

2.7.4 Menstrual cycle association with sleep

Given the importance of sleep to performance and recovery in sport, understanding whether sleep is affected by menstrual cycle phase and symptoms in footballers is required to improve knowledge of underlying factors related to performance and recovery. Across the menstrual cycle, changes in objective sleep measures are equivocal, however, often females report worse perceived sleep quality during their premenstrual (late-luteal) and menstrual (early-follicular) phases (Baker & Lee, 2018). Difficulty sleeping is suggested to be associated with changes in progesterone and oestrogen, irregular menstrual cycles as well as the presence of menstrual symptoms (Baker & Lee, 2018). Of note, the bidirectional relationship between the menstrual cycle and sleep should be acknowledged. For example, shift work has been associated with increased risk of menstrual irregularities due to circadian rhythm disruption and subsequent misalignment of reproductive hormones (Gamble et al., 2013). Additionally, whilst (menstrual) pain can negatively impact sleep quality and duration, poor sleep can alter next day perceptions of pain (Iacovides et al., 2015).

Female athlete specific research is limited and represents only 25% of all athlete sleep research (Power et al., 2024). A pilot study with Australian Rules Football athletes found perceived sleep quality (Likert scale 1 to 5) to be worse during the luteal phase compared with follicular phase (Carmichael et al., 2021a). In comparison, no difference in sleep was reported between menstruation and the mid-luteal phase (day 18-20) for physically active sport science students (Martínez-Cantó et al., 2018) as measured by the Karolinska Sleep Diary. Further, no difference in sleep quality (Likert scale 1 to 7) was found between the late-follicular (days 11–13), middle-luteal (days 21–23), and premenstrual phases (days 28–29) for professional handball players (Graja et al., 2022). The reported differences in findings shown here may be due to the different menstrual phases assessed, the low number of participants (n = 5-10), and with the exception of Carmichael et al. (2021a), only assessed sleep quality during one menstrual cycle per participant. In a group of collegiate athletes (n = 45) objective measures of sleep were assessed by home electroencephalogram monitoring and found lower TST, longer SOL and less deep sleep during menses compared with the mid-follicular phase (Koikawa et al., 2020). However, no comparisons to the luteal phase were conducted for objective sleep measures, despite often reported worse sleep quality during this phase (Baker & Lee, 2018; Carmichael et al., 2021a), which may be associated with the severity of menstrual symptoms (Komada et al., 2019).

To date, no studies have examined the relationship between menstrual phase and sleep for football players, whilst only one study has assessed the influence of menstrual symptoms and day of the menstrual cycle on football players' sleep (Halson et al., 2024). A study of one professional team (n = 12) reported a significant effect of number of menstrual symptoms and day of the cycle on sleep duration, whereby sleep duration increased by 21 min and 0.9 min for every increase in total number of symptoms reported and increase in day of the cycle (relative to day 1 of menstrual bleeding), respectively. Time in bed was also significantly increased by increased total number of symptoms and increase in day of the cycle, though the estimated increase in minutes relative to symptoms and day of cycle were not reported. Increased WASO was associated with increased total number of symptoms only, suggesting disturbed sleep with heightened symptoms and potentially being reason for increased time in bed with increased total symptoms. Subjective sleep quality, SE, WASO, SOL, bedtime and waketime were not influenced by day of the menstrual cycle. Subjective sleep quality, SE and SOL were also unaffected by total number of symptoms. The findings suggest some aspects of sleep are associated with menstrual symptoms in football players, but the effect may differ to the general population as sleep quality was not affected by symptoms in this study (Jeon & Baek, 2023). Nevertheless, the study only analysed one menstrual cycle per player and did not take into consideration match or training schedules which may have influenced the findings. Given this is the first study to explore menstrual symptoms in relation to athlete sleep, further research is required to support these findings. Therefore, the final study of this thesis (Study 4) will explore the relationship of menstrual cycle phase and symptoms with objective and subjective measures of sleep around matches.

The relationship between the menstrual cycle and sleep for athletic populations remains largely unknown, despite the importance of sleep to athletic performance and recovery (Fullagar et al., 2015b; Walsh et al., 2021). The mixed quality of results and lack of studies assessing objective sleep measures across the menstrual cycle in relation to phase and symptoms for athletic populations warrants further research. This is particularly an issue as sleep may be reduced in the nights before and after matches due to the stress of performance expectations (cognitive arousal), late evening/night match schedules (cognitive and physiological arousal) and unfamiliar environments for away matches (Nedelec et al., 2018). Exploring whether sleep fluctuates across the menstrual cycle around competition would therefore be beneficial to understanding the menstrual cycle's effects on match preparation and recovery.

2.8 State of the literature: menstrual cycle association with health, performance, recovery and sleep in football

Research on menstrual health and influence of the menstrual cycle on performance, recovery and sleep of football players is equivocal and warrants further investigation. A growing body of studies have explored components of football player menstrual health, symptomatology and perceived effects on performance (Dasa et al., 2024; Dupuit et al., 2023; Ling et al., 2023; Matsumoto et al., 2023; Mkumbuzi et al., 2021; Molnár et al., 2016; Parker et al., 2022; Pinel et al., 2022; Prather et al., 2016; Read et al., 2021). However, the findings are highly variable, and likely attributable to differences in football demographics (e.g., competition level, age, sociocultural factors) and methodologies (e.g., surveys vs interviews, types of questionnaires). Regardless, menstrual abnormalities can lead to harmful health and athletic performance consequences, which in combination with the lack of generalisable football player menstrual health findings, necessitates the need to explore, and improve our understanding of, the menstrual health of football players within the Australian context where this thesis is based. The mixed findings also extend to research on the menstrual symptoms experienced by, and negative perceptions of the menstrual cycle on performance, for footballers. Given the wide-ranging prevalence of menstrual abnormalities, menstrual symptoms and perceived negative influence of the menstrual cycle on performance for football players, applying the current findings to other football populations is challenging. As such, multi-club research with sufficient sample sizes specific to footballers within Australia is presented within Study 1 (Chapter 3) of this thesis.

Only two studies have examined the effect of menstrual phase on football match running with contrasting findings, though the classification of menstrual phases and speed thresholds assessed differed, making comparisons difficult (Igonin et al., 2022; Julian et al., 2020). Further, no studies have examined the influence of menstrual symptoms on football match running. A systematic review suggests potential negative effects of early-follicular phase on physical performance (McNulty et al., 2020), though acknowledge the variability in the measured outcomes, participant demographics, methodologies and research findings, in addition to lack of high-quality research. Additionally, given the potentially high number of football players reporting menstrual symptoms (Parker et al., 2022; Read et al., 2021), high prevalence of abnormal menstrual hormonal profiles in exercising women (De Souza et al., 2009), and ease of monitoring symptoms compared to menstrual phase, the influence of menstrual symptoms on football match running should be assessed. Hence, future research is needed to confirm the influence of menstrual phase on football match running, and explore whether menstrual symptoms affects match running given the perceived influence of menstrual symptoms on athletic performance.

Study 2 (Chapter 4) of this thesis will build upon previous research by using urinary hormonal testing to improve classification of menstrual phases measured concurrently to football match running, with the addition of monitoring players' self-reported menstrual symptoms.

Studies assessing the relationship between menstrual phase and perceptual responses in football, such as perceived fatigue and soreness, are scarce and have relied on calendar-based estimations of menstrual phase (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024), necessitating future research with more robust menstrual phase estimation methods, which will be achieved in Study 3 (Chapter 5) of this thesis. To date, no studies have examined the influence of menstrual phase on post-match recovery kinetics as indicated by the change in perceptual markers, which be explored within Study 3 (Chapter 5). A systematic review suggests recovery, as indicated by delayed onset muscle soreness and strength losses, may be delayed during the early-follicular phase (Romero-Parra et al., 2021). However, there are concerns regarding the quality of studies included within the review (e.g., lack of sex hormone analyses) as well as the review methods (e.g., inclusion of studies examining only one menstrual phase), introducing uncertainty in the conclusions. Accordingly, future research is needed to examine the relationship between menstrual phase, perceptual responses (e.g., fatigue) and recovery of perceptual responses for athletes, including following football matches. Study 3 (Chapter 5) will employ more robust methods of menstrual phase tracking (i.e., urinary LH and PdG testing) whilst simultaneously measuring player's perceptual fatigue, soreness, stress, sleep and perceived recovery status around football matches.

Lastly, only one study has explored the relationship between menstrual symptoms and sleep in footballers (Halson et al., 2024), though the influence of menstrual phase was not explored, nor was sleep specifically examined around matches. General population research suggests a negative influence of symptoms on sleep, particularly subjective sleep quality, though the influence of menstrual phase on sleep is less clear (Alzueta & Baker, 2023). Combining the importance of sleep to prepare for and recover from matches for football players with the potential negative influence of the menstrual cycle on sleep, further research exploring whether menstrual phases and symptoms are associated with footballers' sleep around matches is required. Study 4 (Chapter 6) will aim to address this gap by examining the relationship between menstrual phase, menstrual symptoms and sleep amongst footballers, with a specific focus on sleep around matches.

With respect to football specific research, very limited research exists on menstrual cycle phase and symptoms effects on match running, perceptual responses, post-match recovery and sleep. Understanding the menstrual health of football players and changes in football performance, recovery and sleep across phases and in relation to menstrual symptoms can guide future menstrual screening processes, monitoring strategies and interventions to target potential negative effects of the menstrual cycle.

Chapter 3: Study 1

Self-Reported Menstrual Health, Symptomatology, and Perceived Effects of the Menstrual Cycle for Elite Junior and Senior Football Players

As based on the publication:

Brown, G. A., Jones, M., Cole, B., Shawdon, A., & Duffield, R. (2024). Self-Reported Menstrual Health, Symptomatology, and Perceived Effects of the Menstrual Cycle for Elite Junior and Senior Football Players. *International Journal of Sports Physiology and Performance*, 19(10), 1012-2020

3.1 Abstract:

Purpose: To describe the self-reported menstrual health, symptomatology and perceived effects of the menstrual cycle on athletic performance for national and international Australian football (soccer) players.

Methods: Players from national and domestic teams were invited to complete an online questionnaire regarding menstrual health, HC use, negative symptomatology and perceived disruption of the menstrual cycle to performance. Descriptive statistics and binomial regressions with Odds Ratios (OR) were used to report the relationship of menstrual-related variables with perceived performance disruption.

Results: One hundred and ninety-nine players (20.9 ± 5.1y) completed the questionnaire, with 18% of players reported using HCs. One primary amenorrhea case was detected, whilst 26% of players reported menarche age ≥15y. For non-HC users, prevalence of secondary amenorrhea was 2%, oligomenorrhea 19% and HMB 11%. Ninety-seven percent of players reported experiencing physical or affective menstrual symptoms (5 ± 1.3/player). Forty percent of all players reported menstrual symptoms impacted their ability to work, study, train or compete. Further, 40% of players perceived their training or performance to be disrupted by the menstrual cycle. Increasing number of menstrual symptoms (OR = 1.43; 95% CI 1.28 - 1.62; $p < 0.001$), HMB (OR = 12.73; 95% CI 3.4 - 82.8; $p < 0.001$) and pelvic pain (OR = 3.40; 95% CI 1.7 - 7.2; $p < 0.001$) increased the likelihood of perceiving the menstrual cycle to disrupt performance.

Conclusions: Heavy menstrual bleeding prevalence and HC use was low amongst this cohort of national and international footballers, whilst amenorrhea and oligomenorrhoea were comparable to other football populations. Nearly all players reported menstrual symptoms, and increased symptomatology was associated with greater perceived effects on performance.

3.2 Introduction

The menstrual cycle is highly individual, with inter- and intra-variability in cycle length, phase durations, bleeding patterns, symptoms and conditions (Bruinvels et al., 2022; Elliott-Sale et al., 2021). Given the extensive training and match schedules of professional football (soccer), players may be in any menstrual phase for any given training or match, and still be expected to perform. Improved understanding of menstrual health, symptomatology and perceptions of how the menstrual cycle affects training and performance is needed to provide support for players. For example, menstrual abnormalities such as oligomenorrhea and amenorrhea are frequently experienced by exercising women (De Souza et al., 2009), however the prevalence of other menstrual abnormalities, such as HMB, also referred to as menorrhagia, remains relatively unknown in athletic populations. Further, menstrual symptoms (e.g., cramps and mood changes) are also commonly experienced, though menstrual symptomatology in relation to athletic performance remains equivocal. Moreover, the number of athletes who perceive a negative impact of the menstrual cycle on performance varies between studies (Taim et al., 2023), likely due to contextual and methodological differences to capture the athlete's experiences. At present, the menstrual health and perceived effects of the menstrual cycle of elite football players in Australia remains unknown, and warrants an understanding given the potential negative effect of the menstrual cycle on athlete health, wellbeing and performance.

Menstrual abnormalities cover a broad array of conditions, of which oligomenorrhea, amenorrhea and HMB are classified as abnormal uterine bleeding ("Practice Bulletin No. 128: Diagnosis of Abnormal Uterine Bleeding in Reproductive-Aged Women," 2012). Oligomenorrhea and amenorrhea, associated with bleeding frequency, can be a consequence of low energy availability (LEA) and/or stress, resulting in functional-hypothalamic-amenorrhea (Gordon et al., 2017). Athletes experiencing functional-hypothalamic-amenorrhea are at increased risk of bone stress injuries, reduced training adaptations and many other negative health and performance consequences (Mountjoy et al., 2023). Often athletes are unaware of the risks that prolonged cycles and absence of menstruation incur, especially given the normalisation of amenorrhea in such populations (Verhoef et al., 2021). In Australia, 9% of recreational to national-level athletes (primarily team and individual land-based sports) reported not having periods, and a further 17% reported irregular periods (Armour et al., 2020), though reports for football in Australia remain scant. Further, HMB as related to menstrual flow and duration, can result in iron deficiency, anaemia and reduced endurance performance (Bruinvels et al., 2016), as well as decreased athlete wellbeing (Vannuccini et al., 2020). For example, of 33 elite runners with HMB, 67% self-reported a negative effect on their performance, whilst only 42% sought medical help (Bruinvels et al., 2016). Given the impact of menstrual dysfunction on athlete health and performance, understanding the prevalence of these conditions in footballers may help guide education strategies.

Menstrual-related symptoms are common, with 74 - 93% of athletes reporting predominantly negative perceptions of symptoms (Armour et al., 2020; Martin et al., 2018; McNamara et al., 2022; Parker et al., 2022). The most common physical symptom amongst athletes is abdominal cramping, whilst psychological symptoms, such mood changes and anxiety are also prevalent (Taim et al., 2023). Symptoms frequently occur during the premenstrual and menstrual phases, often associated with progesterone withdrawal (Bruinvels et al., 2022). This is supported by professional footballers reporting symptoms in the first few days of (59%), and lead up to (17%), menstruation

(Parker et al., 2022). Physical symptoms are reported as the greatest menstrual related barrier to playing football for amateur footballers (Pinel et al., 2022), whilst 4 - 13% of players in the English women's professional league reported missing training or matches due to high symptom severity (Parker et al., 2022; Read et al., 2021). Further, athletes reporting greater than three symptoms are twice as likely to report their performance being affected by their menstrual cycle (McNamara et al., 2022). Despite the high occurrence and severity of menstrual symptoms, research surrounding menstrual symptoms influence on training and performance is lacking (Bruinvels et al., 2022).

Athletes often report the menstrual cycle to negatively impact their training and/or performance, though perceptions are mixed. For example, 100% (n = 10) of interviewed Women's Super League (Read et al., 2021), and 29% (n = 12) of surveyed South African national team (Mkumbuzi et al., 2021) footballers reported a negative effect. Such findings reveal contextual and methodological differences, necessitating research amongst additional football populations. Of those reporting a negative effect, menstruation, or just prior to menstruation, are perceived as the most disruptive phases (Armour et al., 2020; Read et al., 2021). This is perhaps unsurprising given the aforementioned prevalence of negative symptoms experienced by athletes. Further, a systematic review and meta-analysis found exercise performance may be trivially reduced during the early follicular phase (menstruation), though the studies were primarily rated as low quality and large variability existed between study findings (McNulty et al., 2020). In fact, some athletes utilise HCs to control their cycle to avoid menstruating during competition, amongst various other uses (McNamara et al., 2022). Prevalence of HC use amongst footballers differs between studies (10% South African (Mkumbuzi et al., 2021) vs 28% Women's Super League players (Parker et al., 2022)) as might the reasons for and types of HCs, potentially highlighting sociocultural differences. Understanding athlete's perceived impact of the menstrual cycle and HC use will aid player care within their specific sporting environments.

To help optimise the health and performance of female football players, specific female considerations, such as the menstrual cycle, require attention. The aim of this study was to describe the 1) menstrual health, 2) menstrual symptomatology and 3) perceived effects of the menstrual cycle for elite football players in Australia.

3.3 Methods

Participants

International and national female football players from a Federation's national teams (youth and senior, Tier 3 and 4 (McKay et al., 2022)) and domestic first tier professional league (Tier 3 (McKay et al., 2022)) were invited to participate in the study. A total of 199 players (age 20.9 ± 5.1 years [13-42 years]) from the national teams (n = 127, 19.5 ± 4.5 years) and domestic league (n = 72, 23.4 ± 5.3 years) completed the questionnaire (Figure 3.1).

Study Overview

Players in the national team were asked by support staff to complete a menstrual health questionnaire (Appendix F) on the National Federation's athlete management system phone application (Smartabase, Fusion Sport, Brisbane, Australia) whilst in camp every three months between March 2022 and February 2023. The data was identifiable by the national team's sports medicine staff only for screening purposes, though was de-identified prior to downloading for the research. For players with multiple responses, only their first response was included in the dataset (Figure 3.1). The questionnaire was re-created on Jotform (San Francisco, United States) and an online weblink was sent by the research team to the domestic league doctors and high-performance staff to share with their players to anonymously complete during the 2022/23 season. All domestic league player responses were downloaded and merged with the national team dataset. Due to the potential cross-over between players in the national teams and domestic league, repeated responses (responses from the same individual) were identified and removed based on club, age and age of menarche (Figure 3.1). Ethical approval was provided by the institutional Human Research Ethics Committee (ETH22-7624).

Menstrual health questionnaire

The menstrual health questionnaire (Appendix F) was developed based on previous questionnaires (Armour et al., 2020; Bruinvels et al., 2021; Fraser et al., 2015; Nnoaham et al., 2009) and in consultation with the Federation's national team doctors given no validated questionnaire existed. The questionnaire included 4 sections as follows [number of answers available]:

(1) Age (open ended), first period (yes/no).

(2) Age of menarche, diagnosed menstrual conditions (multiple-choice [6]) and negative menstrual symptoms (multiple-choice [18]) (Bruinvels et al., 2021), HC use (yes/no).

(3a) HC type (single-choice [7]), duration of use (open ended), reason for use (multiple-choice [10]) and side effects (yes/no, and open ended).

(3b) Timing of last period (single-choice [3]), menstrual cycle length (open ended and yes/no), duration (open ended), HMB (multiple-choice [4]), intermenstrual spotting (yes/no).

(4) Perceived disruption of the menstrual cycle to training and performance (yes/no), timing of perceived disruption (multiple-choice [4]), aspects of performance disrupted (multiple-choice[9]).

Sections 3a and 3b pertained to the previous 3 months, whilst no time-period was specified for the remaining questions.

The survey was setup with logic to ensure players answered relevant questions only. Section (1) of the questionnaire was used to detect primary amenorrhea. All players who answered Yes to having had a first period were directed to section (2) of the questionnaire. At the end of section (2), players were asked about HC use in the previous three months, as up to three months is required to re-establish eumenorrhea/a regular cycle following HC-use (Elliott-Sale et al., 2021). Players who answered Yes to HC use in the previous three months were directed to section (3a), and those who answered No were directed to section (3b). Section (3b) commenced by asking when a player's last period was (<3 months ago, 4-5 months ago, >6 months ago), where only those selected <3 months ago completed the remaining questions in section (3b). All players, except those identified as having primary amenorrhea in section 1, finished the questionnaire by completing section 4.

Questionnaire completion was 100% i.e., no questions were left unanswered by any players. However, invalid responses were received for some open-ended questions, and removed prior to analysis. For example, players were asked their average menstrual cycle length in days (from the start of 1 period until the day before the start of the next), and any response <14 was deemed invalid ie. players reporting in weeks.

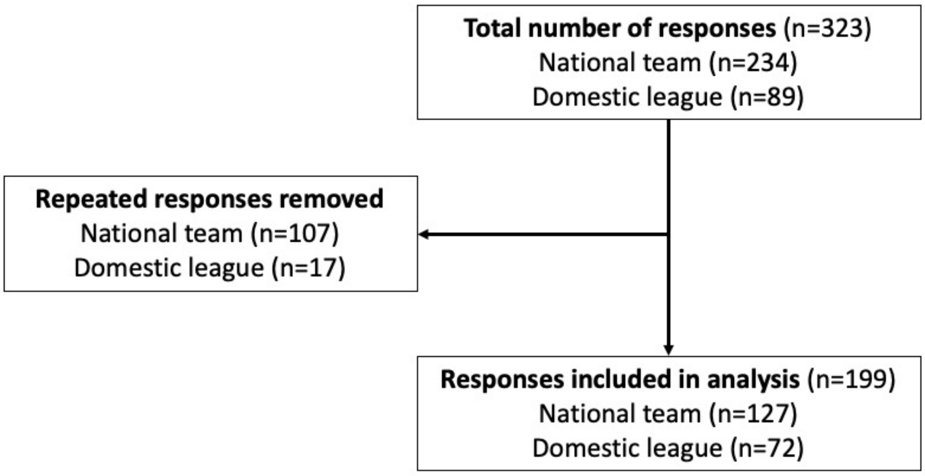

Figure 3.1 Flow chart of total and included questionnaire responses.

In reporting menstrual dysfunction outcomes, it is noted the terminology and definitions that currently exist vary within the literature (Taim et al., 2023). The following terminology was used based on the Australian Institute of Sport and American College of Obstetricians and Gynecologists ("Practice Bulletin No. 128: Diagnosis of Abnormal Uterine Bleeding in Reproductive-Aged Women," 2012):

1. Primary amenorrhea: no period by age 15.
2. Secondary amenorrhea: absence of menstruation for three months or more.
3. Oligomenorrhea: irregular cycles and menstrual cycle length >35 days.
4. HMB (menorrhagia): determined by experiencing two or more of the following (Fraser et al., 2015) (1) pass large blood clots, (2) flood through clothes, (3) bleeding more than 7 days, (4) changing of sanitary items (tampons or pads) every 2 h or 12 sanitary items per day.
5. Intermenstrual bleeding (metrorrhagia): spotting between periods.

Statistical Analysis

Data were imported into R Statistical Software (R Core Team 2020) for analyses. To test the effect of HC use on number of symptoms whilst controlling for age a Poisson regression was performed with HC use and age as fixed effects. Overdispersion was detected, thus a quassi-poisson regression was performed. Normality was checked via residuals plot. To determine the influence of age, HC use, menstruating days, HMB, intermenstrual spotting, endometriosis, pelvic pain and number of symptoms on perceived training and performance disruption, binomial regressions were performed using the glm function with a binomial family. Linearity of logit was tested for binomial regressions with continuous independent factors by visually inspecting partial residual plots using the crPlots function. To determine the combined effect of individual factors found to have a significant effect on performance disruption, a binomial regression was performed and variation inflation factor (<2.5) (Menard, 1995) checked to ensure no multicollinearity between variables. Linearity of logit was not performed on this regression due to inclusion of categorical fixed effects. Significance was set at $p<0.05$ and 95% confidence intervals (CI) were determined for all regression models. Binary data are presented as frequencies and percentages. Count data are presented as means (± standard deviations [SD]) for normally distributed data, and medians (interquartile range [IQR]) for non-normally distributed data, with ranges.

3.4 Results

Menstrual characteristics and abnormalities

Table 3.1 shows the menstrual characteristics of, and menstrual abnormalities experienced by, all players including HC and non-HC users.

Menstrual symptomatology

One or more negative menstrual symptom(s) was experienced by 97% (192/198) of players (Figure 3.2), with no difference between HC and non-HC users ($p = 0.919$). Pelvic pain was the most frequently selected symptom (71%, 141/198), followed by mood changes/anxiety (58%, 114/1198) and tiredness/fatigue (56%, 110/198). Forty one percent of players (81/198) experienced pelvic pain every cycle and 30% of players (60/198) some cycles. The median number of symptoms experienced per player was 5 [IQR 3 - 7], ranging from 0 to 18. Of the 192 players who reported a menstrual symptom, 40% (76/192) reported these symptom(s) interfered with their general ability to work, study, training and/or compete.

Table 3.1 Menstrual characteristics, abnormalities and menstrual related conditions for hormonal and non-hormonal contraceptive users

	Mean ± SD or Median [IQR], (range)	N	Percentage (%)
All players			
Age of menarche (years)	13.5 ± 1.6 (10-18)		
Primary amenorrhoea cases		1/199	0.5
Past primary amenorrhea cases (menarche age 15y)		51/198	26
Self-reported menarche age 15y		31/198	16
Self-reported menarche age ≥16y		20/198	10
Self-reported polycystic ovary syndrome		6/198	3
Self-reported endometriosis		4/198	2
Non-hormonal contraceptive users		163/198	82
Secondary amenorrhoea cases		3/163	2
Oligomenorrhea		24/125	19
Menstrual cycle length (days)	28 [27-30] (18-90)		
Menstruating (bleeding) days	5 ± 1.3 (1-9)		
Heavy menstrual bleeding		17/160	11
Intermenstrual spotting		13/160	8
Hormonal contraceptive users		35/198	18
Type			
Oral contraceptive pill		28/35	80
OCP - Combined pill		21/28	75
OCP - Progestin only pill		2/28	7
OCP - “Unsure”		5/28	18
Hormonal IUD		5/35	14
Hormonal implant		2/35	6
HC side effects experienced		11/35	31

Table 3.1 continued

Reasons for HC use		
Contraception	20/35	57
Reduce period pain	16/35	29
Skip or shift period	13/35	37
Reduce heaviness of bleeding	10/35	29
Make cycle more regular	8/35	23
Acne/skin problems	5/35	14
“Other” reasons	5/35	14
Reduce emotional changes	4/35	11
Reduce other PMS symptoms	4/35	11
Prescribed by doctor due to absence of menstruation	0/35	0

Percentage refers to proportion of group indicated by numerator and denominator in column N.
OCP= oral contraceptive pill; IUD= intrauterine device; PMS= premenstrual syndrome

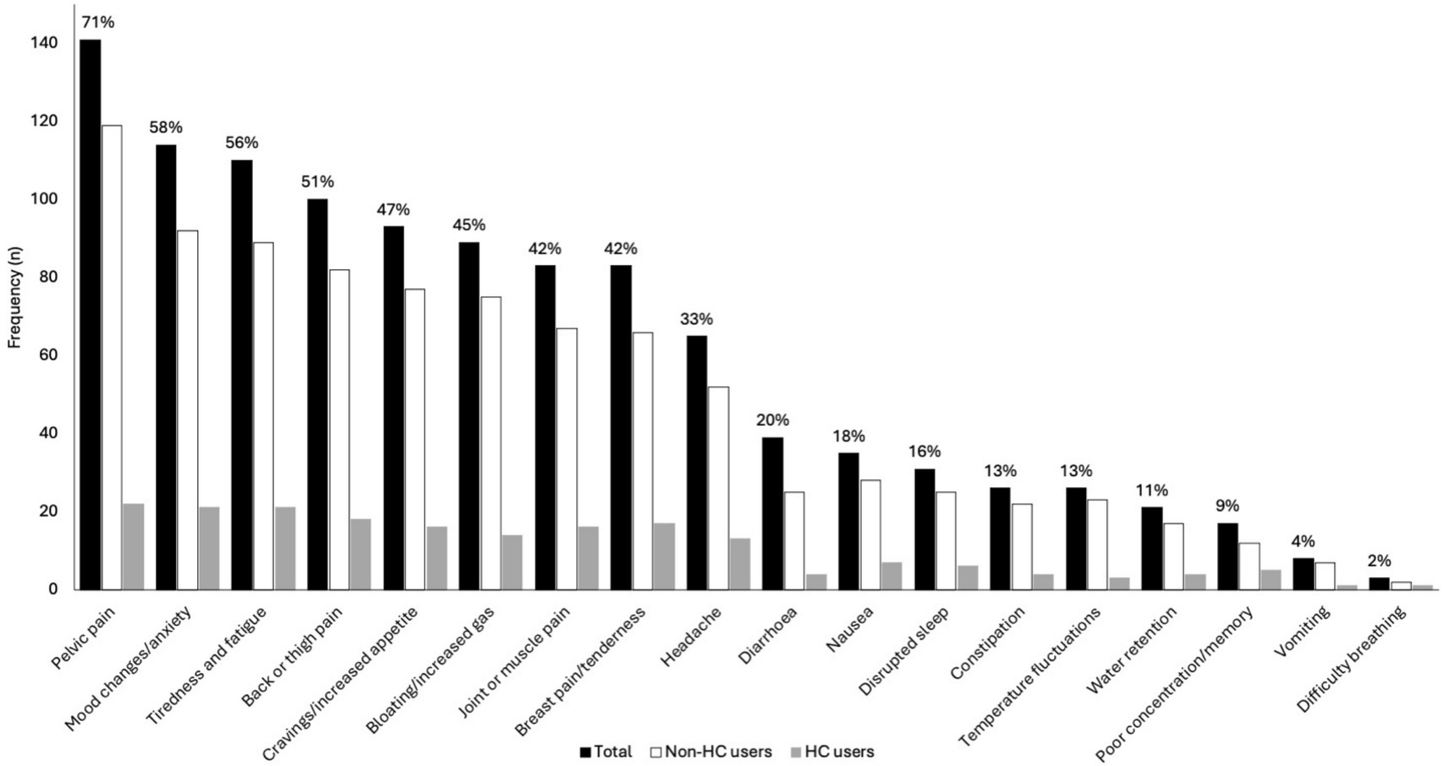

Figure 3.2 Self-reported menstrual symptoms.

% calculated from number of players who selected 1 or more symptom (n=192).

All symptoms listed in the questionnaire are included in the figure. Non-HC users = non-hormonal contraceptive users; HC users = hormonal contraceptive users

Performance disruption

Forty percent of players (79/198) perceived their training and performance to be disrupted by their menstrual cycle. Figure 3.3 shows the timing and aspects of perceived performance disruption. Players most frequently reported "whilst menstruating" as the time of perceived disruption to training and performance (89%, 70/79). Of those who perceived the menstrual cycle to disrupt training and performance, 87% (69/79) reported reduced energy levels as an aspect of performance disruption. Player age, HC use, menstruating days, intermenstrual spotting, and self-reported endometriosis did not affect perceived training and performance disruption ($p > 0.05$). Number of symptoms (OR = 1.43; CI 1.28 - 1.62; $p < 0.001$), pelvic pain (OR = 3.40; CI 1.7 - 7.2; $p < 0.001$) and HMB (OR = 12.73; CI 3.4 - 82.8; $p < 0.001$) all had a significant effect on perceived training and performance disruption. When the combined effect was assessed (perceived training and performance disruption ~ number of symptoms + pelvic pain + HMB), only number of symptoms had a significant effect ($p < 0.001$).

3.5 Discussion

This study describes the menstrual health, symptomatology and perceived effects of the menstrual cycle on performance for elite junior and senior footballers in Australia. The self-reported prevalence of HC use was relatively low, as was abnormal uterine bleeding. Nearly all players experienced at least one menstrual symptom, and a strong association existed between the number of symptoms experienced and perception of the menstrual cycle disrupting performance. Currently, this is the largest menstrual health survey conducted in a single sport for elite athletes and practitioners can use this information to guide menstrual health screening, cycle monitoring and education-focussed strategies.

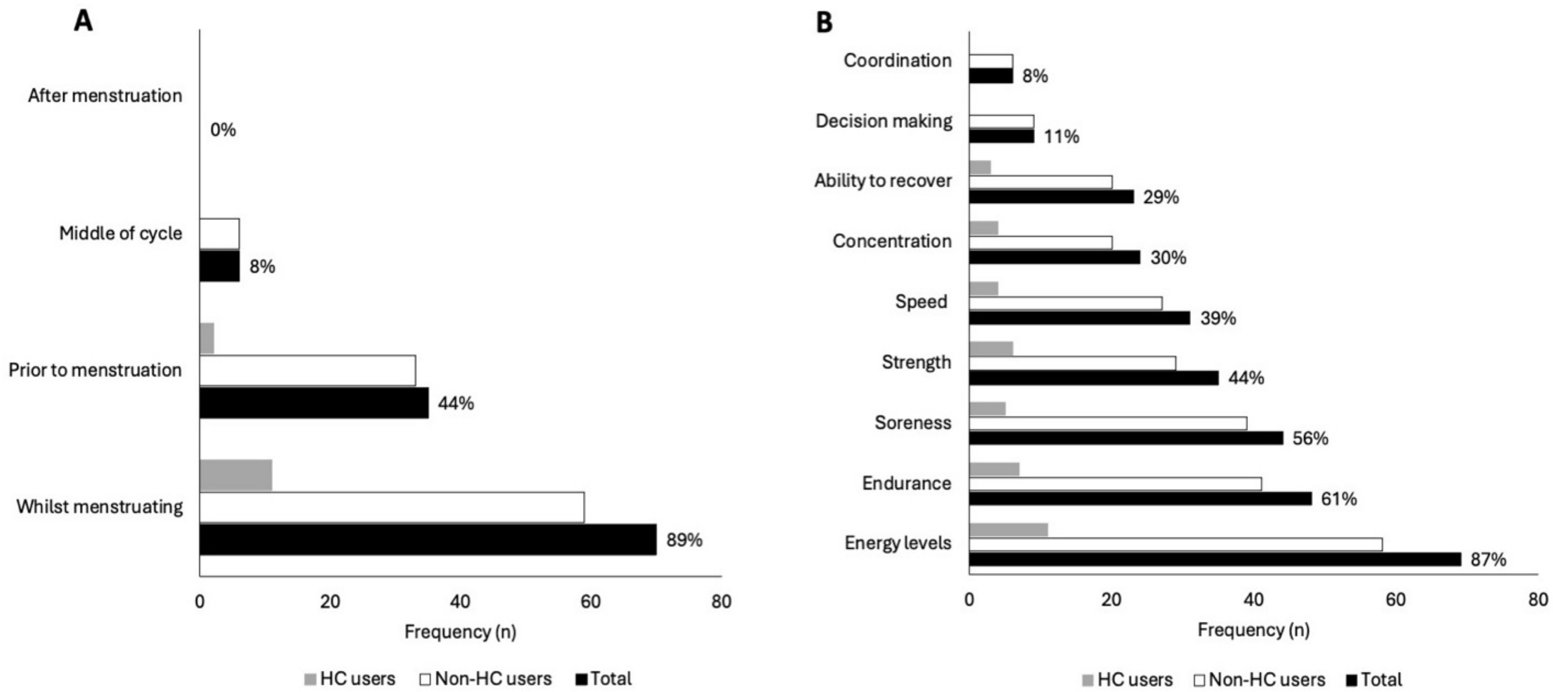

Figure 3.3 Perceived (A) timing and (B) aspects of performance disrupted by the menstrual cycle.

% calculated from number of players who perceive disruption to training or performance (n=79). Non-HC users = non-hormonal contraceptive users; HC users = hormonal contraceptive users.

Hormonal contraceptives are frequently used by athletes to manage menstrual symptoms and period timing (Pinel et al., 2022). Similar to previous research, key reasons for HC use were reducing period pain, reducing heaviness of bleeding and controlling cycles (e.g., avoiding menstruation during competition), alongside contraception (Clarke et al., 2021; McNamara et al., 2022; Oxfeldt et al., 2020). A systematic review and meta-analysis found oral contraceptives may slightly reduce exercise performance compared to non-use, although large variability and trivial effects existed across studies (Elliott-Sale et al., 2020). The benefits of menstrual cycle management may outweigh the negative trivial effects of HC use on performance, though HCs may also cause negative side-effects as reported by 30% of HC users in our study. Thus, an individualised approach to HC use is recommended (Elliott-Sale et al., 2020; Martin et al., 2018). A low prevalence rate of HC use was evident (18%), compared to professional footballers and Australian athletes (28 - 58%) (Clarke et al., 2021; Larsen et al., 2020; Martin et al., 2018; McNamara et al., 2022; Parker et al., 2022), though higher than South African National Team footballers (10%) (Mkumbuzi et al., 2021). Differences may be attributed to the sport, sociocultural or geographical norms. Similar to other athletic populations (Clarke et al., 2021; Larsen et al., 2020; Martin et al., 2018; Parker et al., 2022), oral contraceptive pill was the most common HC type (80%) and combined pill (contains oestrogen and progesterone) was the most common form (75%). Understanding the reasons for HC use, side effects and type may help minimise negative effects and maximise positive effects of HCs amongst footballers.

A low number of self-reported primary amenorrhea (n = 1) cases were detected, though 26% of players reported age of menarche >15y, suggesting an increased percentage of players previously experienced primary amenorrhea. The mean pooled prevalence of primary amenorrhea in athlete studies is 7%, with 0% reported amongst team sports, including football (Taim et al., 2023). Similar proportions (23%) of elite Australian athletes from other football codes also reported age of menarche >15y (Clarke et al., 2021). Further, whilst menstrual cycle length (28 [27-30days]) for non-HC using players was within normal ranges (21-35 days), 19% of non-HC users reported irregular cycles or an average menstrual cycle length >35 days (oligomenorrhea) and 1.5% had secondary amenorrhea (n = 3). The oligomenorrhea prevalence is similar to Australian athletes from other football codes (17%, 21/124) (Armour et al., 2020), UK professional footballers (15%, 8/54) (Parker et al., 2022), and Olympic and Paralympic athletes (23%, 46/195) (McNamara et al., 2022). Lower prevalence of secondary amenorrhea existed compared to UK professional players (8%, n = 6) (Parker et al., 2022) though the prevalence of oligomenorrhea was higher (19% vs 11%), which may be attributed to the "snapshot" nature of questionnaires. Indeed whilst a few players reported having had their period in the previous 3 months, "irregular" was selected for menstrual length with comments such as "sometimes 6 weeks sometimes 12 weeks". Emphasising the importance of this knowledge is the fact that in athletes, oligomenorrhea and amenorrhea may be a sign and symptom of REDs, where problematic low energy availability places athletes at risk of many health and performance consequences (Mountjoy et al., 2023). The low prevalence of primary and secondary amenorrhea in this population is reassuring, perhaps demonstrating a reduced impact of these conditions in elite football populations compared to other athletic populations. Regardless of case numbers the severity of amenorrhea, and percentage of oligomenorrhea justifies encouragement of menstrual monitoring and menstrual health education amongst football players.

Heavy menstrual bleeding, associated with increased menstrual flow volume and duration, is a uterine bleeding menstrual abnormality that may negatively impact athletes (Fraser et al., 2015), and remains under-reported in research compared to oligomenorrhea and amenorrhea. The prevalence of HMB amongst non-HC users in our study (11%) was lower than other athletic populations (18 - 37%) (Bruinvels et al., 2016; McNamara et al., 2022; Oxfeldt et al., 2020), though differences in HMB definitions/classification criteria exist, and inclusion of HC users in some studies makes direct comparisons challenging. The criteria we used (see Menstrual health questionnaire section) was from a large European study (Fraser et al., 2015), and in alignment with a previous athlete HMB study (Bruinvels et al., 2016). Had a less strict criteria (one HMB symptom instead of two) been employed, a higher HMB prevalence (41% vs 11%) would've been reported, highlighting the need for standardisation of HMB classification. Heavy menstrual bleeding may negatively affect performance, as perceived by 67% of elite runners with self-reported HMB (Bruinvels et al., 2016). For example, HMB is associated with fatigue-related symptoms (Armour et al., 2020), anaemia and iron deficiency (Bruinvels et al., 2016); all of which have been shown to reduce physical performance, particularly endurance performance (Bruinvels et al., 2016). Heavy flow can decrease time to exhaustion (de Carvalho et al., 2023), though no studies of HMB effects on physical performance for athletes exist. Poorer mental quality of life and higher perceived stress (Vannuccini et al., 2020) are also associated with HMB, stressing the negative impact on athlete wellbeing. Concerns about "flooding through" clothes and "wearing white shorts" can cause distraction and worry amongst athletes (Findlay et al., 2020), adding to potential performance effects, though HMB effects were not assessed in our study. Given the potential negative effects of HMB on athlete psychophysiological health and performance, further research on its effects for football players would be beneficial.

Nearly all players (97%) reported experiencing one or more negative menstrual symptoms. A similar prevalence has been reported in Olympic and Paralympic athletes (93%) (McNamara et al., 2022), though our results are higher than other Australian athletes (83%) (Armour et al., 2020) and English professional league footballers (74%) (Parker et al., 2022), which may be attributed to the larger number of symptoms to select from here (18 vs 9) (Parker et al., 2022). Most reported symptoms were pelvic pain (71%), mood changes/anxiety (58%), tiredness and fatigue (56%) and back / thigh pain (51%). The presence of physical, mental, and behavioural symptoms suggests that a multidisciplinary approach to symptom management may be required. We did not assess dysmenorrhea, which is painful menstruation primarily associated with pelvic pain (Taim et al., 2023). Instead, we investigated the burden of all menstrual symptoms, given the debilitating nature of some menstrual symptoms not exclusive to pelvic pain, thus providing a holistic indicator of symptoms impact. Athletes may experience positive effects of the menstrual cycle (Armour et al., 2020), though we did not explore these which may be a limitation. Forty percent of players reported symptoms interfered with their ability to study, work or train/play. Whilst the intensity and frequency of symptoms was not surveyed, the average number of symptoms experienced (5 ± 1.3/player) and reported interference to daily living (40%) provides an indication of menstrual symptom burden. As our study is cross-sectional, encouraging players to track symptoms (and severity) longitudinally may be beneficial for further education and management (Bruinvels et al., 2016).

The menstrual cycle was perceived to disrupt training and performance by 40% of players. The percentage of players perceiving a negative effect of the menstrual cycle on training and performance is mixed in football populations (29 - 100%) (Mkumbuzi et al., 2021; Pinel et al., 2022; Read et al., 2021), likely attributed to sociocultural and competition level differences. Methodological differences also existed between these studies (i.e., questionnaires vs interviews), and had smaller sample sizes (n = 15 - 127) than our study (n = 199). The perceived timing of effects is consistent between studies (Armour et al., 2020); menstruation is the most frequently perceived disruptive phase, followed by just prior to menstruation. This may be due to increased menstrual symptoms during these times, which is supported by a higher number of symptoms, including pelvic pain, being associated with an increased likelihood of perceived performance disruption in our study. Heavy menstrual bleeding was also associated with a perceived performance disruption, in alignment with previous elite athlete research (Bruinvels et al., 2016) and providing further support for "whilst menstruating" being the most disruptive menstrual cycle phase. Similarities exist between our study and previous reports on aspects of performance disruption (Read et al., 2021). Physical impacts of the menstrual cycle on football performance are predominant, however psychological (concentration), tactical (decision making), skill (coordination) and recovery (soreness, ability to recovery) were selected by players within this study (Figure 3.3), though other perceived performance impacts could exist given a closed-ended question was implemented. Most research has focussed on menstrual phase effects on performance, associated with the idea that hormonal fluctuations affect physical capacities (Bernstein & Behringer, 2023; McNulty et al., 2020), though findings are equivocal (McNulty et al., 2020), due to methodological and classification concerns. The mixed research outcomes and player perceptions, including aspects and timing of performance disrupted by the menstrual cycle, suggest an individualised approach to menstrual related management for players.

There are several limitations within this study. A partial response bias likely exists as completion was voluntary for domestic players, so those with menstrual health conditions, or who felt their menstrual cycle affected them, may have been more inclined to participate. In contrast, players without a period (i.e., amenorrhea) may not have deemed the survey relevant to them, thus the prevalence of primary and secondary amenorrhea could be higher. The varied age (13 - 42y) and competition level (national and/or international level) of players is also a potential limitation introducing participant heterogeneity. Menstrual symptoms were not assessed within a specific timeframe, which could've resulted in differing responses. The questionnaire used was not validated, as no validated questionnaire existed and responses were susceptible to recall bias. Lastly, as discussed, large variability exists between studies limiting the generalisability of our findings, thus practitioners are encouraged to conduct their own menstrual health screening.

3.6 Conclusion

The presence of severe menstrual dysfunction (amenorrhea) in this cohort was low, though a fifth of players were classified as oligomenorrheic. Similarly, the prevalence of HMB was low, though using a less strict criteria resulted in a much higher prevalence. Less than 20% of elite football players within Australia used HCs, and a third of these players experienced HC side effects. Nearly all players experienced menstrual symptoms, with 40% of players lives negatively affected by these symptoms. Lastly, 40% of the surveyed players perceived the menstrual cycle to disrupt their ability to train and perform.

Chapter 4: Study 2

Influence of menstrual phase and symptoms on match running in professional footballers

As based on the publication:

Brown, G. A., & Duffield, R. (2024). Influence of Menstrual Phase and Symptoms on Match Running in Professional Footballers. *Scandinavian Journal of Medicine & Science in Sports, 34*(10), e14734.

4.1 Abstract

Purpose: This study examined the effects of menstrual cycle phases and symptoms on match running performance in football (soccer) players. *Methods:* Twenty-one non-HC using football players from four professional teams were monitored for up to four menstrual cycles during a domestic league season. Menstrual phases, classified as early-follicular, late-follicular and luteal were determined by self-reporting of menstruation and urinary hormone tests (LH and PdG). On match day players completed a Menstrual Symptom Severity (MSS) questionnaire. In repeated matches, players wore 10Hz GPS devices to measure relative (/min) total distance, high-speed running distance, very high-speed distance, peak speed, acceleration count and deceleration count. Linear mixed models were performed for each GPS measure to determine the relationship with phase or symptoms. *Results:* Data for 7 and 10 players were included for menstrual phase and menstrual symptoms analyses respectively. A significantly higher total distance was reported during late-follicular compared to the early-follicular phase (Δ5.1m·min^{-1}; $p = 0.04$) and luteal phase (Δ5.8m·min^{-1}; $p = 0.007$). Significantly greater high-speed running was reported during late-follicular phase compared to early-follicular phase (Δ1.2m·min^{-1}; $p = 0.012$) and luteal phase (Δ1.1m·min^{-1}; $p = 0.007$). No significant effect of menstrual phase was found for any other GPS measures ($p > 0.05$). Accelerations declined with increasing MSS ($p = 0.021$, estimate = -0.01count·min^{-1}). Menstrual symptom severity did not affect any other GPS measures ($p>0.05$).

Conclusion: In conclusion, greater total distance and high-speed running occurred during the late-follicular phase. Additionally, accelerations minimally decreased with increasing MSS. Large intra- and inter-variability existed, suggesting individualised monitoring and management of menstrual effects on performance would be beneficial.

4.2 Introduction

The menstrual cycle is suggested to affect athletic performance, primarily due to the influence of phase-related fluctuations of oestrogen and progesterone concentrations on physiological functions (Bernstein & Behringer, 2023). Further, the proposed influence of menstrual symptoms (e.g., abdominal cramps) on athletic performance has received increasing attention. In football (soccer), many professional players perceive a negative effect of the menstrual cycle on their match performance (Mkumbuzi et al., 2021; Read et al., 2021). Yet despite this, little research exists on the influence of the menstrual cycle on football match running performance. Match running is one part of overall football performance (Griffin et al., 2020), though remains of critical focus for coaching and support staff for professional players. Understanding how the menstrual cycle affects match running performance of female footballers may aid training prescription, periodisation, and match preparation.

The primary roles of the female sex hormones oestrogen and progesterone are to control the menstrual cycle and reproductive function, however, they've also been shown to influence other physiological functions, including skeletal muscle physiology, cardiovascular responses and exercise metabolism (Bernstein & Behringer, 2023). Research on how these effects translate to athletic performance across menstrual phases remains inconclusive (McNulty et al., 2020). Systematic reviews and a meta-analysis found exercise performance may be trivially reduced during the early follicular phase (menstruation) compared to all other phases, though large variation existed between studies and the majority of studies were rated as "poor quality" (McNulty et al., 2020; Meignie et al., 2021). In terms of physical capacities specific to football performance, one study reported improved YoYo Test performance during the early follicular compared to mid-luteal phase (Julian et al., 2017), though another found no difference in footballers of similar playing level (Tounsi et al., 2018). Inconsistencies in the literature make it difficult to ascertain the effect of menstrual phase on physical performance or football match running performance.

Limited field-based studies exist exploring menstrual phase effects on football match running performance. Whilst lab-based studies provide a highly controlled environment, comparing running performance during matches can provide ecologically valid insights. Julian et al. (2020) reported more very-high intensity running per min (individualised threshold ~ 17-20km·h^{-1}) in the luteal than follicular phase for elite football players when comparing the two phases. However, large individual and match variation existed, and comparing two menstrual phases may have masked subphase effects (e.g., follicular phase consists of low hormone (early) and high oestrogen (late) phases). Comparing three menstrual phases, Igonin et al. (2022) found less distance covered at moderate (7-14km.h^{-1}) and high velocities (14-19km.h^{-1}) in the early follicular phase compared to late follicular and mid-luteal phases. These studies demonstrate potential changes in match running performance between menstrual phases. However, during match data collection both studies (Igonin et al., 2022; Julian et al., 2020) estimated menstrual phases via calendar-based counting, a method unable to detect subtle menstrual disturbances such as anovulation and luteal phase deficiency, which display altered hormonal profiles (Schaumberg et al., 2017) and are common in exercising women (De Souza et al., 2009). Thus, research exploring the effect of menstrual phase on football match running is limited and to date has relied on less accurate menstrual phase classification methods (Schaumberg et al., 2017).

Athletes with three or more menstrual symptoms are twice as likely to report being negatively affected by their menstrual cycle (McNamara et al., 2022). Although up to 93% of athletes report experiencing menstrual symptoms (McNamara et al., 2022), research on symptoms effect on athletic performance is scarce (Bruinvels et al., 2022), with no studies related to football match running. Given menstrual symptoms may be monitored more easily than and regardless of a “normal” hormonal profile, this may be useful to professional football populations. For example, 50% of exercising women may experience subtle menstrual disturbances, like anovulation and luteal phase defect, which affect hormone levels (De Souza et al., 2009) and preclude them from the phase-based comparisons (Elliott-Sale et al., 2021). Hence, assessing whether menstrual symptoms affect match running may complement phase-based monitoring to provide a deeper understanding of menstrual cycle effects on performance, alongside more feasible methods of monitoring and managing menstrual-related effects on performance.

To support the physical performance of female football players it’s essential to understand the influence of the menstrual cycle on match running performance. Therefore, the aims of the study were to examine (1) the effects of menstrual cycle phases (early-follicular, late-follicular, luteal) on match running performance and (2) the effects of menstrual symptoms on match running performance. We hypothesised that match running would be reduced during the menstruation phase and with increasing MSS.

4.3 Methods

Participants

Professional female football players from a national first tier league were invited to participate in the study following stipulation of the inclusion criteria: (1) not pregnant,

(2) not using HCs or used in the previous three months, (3) average menstrual cycle in the previous three months was 21 - 35 days, (4) not diagnosed with any illness or disease which disrupts the menstrual cycle (e.g., polycystic ovary syndrome) (Elliott-Sale et al., 2021). Following description of all testing procedures, 32 players consented to participating in the study and completed an online eligibility questionnaire to ensure they met the inclusion criteria. Eleven players were excluded or withdrew prior to study commencement (goalkeepers [n = 4], highly irregular cycles and/or cycle lengths >35days [n = 3], personal reasons [n = 3], season long injury [n = 1]), resulting in 21 players participating in the study. Following strict inclusion criteria (explained throughout the methods), 11 players data was analysed: 7 players (27.7 ± 6.0y, 166.7 ± 5.3cm, 63.3 ± 5.0kg) in the menstrual phase analysis and 10 players (25.6 ± 6.2y, 164.9 ± 5.9cm, 62.8 ± 5.4kg) in the menstrual symptoms analysis. A typical training week for these professional clubs included four to five field sessions, one to two gym sessions and one match. A multi-club, repeated measures design was used to maximise participant numbers and observations given the sample size limitations associated with elite athlete populations (Alexiou & Coutts, 2008), menstrual phase research and the high prevalence of abnormal cycles in exercising women (De Souza et al., 2009), and the field-based nature of the study. Though a small sample size transpired, which should be considered when interpreting the results, we believe this study positively contributes to the emerging body of research. Given the wide geographical spread of clubs involved, communication between the players and lead researchers was via WhatsApp (Facebook, Inc).

Study Overview

To assess changes in football match running in relation to menstrual cycle phase and symptoms, players were monitored for up to four menstrual cycles during the 2022/23 season. Players monitored their menstrual cycle via self-reporting of menstruation and urinary hormonal testing. Players were also asked to complete a Menstrual Symptom Severity questionnaire on the evening after matches and wear their club's GPS devices during matches. Ethical approval was provided by the Institutional Human Research Ethics Committee (ETH22-7106) and written informed consent provided by all players, and parents for players aged 16-17 years.

Menstrual status

Menstrual status was assessed via cycle length and urinary hormonal testing. Prior to commencing hormonal testing, to confirm a normal cycle length (21 – 35 days) the lead researcher contacted players twice a week regarding onset of menses for a minimum of one menstrual cycle. Players were then setup on an online platform, Smartabase (Fusion Sport, Brisbane, Australia) to self-report days of menstruation.

To accurately predict ovulation, players were provided urinary ovulation tests (Clearblue Ovulation Digital Test kits, Geneva, Switzerland) (Godbert et al., 2015; Janse de Jonge, 2003). The tests are 99% effective at detecting a surge in LH (> $40 mlU \cdot mL^{-1}$) (Ellis et al., 2011), which predicts ovulation within 24 – 48 h of a positive test (Miller & Soules, 1996). The LH test start date was calculated by the researcher according to the manufacturers instruction and communicated to players each menstrual cycle. Players were instructed to test daily at approximately the same time, until a positive test was obtained. If players did not receive a positive test after 10 days, the researcher contacted the player to determine whether additional testing days would be beneficial (e.g., in the case of longer cycles, or cycles with more variation), or to instruct the player to stop testing. When a positive test was not detected, the player was deemed to have an anovulatory cycle and only data during their early-follicular phase was retained.

Players who obtained a positive LH test were asked to complete urinary progesterone tests (Confirm Kit, Proov, USA). The at-home tests detect an increase in PdG (> 5µg·mL^{-1}), the urinary metabolite of progesterone, which has been shown to correlate to serum progesterone levels (r = 0.81) (Roos et al., 2015). Players were instructed to test from seven days following a positive LH test, and reminders were sent by the lead researcher. If a positive test was not obtained, only the early-follicular phase data was retained. Players were provided with written and video test instructions for both at home urinary hormone tests and asked to upload a photograph of each test result to Smartabase for visual confirmation by the researcher (Elliott-Sale et al., 2021). The most accurate method of verifying menstrual phase requires confirmation of hormone concentrations via blood samples; however, players trained and played at multiple club locations, therefore serum testing was not possible.

Menstrual phase classification

The menstrual cycle can be classified in up to seven phases (Elliott-Sale et al., 2021) though in the absence of analysing bloods this is not possible to accurately achieve, thus a three-phase model was used (Bruinvels et al., 2022). (1) early-follicular phase - days of menstruation or until day five of each cycle (whichever was longer), where > 2 days of bleeding occurred. (2) late-follicular phase - from the day after the early-follicular phase until one day after a positive LH test. (3) luteal phase - from the day after late-follicular phase until the day prior to the next cycle starting, when a positive PdG test was detected, and the luteal phase was ≥10 days (Schaumberg et al., 2017). If a player did not obtain a positive LH or PdG test, only their early-follicular phase data was retained for that cycle as this continues to be a "low hormone" phase. The three-phase model represents low sex hormones (early-follicular phase), high oestrogen (late-follicular phase), high oestrogen and progesterone (luteal phase) (Bruinvels et al., 2022).

Menstrual symptoms severity

Players completed a Menstrual Symptoms Severity questionnaire on the night of match days. The questionnaire was adapted from the Menstrual Symptoms Index (Bruinvels et al., 2021), which is an online survey to assesses symptom presence and frequency. It is recognised this questionnaire is not psychometrically validated as yet. The questionnaire consisted of 18 physical and psychological menstrual related symptoms (see Bruinvels et al., 2021), which players were asked to rate on a Likert Scale; 0 – none, 1 – mild, 2 – moderate, 3 – severe. Players' daily ratings were summed from 0 (no symptoms) to 54 (maximal number and severity of symptoms) to provide a single MSS score.

Match running

Match running was measured using 10Hz GPS devices, and given the multi-club, multi-city methodology, GPS brands differed between teams (STATSports Apex, Catapult Playertek and Catapult One), though players used the same GPS unit for the entirety of the research period to allow intra-subject comparison. Good inter-unit reliability for distances and maximum speed (CV range and 90% confidence limits: 0.2% ± 1.5 % – 1.5% ± 1.6%) have been reported for 10Hz STATSports and other Catapult devices using manufacturer software (Compton et al., 2018), though reliability of accelerometery counts is unknown. Players and team sport scientists turned on devices under clear sky prior to each match to allow time for satellite connectivity and players wore vests which hold the GPS devices securely between their scapulae. Following each match, data was downloaded and processed by each team's sport scientist using the manufacturer GPS analysis software (Sonra for STATSports, Catapult PlayerTek Online and Catapult One Online). The following measures and thresholds were standardised across teams based on previous research (Andersson et al., 2010; Mara et al., 2017): minutes played, peak speed ($km \cdot h^{-1}$), total distance, high-speed running distance (18-25$km \cdot h^{-1}$) and very high-speed running distance (>25$km \cdot h^{-1}$) (Andersson et al., 2010), number of acceleration and decelerations (>2$m \cdot s^2$) (Mara et al., 2017). To account for differences in minutes played we calculated total distance, high-speed running distance, very high-speed running distance, acceleration count and deceleration count relative to minutes played (i.e., $m.min^{-1}$ and $count.min^{-1}$). Given positional differences exist for match running, playing position for each player was provided by the team's sport scientist as central defence, wide defence, central midfield, wide midfield and forward for each match (Griffin et al., 2020). Excel data files were shared by the team's sport scientist with the researchers via password protected OneDrive folders.

Whilst repeated match observations in all phases across multiple cycles is desirable (Elliott-Sale et al., 2021), due to field-base nature of the study this was not possible. However, to reduce intra-participant variability and increase power, the following criteria were set 1) to be included in the menstrual phase analyses, a minimum of two menstrual phases and two matches per phase per player were required, in addition to the aforementioned menstrual cycle status and phase classification criteria; 2) to be included in the menstrual symptoms analyses, a minimum of two MSS scores aligned with matches per player were required, regardless of menstrual cycle status.

Statistical Analysis

Data (player ID, date, team, GPS, menstrual phase, menstrual symptoms) which met the above inclusion criteria were merged to one excel spreadsheet and imported into R Statistical Software (R Core Team 2020) for analysis. To determine the minimum minutes played required for inclusion in the final dataset, the effect of *minutes played* on match running (total distance, high-speed running distance, very high-speed running distance, peak speed, acceleration count, deceleration count) in this dataset was assessed using linear mixed effect models (lme4 package) with *minutes played* specified as the fixed effect, *player ID* and *position* as random effects, whilst controlling for *GPS brand*. *Player ID* was included to account for repeated measures and non-independence, *position* was included to account for its effect on match running (Griffin et al., 2020) and *GPS brand* was included as a covariate (fixed effect) due to different GPS systems used. Starting with a minimum of 60min playing time, 5min increments were used until the effect of *minutes played* had no effect on any match running variable ($p>0.05$). Hence, ≥70min was used as the minimum inclusion criteria for the final dataset as no effect existed on any relative match running outputs.

To determine the effect of *menstrual phase* and *symptoms*, linear mixed effect models were performed for GPS measures (total distance, high-speed running distance, very high-speed running distance, peak speed, acceleration count, deceleration count) with *player ID* and *position* as random effects, whilst controlling for GPS brand. Separate models were performed for *menstrual phase* and *menstrual symptoms* as the fixed effect due to differing datasets. Homogeneity and normality of residuals were assessed using residuals vs fitted plots and QQ plots respectively. To examine within-participant differences between menstrual phases, post-hoc pairwise comparisons were performed using estimated marginal means (emmeans package) and Tukey's adjustment, with significance set at $p<0.05$. Numerical estimates and their 95% CI are reported for significant pairwise effects. Standard deviation of the random effects on the same scale as the outcome variable are reported for each model (see Table 4.1). R^2 are reported for each model to explain the proportion of variance explained by phase or symptoms, plus total model (fixed and random effects; see Table 4.1). Of note, *position* provided zero variance for total distance, so the model was re-run without *position*, which did not improve model fit nor change the interpretation of significance of results, thus the initial models was retained. Heteroscedasticity was detected for the very-high speed running distance models, consequently data was transformed using log(x+1) due to the presence of zeros. No improvement to the very-high speed running distance model fits were observed, thus the initial models were retained which should be considered when interpreting results.

4.4 Results

The number of menstrual cycles monitored was 2.8 ± 0.8/player (range 1 - 4). Cycle length was 29.3 ± 4.8 days (with 40% CV) for the cycles analysed. Amongst the cycles which met the menstrual phase criteria, late-follicular phase length was 12.3 ± 4.9 days (CV = 37%), and luteal phase length was 10.7 ± 4.0 days (CV = 16%). Two players experienced one or more cycle lengths of 37-38 days, which did not meet the initial stipulated criteria, though reported positive LH and PdG tests for all cycles and meets the International Federation of Gynecology and Obstetrics for regular menstrual bleeding (Munro et al., 2022), therefore their data was included in analyses. Match player position and GPS was obtained for 134 individual observations. Included in the final datasets were 54 menstrual phase vs GPS observations (8 ± 3/player; early-follicular phase = 14, late-follicular phase = 17, luteal phase = 23) and 57 menstrual symptom vs GPS observations (6 ± 3/player).

Menstrual phase

The effects of menstrual phase on match running are reported in Figure 4.1, whilst the main effect, random effect SD and R^2 for all menstrual phase models are reported in Table 4.1. A significantly higher total distance was reported during the late-follicular phase compared to the early-follicular phase ($p = 0.045$, Δ 5.0 $m.min^{-1}$, CI 0.1 – 10.0) and luteal phase ($p = 0.007$, Δ 5.7 $m.min^{-1}$, CI 1.4 - 9.9). Similarly, a significantly higher HSR was reported during the late-follicular phase compared to the early-follicular phase ($p = 0.009$, Δ 1.2 $m.min^{-1}$, CI 0.3 - 2.1) and luteal phase ($p = 0.006$, Δ 1.1 $m.min^{-1}$, CI 0.3 - 1.9). No significant difference in very-high speed running, peak speed, accelerations or decelerations were observed between any menstrual phases ($p > 0.05$).

Figure 4.2 shows box plots representing the individual variability in total distance and HSR across phases, noting raw data points have been used, thus position has not been accounted for. As reference, player 1 played central midfield, wide defence and forward; player 2 played central midfield; player 3 played central defence, player 4 played wide defence, player 5 played central midfield, wide midfield and one match at centre back; player 6 played forward; player 7 played central defence and wide defence.

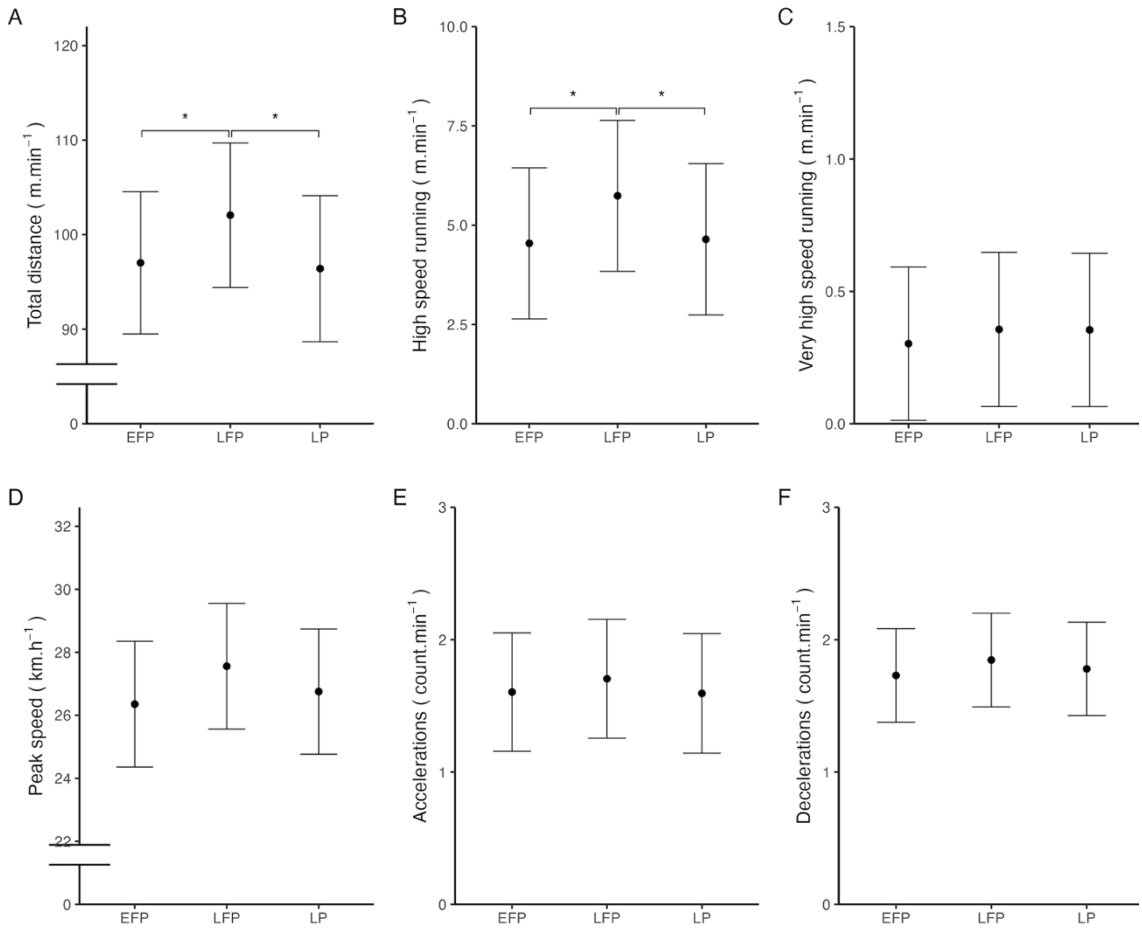

Figure 4.1 Relative match running across the menstrual phases for A) total distance, B) high speed running, C) very high-speed running, D) peak speed, E) accelerations, F) decelerations.

Results are reported as estimated marginal means and 95% confidence intervals * indicates a significant difference ($p<0.05$) Number of match observations per phase: early-follicular phase (EFP) = 14, late-follicular phase (LFP) = 17, luteal phase (LP) = 23. Number of players per phase: EFP = 6, LFP = 5, LP = 7.

Table 4.1 Model outputs for main effect of menstrual phase and symptoms on match performance variables

	Menstrual phase models					Menstrual symptoms models					
	Fixed Effect	Random Effects		R^2		Fixed Effect		Random Effects		R^2	
	Phase (p-value)	Team: Player (SD)	Position (SD)	Marginal	Conditional	Symptoms (p-value)	Symptoms (estimate)	Team: Player (SD)	Position (SD)	Marginal	Conditional
TD ($m.min^{-1}$)	0.005*	5.6	0	0.11	0.60	0.584	-0.08	6.0	3.4	0.002	0.76
HSR ($m.min^{-1}$)	0.003*	1.3	0.6	0.08	0.73	0.852	-0.006	2.1	0	<0.001	0.86
VHSR ($m.min^{-1}$)	0.55	0.3	0.07	0.01	0.79	0.438	-0.004	0.2	0.04	0.01	0.66
ACC ($count.min^{-1}$)	0.05	0.3	0.04	0.02	0.85	0.02*	-0.01	3.7	0	0.02	0.90
DEC ($count.min^{-1}$)	0.24	0.3	0.1	0.02	0.76	0.093	-0.01	0.5	0.1	0.01	0.88
Peak speed ($km.h^{-1}$)	0.10	0.8	1.4	0.05	0.53	0.289	-0.04	0.7	0.7	0.02	0.32

TD = total distance; HSR = high-speed running; VHSR = very high-speed running; ACC = accelerations; DEC = decelerations; SD = standard deviation; * = significant effect

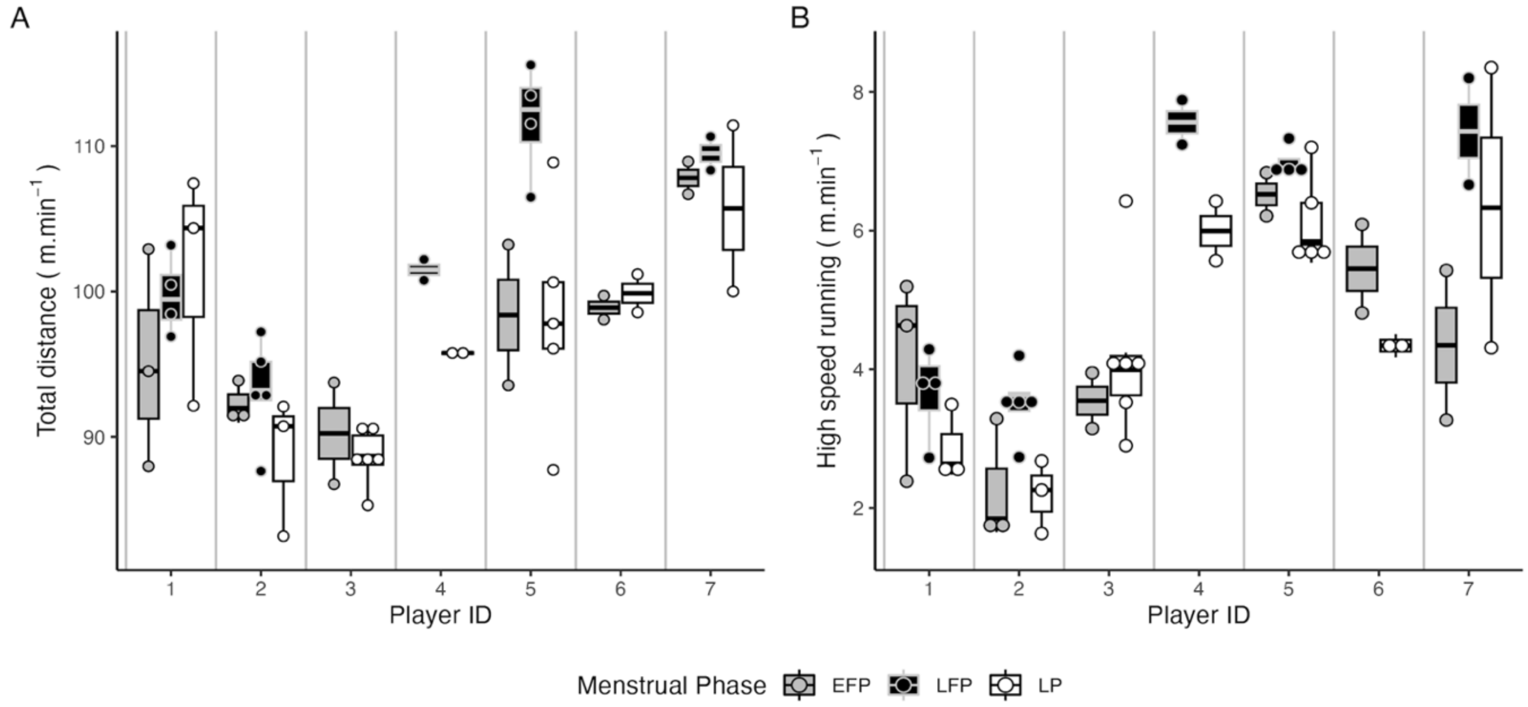

Figure 4.2 Variability in match running across the menstrual phases for relative (A) total distance and (B) high-speed running as represented by box plots.

Each dot represents a single match observation. EFP = early-follicular phase; LFP = late-follicular phase; LP = luteal phase.

Menstrual Symptom Severity

The effects of MSS on match running are reported in Figure 4.3, whilst the main effects, random effects SD and R^2 for menstrual symptom severity models are reported in Table 4.1. Median MSS was 6 (IQR 2 - 8, range 0 - 25). Menstrual symptom severity had a significant effect on accelerations ($p = 0.03$), where accelerations decreased by 0.01 count.min-1 per 1 unit increase in MSS. Menstrual symptom severity did not affect total distance ($p = 0.52$), high-speed running ($p = 0.79$), very-high speed running ($p = 0.38$), peak speed ($p = 0.16$) or decelerations ($p = 0.12$).

4.5 Discussion

This novel study investigated the effects of menstrual phase and symptoms on match running in professional footballers. The main findings were a greater total distance and HSR during the late-follicular phase compared to the early-follicular phase and luteal phase, though large variability existed in GPS measures based on phase and player. Additionally, increasing MSS resulted in lower accelerations. Given the small sample size and variability of results, an individualised approach to the management of menstrual phase and symptoms effects on football performance seem appropriate.

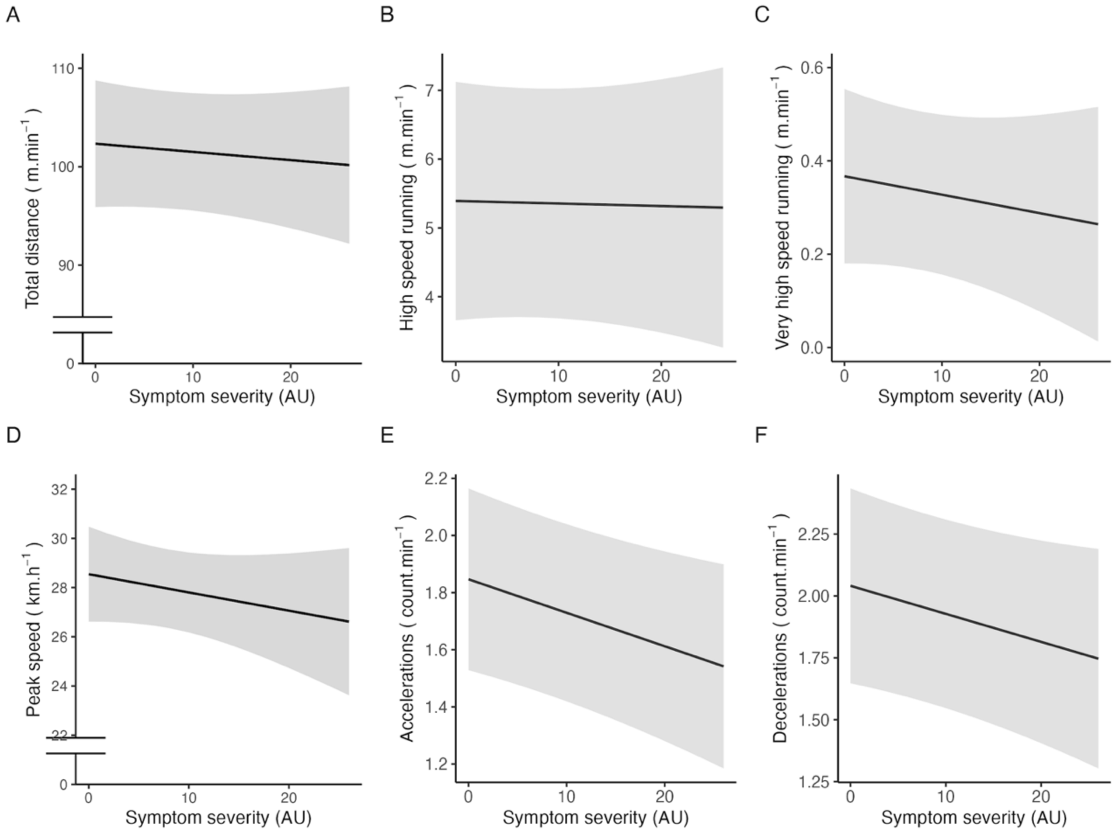

Figure 4.3 Relative match running in response to menstrual symptom severity for relative A) total distance, B) high speed running, C) very high-speed running, D) peak speed, E) accelerations, F) decelerations.

Menstrual phase had a significant effect on total distance, with increased total distance during the late-follicular phase than the early-follicular phase and luteal phase. Previously, Igonin et al. (2022) also reported greater total distance in the late-follicular phase than early-follicular phase, though without differences to luteal phase possibly due to the shorter windows used to classify phases (late-follicular phase days 10-13, mid-luteal phase days 20-23; Igonin et al., 2022). Julian et al. (2020) found no difference in total distance between the follicular phase and luteal phase, though didn't distinguish early-follicular from late-follicular, perhaps masking any effect. In the current study, the estimated difference in total distance across 90min correlates to ~460m (early-follicular phase vs late-follicular phase) and ~520m (late-follicular phase vs luteal phase), which is greater than the typical within-player SD for elite female footballers match (259m, 90% CI = 239-277m; Baptista et al., 2022). Hence, these findings support the frequently self-reported perceived reduction in athletic performance during the early-follicular phase and/or premenstrual phase (Read et al., 2021), though the premenstrual phase was included within the luteal phase due to the small number of observations. Whilst menstrual phase had a significant effect on total distance, the SD of player ($5.6 m \cdot min^{-1}$) was similar to the estimated total distance difference between phases ($5.1\text{-}5.8 m \cdot min^{-1}$), highlighting the effect of phase on total distance varies greatly between and within players. This is supported by Figure 4.2 where total distance and high-speed running for player 4 (wide defence in all matches) is distinctly higher in the late-follicular phase than luteal phase, whereas player 1 (central and wide midfield) demonstrates generally higher total distance in the luteal phase and high-speed running in the late-follicular phase with large overlap between phases. The evidently large within and between player variability highlights individualised monitoring and management of menstrual phase effects is required.

Greater high-speed running (18-25km·h^{-1}) was evident during the late-follicular phase compared to the early-follicular phase and luteal phase, though phase had no effect on very-high speed running (>25km·h^{-1}). This contrasts to Julian et al. (2020) who reported more running at ~17-20km·h^{-1} in the luteal phase than follicular phase, no difference in running >20km·h^{-1} and Igonin et al. (2022) who found no difference in running >19km·h^{-1}. Differing speed thresholds make direct comparisons between studies difficult. Further, these studies used calendar-based phase estimations which increase the risk of including anovulatory and luteal phase deficient cycles, resulting in sampling heterogeneity (Elliott-Sale et al., 2021). Across a 90min match, our results extrapolate to ~100m greater high-speed running in the late-follicular phase than early-follicular phase and luteal phase. Within-player match variability for running distances in speed thresholds 16-20km·h^{-1} and >20km·h^{-1} have been reported as 160m (90% CI 148-171m) and 73m (68-78m) respectively (Baptista et al., 2022). Therefore, whether a reduction of 100m high-speed running is of concern to practitioners may be player dependant and interpreted within the context of normal match-to-match variations, such as those cause by situational factors (e.g., opposition quality and match outcome) (Trewin et al., 2018b). Whilst speculative, menstrual phase influence on substrate metabolism (Oosthuyse et al., 2023) may contribute to differences in match running; however, research using high-intensity intermittent exercise is scarce, with one study showing significantly greater muscle glycogen utilisation in the late- compared to early- follicular phase (Matsuda et al., 2022). No significant differences in very-high speed running were reported (<7m difference between phases across 90min) and the large overlap of 95% CI's with very low variance (marginal $R^2 = 0.01$) explained by menstrual phase for very-high speed running may be attributed to the higher match-to-match variability that exists with increasing speed thresholds (Baptista et al., 2022). Such variability may be greater than that observed between phases, highlighting the importance of ecological studies, and the need for larger sample sizes due to individual variability and confounders.

Accelerations and decelerations occur frequently during matches, particularly given most sprints are <10m (Griffin et al., 2020). These actions, alongside maximal effort sprints, are important to goal scoring opportunities in women's football (Martínez-Hernández et al., 2023). Menstrual phase did not significantly affect accelerations, decelerations or peak speed. Julian et al (2017) reported no difference in 30m sprint performance across menstrual phases for football players, however, a basketball study found a greater magnitude of accelerations and decelerations during the ovulatory phase (late-follicular phase) than the early-follicular phase, mid-follicular phase or luteal phase (Arenas-Pareja et al., 2023). Regardless, the low variance of accelerations, decelerations and peak speed explained by menstrual phase (R^2 0.01 - 0.05) further highlights the lack of menstrual phase effect. Given this is the first study to assess accelerations, decelerations and peak speed during football matches, further research is required to support these findings.

Menstrual symptoms are associated with a perceived negative effect of the menstrual cycle on athletic performance (Oester et al., 2024), though observational studies exploring their effect on athletic performance are lacking. Increasing MSS significantly reduced accelerations, albeit large individual variability exists, and MSS did not affect any other match running measures. In support of this, a study of recreationally active females found reduced lower-body power, measured by jump height and Wingate test, coincided with higher levels of self-reported physical pain; whilst improved performance was positively correlated with motivation, arousal and pleasure without effect of menstrual phase (Dam et al., 2022). Though not explicitly stated in our questionnaire, a "negative" focus of symptoms is implied, and few psychological symptoms were assessed, which could have limited our findings. Indeed, the symptom severity questionnaire is yet to be validated and remains to be explored in future research on menstrual symptomology. Another factor that may explain the lack of symptoms effect is that athletes appear more likely to report a negative menstrual cycle effect during training compared to competition (McNamara et al., 2022). Selective attention or expectations to perform during competition may supersede symptom distraction and effects on performance (Armour et al., 2020; Findlay et al., 2020). Further, median symptom severity appeared low being 6 (IQR 2 - 8) out of a possible 54, though limited longitudinal studies exist for comparison. Given the ecological nature of the study, it's possible we did not capture players with, or matches when, players were experiencing higher symptom severity. Overall symptom severity explained <2% of the variance (R^2) in each model, highlighting the limited predictability of menstrual symptoms for match running. Whilst we found limited influence of menstrual symptoms on match running, other performance aspects such as tactical and technical factors remain to be investigated.

Several limitations exist within the study. Whilst this is the first study to measure LH and PdG urine concurrent to football match GPS measures, the gold standard blood hormone analysis was not performed, preventing further sub-phase classification and increasing the possibility of including players with anovulatory or luteal phase deficient cycles. Clubs used different manufacturers GPS units and processing software, though previous research shows good inter-unit reliability between the brands used (Compton et al., 2018), we controlled for GPS brand in the models, and the models explore within subject effects. Contextual factors may influence match running and whilst match outcome, opposition quality and possession show trivial effects (Trewin et al., 2017), we acknowledge not controlling for environmental conditions is a limitation. Lastly, the sample size for each analysis was relatively small (n = 7 - 10 players). Initially, 32 players were recruited but many players or menstrual phases were excluded due to menstrual status, with further observations limited by injuries, match scheduling and player selection for matches – which are common concerns in such research contexts.

4.6 Conclusion

This novel study reports some match running variables for professional football players were affected by menstrual phase, whilst symptoms minimally affected match running. Specifically, greater total distance and high-speed running occurred during the late-follicular phase, compared to the early-follicular phase and luteal phase. Additionally, accelerations decreased with increasing MSS. Given the small sample size and variability presented, an individualised approach to management of the menstrual cycle's effects on football performance is recommended and further research is required to inform these findings.

Chapter 5: Study 3

Menstrual phase and post-match perceptual recovery responses for naturally menstruating football players

As based on the publication:

Brown, G. A., Fullagar, H.H.K. & Duffield, R. Menstrual phase and post-match perceptual recovery responses for naturally menstruating football players. *International Journal of Sports Physiology & Performance (In press)*

5.1 Abstract

Purpose: To explore the influence of menstrual phase on post-match perceptual responses and the time-course of recovery for professional footballers.

Methods: Thirteen naturally menstruating footballers tracked their menstrual cycle and reported perceptual responses for up to four cycles. Menstrual phases were determined by calendar-based tracking and urinary hormone tests and classified as early-follicular, late-follicular or luteal. On match days (MD) and the following two days (MD+1, MD+2) players completed perceptual questionnaires on fatigue, soreness, stress, sleep and PRS. Total high-speed running distance (THSRD) during matches was recorded using GPS devices to represent load. Data was analysed using linear mixed models.

Results: Day x THSRD affected PRS ($p < 0.001$), total wellness ($p < 0.001$), fatigue ($p = 0.047$), soreness ($p < 0.001$) and stress ($p = 0.044$). Significant main effects were found for menstrual phase on PRS ($p = 0.038$), Day on stress ($p = 0.034$), and THSRD on soreness ($p = 0.045$). During the early-follicular phase, moderate ES existed for worse PRS on MD and MD+2 ($p = 0.07 - 0.28$, $ES > 0.51$), and better sleep quality on MD+2 ($p = 0.13$, $ES = 0.56$). No significant differences between menstrual phases existed ($p > 0.05$) and all other ES were trivial to small ($ES < 0.50$). All perceptual measures, except stress, differed significantly between Days ($p < 0.05$), with differences based on match load and to a lesser extent menstrual phase.

Conclusion: PRS may be worse during the early-follicular phase, though menstrual phase has limited association with post-match perceptual responses. Variability in the recovery time-course for perceptual measures exists between menstrual phases, though evidence for consistently impaired recovery time-course in any phase was not evident.

5.2 Introduction

Football matches induce psycho-physiological fatigue from match loads (i.e., total or high-speed running), for which female players may require up to 72h for full recovery (Goulart et al., 2022). Optimising player recovery is of importance for performance staff, especially given the increasing frequency of multi-match weeks in women's football (FIFPRO, 2023) and teams training within 48h following a match. Whilst post-match recovery for male footballers has been well-researched (Silva et al., 2018), fewer studies exist for women, especially considering the menstrual cycle (Goulart et al., 2022). Fluctuating concentrations of oestrogen and progesterone depict the menstrual cycle and classify its phases as early-, mid-, late- follicular and luteal (Bruinvels et al., 2022). Oestrogen and progesterone can affect various physiological functions (Bernstein & Behringer, 2023) and hence, may influence recovery, though football-specific research is limited (Beato et al., 2024). For example, oestrogen has protective effects for skeletal muscle tissue, which can reduce exercise-induced muscle damage (Bernstein & Behringer, 2023), thus when oestrogen levels are high during the late-follicular and mid-luteal phases of the menstrual cycle, there is potential for improved recovery (Romero-Parra et al., 2021). Given the scarcity of field-based recovery research in this cohort, understanding whether the menstrual cycle affects post-match recovery may aid recovery strategy implementation and load management for female footballers.

Following a football match players experience fatigue due to muscle damage, neuromuscular fatigue, cognitive stress, substrate depletion and hypohydration (Nedelec et al., 2012). Whilst match-based data is not available, laboratory research involving 90min of treadmill running at 70% VO_2max showed higher creatine kinase and interleukin-6 (biomarkers of muscle damage) concentrations at 24h and 72h post-exercise during the mid-follicular compared to mid-luteal phase in trained runners (Hackney et al., 2019). Further, following treadmill running in untrained females, worse perceptual muscle soreness was reported during early-follicular and late-follicular phases compared to the mid-luteal phase, despite no differences in creatine kinase (Oosthuyse & Bosch, 2017). Similarly, worse perceived recovery was reported during the early-follicular phase compared to ovulatory and mid-luteal phases in untrained females following a treadmill test (Delp et al., 2024). Collectively, a recent systematic review and meta-analysis found that longer post-exercise recovery may be required during the early-follicular phase and enhanced during the mid-luteal phase (Romero-Parra et al., 2021). However, the included studies were primarily laboratory-based, limiting their application to post-match recovery in football. An important driver of fatigue in football is the match running performed, which affects the magnitude of psycho-physiological responses and recovery time-course (Impellizzeri et al., 2019). Thus, the influence of menstrual phase on any recovery parameter (e.g., fatigue scales) should be interpreted within the context of match-loads encountered (i.e., GPS).Whilst biomarkers of muscle damage are valuable measures of the response to match loads, they are invasive and costly, thus perceptual markers of recovery are more frequently used as practical monitoring tools (Thorpe et al., 2016). For example, a systematic review and meta-analysis of female footballers' post-match fatigue and recovery found that most perceptual measures are recovered after 48h, as determined by no significant differences to pre-match values (Goulart et al., 2022). However, of the seven perceptual recovery studies included (Goulart et al., 2022), only two measured responses ≥48h post-match, two kept menstrual phase consistent and no studies compared perceptual responses between menstrual phases.

Regardless of the recovery measure used, the influence of menstrual phase on perceptual responses remains equivocal. For example, a mixed-sport systematic review and meta-analysis reported limited phase effect, though highlighted the wide range of perceptual measures, menstrual phases and methodologies that limited generalisability of findings (Paludo et al., 2022). Amongst footballers, one professional club reported no difference in perceptual responses as based on menstrual phase on match day and the following three days (Abbott et al., 2024). However, amongst national team footballers, an increased fatigue response 48h post-match was found during the luteal compared to follicular phase, with no other perceptual differences reported (Scott et al., 2024). Whilst the limited evidence suggests minimal influence of menstrual phase on football post-match perceptual responses, both studies (Abbott et al., 2024; Scott et al., 2024) estimated phase using calendar-based tracking only. This method increases the likelihood of phase misclassification and including players with menstrual disturbances (i.e., abnormal hormonal profiles) which are common amongst exercising women (De Souza et al., 2009), thus introducing sampling heterogeneity (Elliott-Sale et al., 2021). Research with more robust menstrual phase measures (Beato et al., 2024) would improve reliability of between-phase comparisons. Additionally, the studies compared perceptual measures between menstrual phases at given timepoints (e.g., 48h post-match). Examining the difference in perceptual measures across days (e.g., match day to 48h post-match), provides a more representative measure of the recovery time-course as based on menstrual phase. Further research is required to better understand the effect of menstrual phase on post-match perceptual responses and recovery timelines in football.

This study aims to explore the influence of menstrual phase on i) post-match perceptual responses on match day and the following two days, and ii) the time-course of recovery as indicated by the difference in perceptual measures between days, for naturally menstruating (i.e., not using hormonal contraceptives) footballers. To better highlight the initial aim, a secondary analysis will describe the effect of match loads and post-match timelines on the perceptual responses as context to the fatigue-recovery response.

5.3 Methods

Participants

Football players from four teams in a professional domestic league (Tier 3 (McKay et al., 2022)) were invited to participate in the study during their 2022/23 season. Players were invited to participate if they (1) had no use of HCs within the past 3 months, (2) were not pregnant, (3) had an average menstrual cycle length 21-35 days in the previous 3 months, (4) were not diagnosed with any condition that would severely disrupt the menstrual cycle (e.g., polycystic ovary syndrome) (Elliott-Sale et al., 2021). Initially, 32 players consented to participate in the study and data from 13 players (age: 26.5 ± 6.8y, height: 166.7 ± 5.3 cm, weight: 63.3 ± 5.0kg) was included in the final dataset following participant withdrawals and exclusions (Figure 5.1). Ethical approval was obtained from the Institutional Human Research Ethics Committee (ETH22-7106) and written consent provided by all players, including parents for those aged 16-17y.

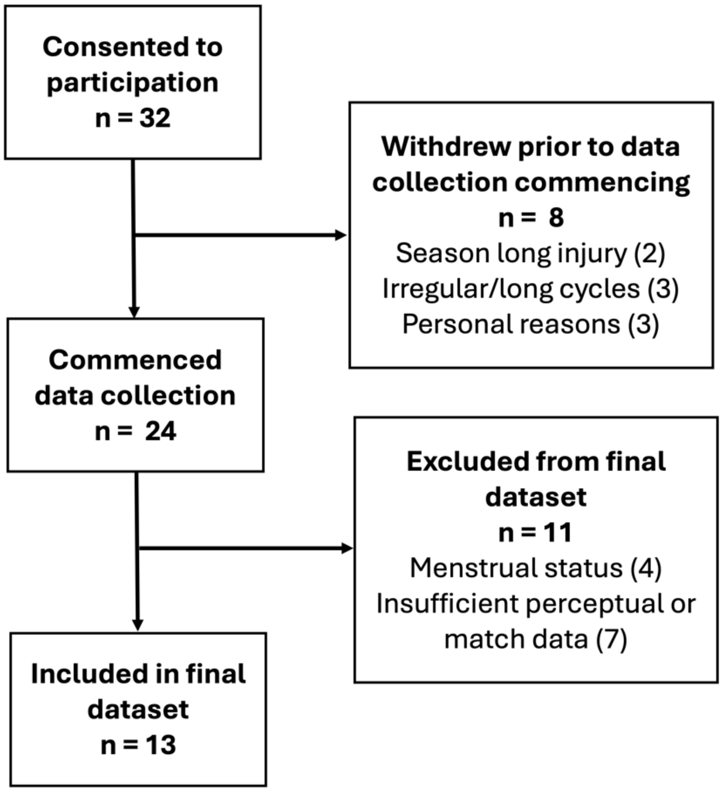

Figure 5.1 Participant inclusion flowchart.

Study Overview

Prior to the monitoring period commencing, players completed an online questionnaire to confirm eligibility to participate and tracked at least one menstrual cycle by self-reporting of menses to confirm cycle length. Players then tracked their menstrual cycle via self-reporting of menses and urinary hormone testing for one to four consecutive menstrual cycles, and also reported their perceived wellness and recovery around match days. Match load was measured concurrently to menstrual cycle and recovery data.

Menstrual cycle status and phase classification

To establish the existence of natural cycles and to assist menstrual phase classification, players self-reported days of menstruation online (Smartabase, Fusion Sport, Brisbane, Australia) and used urinary hormone tests. Players used LH tests (Clearblue Ovulation Digital Test kits, SPD Swiss Precision Diagnostic GmbH, Switzerland) which are 99% effective at detecting a LH surge (>40mlU$\cdot$mL^{-1}) (Ellis et al., 2011), and assume ovulation within 2-days of a positive test (Schaumberg et al., 2017). Players who obtained a positive LH test were then instructed to use urinary PdG tests (Confirm Kit, Proov, USA) to detect an increase in PdG (>5μg$\cdot$mL^{-1}). Pregnanediol glucuronide, the urinary metabolite of progesterone, has been shown to correlate to serum progesterone levels (r = 0.81) (Roos et al., 2015). Written and video instructions were provided, including instruction to upload test result photos for confirmation by the lead researcher (Elliott-Sale et al., 2021). The lead researcher calculated all LH and PdG test start dates according to the manufacturer's instructions and communicated dates to players via WhatsApp (Facebook Inc).

Three menstrual phases were categorised: 1) early-follicular phase: days of menstruation or days one to five of a cycle (whichever was longer), where >2 days of menstruation occurred; 2) late-follicular phase: from the day after the early-follicular phase until one day following a positive LH test; 3) luteal phase: from the day after the late-follicular phase until the day prior to the next cycle occurring, when a positive PdG test was detected and the luteal phase was $\geq$10 days (Schaumberg et al., 2017). If a player did not meet the criteria for each phase, in addition to a cycle length 21-38 days, the data for that cycle was removed from the analysis to minimise risk of including anovulatory and luteal phase deficient cycles (Munro et al., 2022; Schaumberg et al., 2017). Whilst recognising the gold standard classification and verification of menstrual phase recommends serum oestrogen and progesterone analysis (Schaumberg et al., 2017), this was not possible in the current study due to players training and playing matches in multiple states.

Match load

Match load was measured by 10Hz GPS devices. Three GPS models were used based on what the club owned (STATSports Apex, Catapult Playertek and Catapult One), though players used the same GPS device each match. Good inter-unit reliability for distances has been reported for 10Hz STATSports and Catapult devices, though the Catapult models we used differed to this study (Compton et al., 2018), which is a limitation. As part of standard team procedures, each team's sport scientist downloaded and processed GPS data using their manufacturer's software. The individual match data was shared with the researchers via password protected OneDrive folders. Total high-speed running distance (>18km$\cdot$h^{-1}) was selected as the match load measure to use in the mixed-models due to its sensitivity to changes in perceptual fatigue (Thorpe et al., 2015). Player data was included in the analysis if they were selected in the match day squad regardless of whether they played.

Perceptual measures

Players were asked to complete the PRS scale and modified Hooper Index questionnaire on the mornings of match day (MD), the morning after match day (MD+1) and two mornings after match day (MD+2) online. The PRS, which is a single item Likert scale question from 0 (very poorly recovered) to 10 (very well recovered), is moderately correlated (r = -0.63) to changes in sprint performance, and is a validated psycho-physiological tool to measure recovery (Laurent et al., 2011). The modified Hooper Index rates perceptions of fatigue, muscle and joint soreness, sleep quality and stress on seven-point Likert scales, with 1 being very, very low/good and 7 being very, very high/bad (Hooper & Mackinnon, 1995). A daily total wellness score was calculated via summing the subscales, resulting in a score from 4 (best possible wellness) to 28 (worst possible wellness) (Moalla et al., 2016). Athlete self-reported measures are frequently used in football populations to assess perceptual recovery and wellness (Moalla et al., 2016). Such measures demonstrate increased sensitivity and consistency in their response to training loads than objective measures (Saw et al., 2016).

Statistical analysis

To reduce intra-participant variability and increase statistical power, the final dataset included the following inclusion criteria; perceptual measures for a minimum of two menstrual phases (early-follicular, late-follicular, luteal) and two days (MD, MD+1, MD+2) for each player, where the aforementioned menstrual phase criteria were met. Analyses were performed using R Statistical Software (R Core Team 2020). Linear mixed models (lme4 package) were used to assess the influence of menstrual phase (early-follicular, late-follicular, luteal), Days (MD, MD+1, MD+2) and THSRD on perceptual measures. Whilst the response variables are ordinal, linear mixed models were used due to interpretability of results, with recent studies performing similar analyses (De Martin Topranin et al., 2023). Separate models were used for each perceptual measure (PRS, total wellness, fatigue, soreness, stress, sleep). In each model menstrual phase, Day and THSRD were included as fixed effects; menstrual phase x Day, and Day x THSRD were included as interaction terms; and player ID as a random effect to account for repeated measures. Homogeneity of variance and normality of residuals were assessed visually by residuals vs fitted plots and QQ plots respectively. Marginal and conditional R^2 are reported to explain the portion of variance explained by the fixed effects and entire model respectively. Post-hoc pairwise comparisons for menstrual phase and Day were performed using estimated marginal means (emmeans package) with Tukey adjustment. Due to the significant Day x THSRD interaction effect, post-hoc pairwise comparisons with Tukey adjustment between Days were performed holding THSRD at -1SD (136m) and at +1SD (603m) to account for the differing effects of match load. Effect sizes for pairwise comparisons were estimated using Cohens d as follows <0.2 trivial, >0.2 small, >0.5 moderate and >0.8 large (Cohen, 1988). Significance was set at $p < 0.05$.

5.4 Results

A total of 37 menstrual cycles were tracked across 13 players (2.9 ± 0.8 cycles/player) with 29 cycles deemed natural cycles. There were: 7 ± 3.4 matches/player, 2.4 ± 0.5 perceptual responses/player/phase/Day, 221 PRS model observations (early-follicular = 48, late-follicular = 88, luteal = 85 and MD = 72, MD+1 = 77, MD+2 = 72) and 251 Hooper Index observations (early-follicular = 55, late-follicular = 101, luteal = 95 and

MD = 84, MD+1 = 83, MD+2 = 84). Sixteen percent of PRS responses were missing (6 ± 6/player; early-follicular = 9, late-follicular = 17, luteal = 15) and 10% of Hooper Index responses (4 ± 4/player; early-follicular = 6, late-follicular = 10, luteal = 14).

The interaction and main effects for each model, and R^2, are presented in Table 5.1. No significant menstrual phase x Day interaction effects were found for any perceptual measures. Significant interaction effects for Day x THSRD existed for PRS ($p < 0.001$), total wellness ($p < 0.001$), fatigue ($p = 0.047$), soreness ($p < 0.001$) and stress ($p = 0.044$), such that the relationship between THSRD and each perceptual measure was dependent on the Day, as illustrated in Figure 5.2. Significant main effects were found for menstrual phase on PRS ($p = 0.038$), for Day on stress ($p = 0.034$), and for THSRD on soreness ($p = 0.045$). No significant interaction or main effects of phase, Day or THSRD were found for sleep ($p > 0.05$).

Menstrual phase

Despite a main effect of menstrual phase on PRS (Table 5.1), no significant differences existed between menstrual phases on any Day (Table 5.2). However, moderate ESs were reported for PRS on MD between the early-follicular and late-follicular phases ($p = 0.07$, ES = -0.69), early-follicular and luteal phases ($p = 0.08$, ES = -0.7), and on MD+2 between the early-follicular and luteal phases ($p = 0.28$, ES = -0.51), trending towards worse PRS during the early-follicular phase. Though not significant, a moderate ES was also reported for better sleep quality during the early-follicular phase than luteal phase on MD+2 ($p = 0.13$, ES = -0.56). No post-match perceptual measures were significantly different between menstrual phases on any Days ($p > 0.05$) and ESs were trivial to small (ES < 0.50).

Table 5.1 Interaction and main effects for PRS and Hooper Index measures

	Interaction Effects		Fixed (main) Effects					
	Phase x Day (p-value)	**Day x THSRD (p-value)**	**Phase (p-value)**	**Day (p-value)**	**THSRD (p-value)**	**R^2m**	**R^2c**	**AIC**
PRS	0.71	<0.001***	0.038*	0.92	0.48	0.19	0.61	824
Total Wellness	0.77	<0.001***	0.86	0.36	0.11	0.11	0.71	1182
Fatigue	0.54	0.047*	0.27	0.05	0.24	0.16	0.55	703
Soreness	0.45	<0.001***	0.90	0.16	0.045*	0.16	0.57	711
Stress	0.97	0.044*	0.36	0.034*	0.33	0.02	0.62	656
Sleep	0.44	0.13	0.47	0.42	0.46	0.09	0.49	751

THSRD = total high-speed running distance; R^2m = marginal R^2; R^2c = conditional R^2; AIC = Akaike Information Criterion; PRS = perceived recovery status

* p<0.05; **p<0.01; ***p<0.001

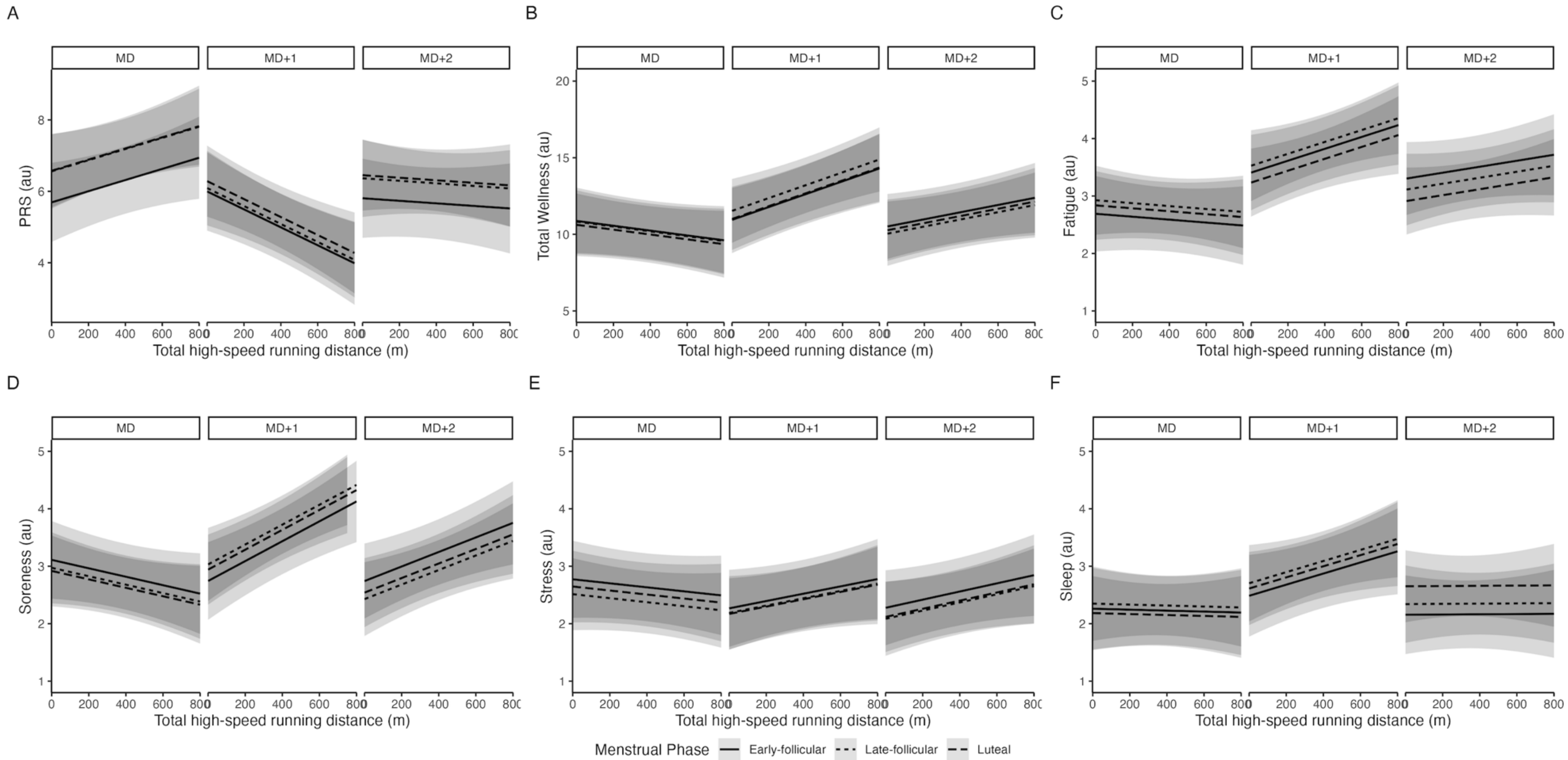

Figure 5.2 Post-match perceptual recovery and wellness variables as determined by menstrual phase, day and total high-speed running distance.

Table 5.2 Absolute PRS and Hooper Index measures compared between menstrual cycle phases for each Day.

	EFP vs LFP		EFP vs LP		EFP vs LP	
	p value	**Cohens *d***	**p value**	**Cohens *d***	**p value**	**Cohens *d***
PRS						
MD	0.07	-0.69[#]	0.08	-0.70[#]	1.0	-0.01
MD+1	0.97	-0.07	0.75	-0.23	0.84	-0.15
MD+2	0.39	-0.44	0.28	-0.51[#]	0.97	-0.07
Total Wellness						
MD	1.00	0.02	0.92	0.12	0.92	0.10
MD+1	0.62	-0.28	1.00	-0.03	0.60	0.25
MD+2	0.74	0.22	0.92	0.12	0.91	-0.11
Fatigue						
MD	0.57	-0.30	0.82	-0.18	0.89	0.11
MD+1	0.86	-0.15	0.75	0.22	0.32	0.37
MD+2	0.70	0.24	0.21	0.49	0.59	0.25
Soreness						
MD	0.83	0.17	0.71	0.24	0.96	0.07
MD+1	0.45	-0.36	0.70	-0.25	0.90	0.11
MD+2	0.39	0.39	0.67	0.25	0.85	-0.14
Stress						
MD	0.43	0.37	0.83	0.18	0.74	-0.19
MD+1	0.92	0.11	0.90	0.14	1.00	0.02
MD+2	0.64	0.27	0.72	0.22	0.98	-0.05
Sleep						
MD	0.94	-0.10	0.96	0.09	0.74	0.19
MD+1	0.68	-0.25	0.88	-0.14	0.91	0.10
MD+2	0.76	-0.2	0.13	-0.56[#]	0.35	-0.35

EFP = early-follicular phase; LFP = late-follicular phase; LP = luteal phase; MD = match day; MD+1 = day after match day; MD+2 = 2 days after match day; PRS = perceived recovery status. Results are reported as p-values and Cohens d (effect size); positive Cohens d represents worse PRS and improved Hooper Index; negative Cohens d represents improved PRS and worse Hooper Index; # moderate effect size

Days and THSRD threshold

Perceptual measures by Day for each menstrual phase when holding THSRD at ±1SD (136m, 603m) are reported in Table 5.3. Despite a main effect of Day on stress (Table 5.1), no significant differences were found between Days during any menstrual phase at ±1SD THSRD and ESs were trivial (ES < 0.20). At -1SD THSRD (i.e., lower match loads), PRS ($p = 0.02$, ES = 0.81) and total wellness ($p = 0.04$, ES = 0.7) during the late-follicular phase, and fatigue in all phases ($p < 0.05$, ES > 0.72) were worse on MD+1 than MD. Total wellness ($p = 0.018$, ES = 0.82) and soreness ($p = 0.017$, ES = 0.83) during the late-follicular phase improved from MD+1 to MD+2. Fatigue ($p = 0.034$, ES = 0.91) during the early-follicular phase was worse on MD+2 than MD. At +1SD THSRD (i.e., higher match loads), PRS, total wellness, fatigue, soreness and sleep in all phases were worse on MD+1 than MD ($p < 0.05$, ES = 0.98 - 2.33). Perceived recovery status, total wellness, fatigue and soreness during the late-follicular and luteal phases, plus sleep during the early-follicular and late-follicular phases, improved from MD+1 to MD+2 ($p < 0.05$, ES = 0.88 - 1.25). Perceived recovery status during the late-follicular and luteal phases ($p < 0.05$, ES = 1.02-1.07), total wellness and soreness in all phases ($p < 0.05$, ES = 0.75 - 1.04), and fatigue during the early-follicular and luteal phases ($p < 0.05$, ES = 0.82 - 1.36), were worse on MD+2 than MD, indicating these variables had not recovered.

Table 5.3 Absolute Perceived Recovery Status and Hooper Index measures compared between Days for each menstrual cycle phase, according to total high-speed running distance.

		MD vs MD+1				MD+1 vs MD+2				MD vs MD+2			
		136m THSRD		603m THSRD		136m THSRD		603m THSRD		136m THSRD		603m THSRD	
		p	Cohens *d*	p	Cohens *d*	p	Cohens *d*	p	Cohens *d*	p	Cohens *d*	p	Cohens *d*
PRS													
	EFP	0.86	0.20	<0.001***	1.71$^{\$}$	0.98	-0.08	0.09	-0.88$^{\$}$	0.95	0.12	0.11	0.83$^{\$}$
	LFP	0.02*	0.81$^{\$}$	<0.001***	2.33$^{\$}$	0.34	-0.45	<0.001***	-1.25$^{\$}$	0.50	0.36	0.002**	1.07$^{\$}$
	LP	0.09	0.67$^{\#}$	<0.001***	2.18$^{\$}$	0.45	-0.37	<0.001***	-1.17$^{\$}$	0.60	0.31	0.005**	1.02$^{\$}$
Total Wellness													
	EFP	0.52	-0.40	<0.001***	-1.68$^{\$}$	0.64	0.32	0.12	0.73$^{\#}$	0.97	-0.08	0.03*	-0.95$^{\$}$
	LFP	0.04*	-0.70$^{\#}$	<0.001***	-1.98$^{\$}$	0.018*	0.82$^{\$}$	<0.001***	1.23$^{\$}$	0.91	0.12	0.03*	-0.75$^{\#}$
	LP	0.16	-0.55$^{\#}$	<0.001***	-1.83$^{\$}$	0.25	0.47	0.011*	0.88$^{\$}$	0.96	-0.08	0.005**	-0.95$^{\$}$
Fatigue													
	EFP	0.007**	-1.27$^{\$}$	<0.001***	-1.89$^{\$}$	0.81	0.22	0.34	0.52$^{\#}$	0.034*	-0.91$^{\$}$	<0.001***	-1.36$^{\$}$
	LFP	0.002**	-0.98$^{\$}$	<0.001***	-1.74$^{\$}$	0.11	0.61$^{\#}$	0.006**	0.92$^{\$}$	0.43	-0.37	0.012*	-0.82$^{\$}$
	LP	0.046*	-0.72$^{\#}$	<0.001***	-1.48$^{\$}$	0.21	0.49	0.023*	0.80$^{\$}$	0.172	-0.23	0.058	-0.68$^{\#}$
Soreness													
	EFP	0.99	0.04	<0.001***	-1.39$^{\$}$	0.97	0.08	0.62	0.35	0.94	0.12	0.015*	-1.04$^{\$}$
	LFP	0.21	-0.49	<0.001***	-0.82$^{\$}$	0.017*	0.83$^{\$}$	<0.001***	1.10$^{\$}$	0.48	0.34	0.016*	-0.82$^{\$}$
	LP	0.30	-0.45	<0.001***	-1.88$^{\$}$	0.12	0.57$^{\#}$	0.015*	0.85$^{\$}$	0.90	0.13	0.002**	-1.03$^{\$}$

Table 5.3 continued

Stress												
EFP	0.33	0.53#	0.94	-0.13	1.0	-0.03	0.98	-0.07	0.35	0.50#	0.85	-0.20
LFP	0.61	0.27	0.37	-0.38	0.90	0.13	0.96	0.08	0.36	0.40	0.57	-0.30
LP	0.25	0.48	0.84	-0.17	0.98	0.06	1.0	0.01	0.16	0.54#	0.86	-0.15
Sleep												
EFP	0.49	-0.42	0.023*	-0.98$	0.32	0.52#	0.018*	1.03$	0.96	0.10	0.99	0.05
LFP	0.12	-0.57#	<0.001***	-1.12$	0.15	0.56#	0.001**	1.06$	1.0	-0.01	0.98	-0.06
LP	0.08	-0.65#	<0.001***	-1.21$	0.93	0.10	0.11	0.61#	0.15	-0.55#	0.11	-0.60#

EFP = early-follicular phase; LFP = late-follicular phase; LP = luteal phase; MD = match day; MD+1 = day after match day; MD+2 = 2 days after match day; PRS = perceived recovery status; THSRD = total high-speed running distance. 136m THSRD represents -1SD; 603m THSRD represents +1SD. Results are reported as p-values and Cohens d (effect size): positive Cohens d represents worse PRS and improved Hooper Index; negative Cohens d represents improved PRS and worse Hooper Index.
*p<0.05; **p<0.01; ***p<0.001; # moderate effect size; $ large effect size.

5.5 Discussion

This study observed small differences in post-match perceptual measures, as well as the time-course of perceptual recovery, between menstrual phases for professional footballers. Overall, menstrual phase had only small relationships with match day and post-match perceptual responses. As expected, a combined effect of match load (i.e., THSRD) and Day (MD, MD+1, MD+2) had the predominant effects on recovery measures. A recovery timeline was evident from the reduction and increase in perceptual measures from MD to MD+2, which differed based on match load and to a lesser extent menstrual phases. However, a consistently impaired recovery time-course in one menstrual phase was not evident.

No significant effect of menstrual phase was evident on the post-match perceptual responses on any Day. However, moderate ESs were reported for worse PRS and better sleep during the early-follicular phase on MD and MD+2 (Table 5.2). Previous research also reported worse PRS during the early-follicular phase following a graded exercise test (Delp et al., 2024), whilst worse perceived sleep quality has been reported during the luteal compared to follicular phase with no difference to the early-follicular phase (De Martin Topranin et al., 2023). Although speculative, the low sex hormone concentrations during the early-follicular and late-follicular phases (Bernstein & Behringer, 2023), or self-reported menstrual symptoms which are commonly reported during early-follicular (McNulty et al., 2023), could contribute to this moderate ES of worse PRS. That said, we found no effect of menstrual phase on total wellness, fatigue, soreness or stress on any Day. This aligns with previous academy and professional football studies (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024); although worse fatigue 48h post-match during the luteal compared to follicular phase has been reported (Scott et al., 2024). The lack of effects in these studies could involve reliance on calendar-based tracking for phase estimation, which increases risk of heterogenous sampling and inaccurate phase classifications (Elliott-Sale et al., 2021). However, our findings were similar to the previous findings, and may relate to the reduced validity of single-item scales (Jeffries et al., 2020) and lower study power (Paludo et al., 2022). Nonetheless, other markers of fatigue not assessed in the present study, such as biomarkers, may still be affected by the menstrual cycle.

Recovery refers to the timeline of restoration of disturbed psychophysiological states and can be measured by the change in recovery markers over time (Kellmann et al., 2018). As context to the influence of menstrual phase on the time-course of recovery, the effect of match load (i.e., THSRD) on perceptual measures must be examined. Except for stress, the perceptual scales worsened from MD to MD+1, and improved from MD+1 to MD+2, though remained worse than MD levels, thus demonstrating an inferred fatigue and recovery response. Although the use of the Hooper Index and its subscales has been cautioned due to validity concerns (Jeffries et al., 2020), the subjective measures used show a response to the acute match load (Saw et al., 2016). This is supported by studies reporting perceptual fatigue being moderately correlated with total high-intensity-running distance ($r = -0.51$) in elite footballers (Thorpe et al., 2015). Whilst recognising we only assessed perceptual recovery, and other physical and physiological markers exist, our results show they were responsive to match load.

The time-course of perceptual recovery, as indicated by the difference in perceptual responses between Days, varied between menstrual phases, and was influenced by THSRD. When comparing MD+1 to MD+2 and MD to MD+2, differences in recovery profiles between phases existed. For example, PRS, total wellness, fatigue and soreness were improved MD+2 compared to MD+1 during the luteal and late-follicular phases, indicative of impaired early-follicular phase recovery. However, PRS during the early-follicular phase and fatigue during the luteal phase returned to MD levels by MD+2, suggesting longer recovery times during the late-follicular phase and limited influence of phase on total wellness and soreness. This contrasts with findings from a systematic review and meta-analysis, whereby increased soreness during the early-follicular phase was attributed to low oestrogen, given its protective effects against exercise-induced muscle damage (Romero-Parra et al., 2021). Of note, whilst PRS recovery appears enhanced during the early-follicular phase this may be offset by the overall lower (worse) PRS scores during the early-follicular phase. At lower match loads fatigue returned to MD levels by MD+2 in all phases except the early-follicular phase, inferring slower early-follicular phase recovery. Additionally, an increased perceptual response was evident during the late-follicular phase with significant differences from MD to MD+1 for PRS and total wellness, as well as from MD+1 to MD+2 for total wellness and soreness. Thus, whilst variable perceptual recovery timelines as based on menstrual phases exist, a consistent effect within or between phases is lacking. Contextual factors not controlled for (e.g., travel, match outcome, environmental conditions) are likely to have influenced the change in perceptual wellness responses. Further, physical recovery measures may be more responsive to menstrual phase, as demonstrated by muscle strength, but not soreness, returning to baseline quicker during ovulation than the follicular phase (Sipavičienė et al., 2013). Overall, individualised consideration of menstrual phase may be beneficial when interpreting post-match perceptual recovery timelines, though the influence of phase is variable.

When interpreting the influence of menstrual phase on post-match recovery, several limitations need to be considered. Firstly, only perceptual recovery was examined, which whilst applicable to professional clubs is one part of recovery. Marginal R^2 was relatively low (0.02-0.19) for all models, and perhaps other recovery measures (e.g., biomarkers) would be more sensitive to menstrual cycles changes. Serum hormone verification was not conducted as players trained and played matches in multiple states, which may have resulted in inclusion of abnormal hormonal profiles. However, more robust methods were used (Beato et al., 2024) in comparison with previous football research (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024). The GPS brands and models differed between clubs, though good inter-unit reliability has previously been reported with the same brands though different Catapult models (Compton et al., 2018). Recovery strategies used were not controlled for or monitored, nor were contextual factors such as match outcome and environmental conditions, which could affect the perceptual responses. Lastly, the sample size was small, which is common for menstrual phase effects research (Paludo et al., 2022) due to strict menstrual inclusion criteria (Elliott-Sale et al., 2021), and high prevalence of menstrual disturbances in exercising women (De Souza et al., 2009).

5.6 Conclusion

In summary, menstrual phase had minimal influence on PRS and sleep quality, with PRS appearing moderately worse during the early-follicular phase on MD and MD+2, and sleep quality appearing moderately better during the early-follicular phase on MD+2. Perceived total wellness, fatigue, soreness, and stress on match day and the following two days were unaffected by menstrual phase. The effect of match load on the perceptual responses was related to the Day, demonstrating a fatigue and recovery response whereby most perceptual measures remained below MD on MD+2. Recovery timelines differed depending on the perceptual scale as based on menstrual phase and match load, without consistent influence of one phase.

Chapter 6: Study 4

Influence of menstrual phase and symptoms on sleep before and after matches for professional footballers

As based on the publication:

Brown, G. A., Fullagar, H.H.K. & Duffield, R. Influence of Menstrual Phase and Symptoms on Sleep Before and After Matches for Professional Footballers. *Scandinavian Journal of Medicine & Science in Sports, 35*(1), e70011.

6.1 Abstract

Purpose: This study investigated the association of menstrual cycle phase and symptoms with objective and subjective sleep measures from professional footballers before and after matches.

Methods: Twenty-three non-HC-using professional footballers (from four clubs) were monitored for up to four menstrual cycles during a domestic league season. Menstrual phases (early-follicular, late follicular, luteal) were determined using calendar-counting and urinary hormone tests (LH and PdG). Players rated the severity of 18 symptoms on the evenings of matches and the following two evenings. Individual daily MSS scores were calculated. Subjective sleep quality was rated the morning of matches and following two mornings. Objective sleep (bedtime, waketime, TST, SOL, WASO, SE) obtained from actigraphy was measured the night prior to (MN-1), of (MN) and following (MN+1) matches. Linear mixed models were performed for each sleep measure to examine the effects of menstrual phase and symptoms.

Results: Bedtime was significantly later for MN ($p < 0.001$), waketime was significantly earlier for MN+1 ($p < 0.001$) and TST was significantly longer for MN-1 ($p < 0.001$). Menstrual phase did not have a significant effect on any sleep variable ($p>0.05$). Increased MSS score was associated with increased TST ($p = 0.03$) and increased waketime ($p = 0.03$). Increased lower back pain severity and mood changes/anxiety severity were associated with increased waketime ($p = 0.048$) and TST ($p = 0.009$) respectively.

Conclusion: Overall, bedtime and waketime were affected by the night related to matches, with increased TST the night before a match. Menstrual phase was not related to any objective or subjective sleep variables, whilst increasing MSS was related to later waketime and longer TST.

6.2 Introduction

To optimise football performance, sufficient volume and quality of sleep is considered an important part of preparation and recovery for training and competition (Fullagar et al., 2015b). As such, understanding factors influencing players' sleep duration, quality and behaviour is essential, particularly around matches where athlete sleep is disrupted (Fullagar et al., 2015a). However, compared to male athlete sleep research, female athlete research is scarce with only 25% of studies reporting female-specific sleep data (Power et al., 2024). As such, understanding the influence of female specific factors, such as the menstrual cycle, which may negatively impact sleep is limited (Power et al., 2024). Indeed, the menstrual cycle, which involves endogenous sex hormones fluctuations that primarily control reproductive function (McNulty et al., 2020), may affect sleep patterns, behaviours and perceptions (Power et al., 2024), though this is yet to be explored in football players as related to match days. The influence of the menstrual cycle on sleep may be related to phase-based hormonal fluctuations (Alzueta & Baker, 2023), as well as the presence of menstrual symptoms, like headaches and abdominal cramps (Alzueta & Baker, 2023). Given disrupted sleep can affect performance (Fullagar et al., 2015b), understanding whether menstrual phase and symptoms affect footballers' sleep may assist in the implementation of sleep monitoring and player management strategies to optimise performance and post-match recovery.

The effect of menstrual phase on sleep in relation to hormonal variations is complex. Theoretically, oestrogen and progesterone fluctuations may influence sleep due to the locations of their receptors throughout the central nervous system in areas of sleep modulation (Alzueta & Baker, 2023). Evidence of objective sleep responses across menstrual phases show conflicting results (Alzueta & Baker, 2023), though subjective sleep quality is frequently reported to be disturbed during and prior to menstruation (Alzueta & Baker, 2023). In athlete specific studies, objective sleep measures, TST and SE, are demonstrated to vary between menstrual phases (Hrozanova et al., 2021; Koikawa et al., 2020). Additionally, professional footballers subjective sleep quality was unaffected by menstrual phase on match day and the following three days (Abbott et al., 2024). Of note, these studies (Abbott et al., 2024; Hrozanova et al., 2021; Koikawa et al., 2020) used calendar-based counting to estimate menstrual phase, which cannot accurately determine phase and increases the likelihood of including participants with subtle menstrual disturbances and heterogenous hormonal profiles (Elliott-Sale et al., 2021). Research with more robust menstrual phase measures is required to better understand the association between menstrual phase and sleep for footballers, particularly around matches where optimising sleep is critical to performance and recovery.

Sleep disturbance is common amongst women with menstrual symptoms, particularly women with menstrual dysfunction such as premenstrual syndrome (Alzueta & Baker, 2023). Between 24 and 100% of athletes are reported to experience negative menstrual symptoms (Oester et al., 2024); however, little is known about their effect on athlete sleep. Amongst professional footballers sleep duration and WASO increased with increasing number of symptoms, though number of symptoms had no relationship with subjective sleep (Halson et al., 2024). In contrast, a cross-sectional study of trained to international level athletes found increasing menstrual symptom frequency was associated with decreased subjective sleep quality and unfavourable sleep behaviour (Kullik et al., 2024). Whilst these studies demonstrate variable effects of menstrual symptoms on athlete sleep, the effect of menstrual symptoms on athlete sleep around competition has not been examined, which is arguably the most important time for sleep given the likelihood for impaired sleep is highest due to match loads and schedules (Fullagar et al., 2015a; Fullagar et al., 2015b). Given the high prevalence of menstrual symptoms, and the importance of sleep to athletic performance and recovery, further studies are required to confirm these findings.

The aims of this study were to explore whether there is an association between football players' objective and subjective sleep around matches and i) menstrual phase and ii) menstrual symptoms. A secondary aim was to examine the influence of each night (night before, of and following matches) to understand changes in footballers' sleep around matches.

6.3 Methods

Participants

Female footballers from four clubs in a professional national domestic league were invited to participate in the study. Initial stipulation of the exclusion criteria involved pregnancy, using HCs or having used HCs in the previous 3 months, average menstrual cycle in the previous three months <21 days or >35 days, diagnosed with any illness or disease which disrupts the menstrual cycle (e.g., polycystic ovary syndrome) (Elliott-Sale et al., 2021). Following this, 32 players consented to participate and completed an online questionnaire regarding the exclusion criteria to confirm eligibility. Nine players were excluded or withdrew prior to commencing any sleep measures (irregular cycles and/or cycle lengths >35days [n = 3], season long injuries [n = 2], personal reasons [n = 4]), resulting in 23 players data being included in the study (23.9 ± 6.0y, 167.9 ± 6.5cm, 65.1 ± 8.9kg). Ethical approval was provided by the Institutional Human Research Ethics

Committee (ETH22-7106) and written informed consent was provided by all players, including parents for those aged 16-17y.

Study Overview

Menstrual cycle and sleep data were collected from 23 professional football players during their 2022/23 season. Participants were asked to track their menstrual cycle via urinary hormonal testing and self-reporting menses, monitor menstrual symptoms via a questionnaire, and record objective sleep via actigraphy. This study was part of a larger study which monitored participants for up to four menstrual cycles, measuring several performance and recovery related factors on match day and the following two days, including subjective sleep quality. Of note, mean kick-off time was 3:30pm ± 1h 15min, range 1:00pm – 7:00pm). To minimise participant burden and maximise compliance, participants were asked to track their objective sleep concurrent to menstrual cycle monitoring for up to two menstrual cycles.

Menstrual phase classification

Following completion of the exclusion criteria questionnaire and confirmation of a 21-35 day menstrual cycle, participants were setup on Smartabase (Fusion Sport, Brisbane, Australia) to report days of menstruation. To estimate menstrual phase and reduce the risk of including anovulatory cycles/heterogeneous hormonal profiles, participants were provided with urinary LH and PdG test kits, with written and video instructions. The lead researcher calculated all LH and PdG test start dates as per the manufacturer's instructions and communicated dates to participants via WhatsApp (Facebook, Inc). The LH (Clearblue Ovulation Digital Test kits, Geneva, Switzerland) tests are 99% effective at detecting a surge in LH (> 40mlU.mL^{-1}) (Ellis et al., 2011), which predict ovulation within

24 – 48h of a positive test (Miller & Soules, 1996). Participants were instructed to test daily at approximately the same time, until a positive test was obtained or until 10 consecutive days without a positive test. If participants did not receive a positive test after 10 days, the researcher assessed whether additional testing days were beneficial (e.g., for longer cycles), or instructed participants to stop testing. Participants with a positive LH test were asked to complete PdG tests (Confirm Kit, Proov, USA) to confirm an increase in PdG > $5 \mu g \cdot mL^{-1}$, which correlates to serum progesterone (Roos et al., 2015). Participants were instructed to start testing seven days after a positive LH surge for four consecutive mornings. The menstrual cycle was classified into three phases (Bruinvels et al., 2022):

- Early-follicular phase: days of menstruation or until day five of each cycle (whichever was longer), when >2 days of bleeding occurred, regardless of LH and PdG test results as this represents the low hormone phase.
- Late follicular phase: from the day after the early-follicular phase until 1 day after a positive LH test, only if a positive LH test was received.
- Luteal phase: from the day after the late-follicular phase until the day prior to the next cycle starting, when positive LH and PdG tests were detected, and the luteal phase was ≥10 days (Schliep et al., 2014).

Verification and further subclassification of menstrual phases require confirmation of hormone concentrations via blood samples (Elliott-Sale et al., 2021), however, this was not possible in the current study due to participants training and competing across multiple states and countries.

Menstrual symptoms severity

On the evening of match days and the following two evenings participants completed a daily Menstrual Symptoms Severity questionnaire. The questionnaire consisted of 18 menstrual related symptoms rated on a Likert Scale; 0 – none, 1 – mild, 2 – moderate, 3 – severe. A daily MSS score was calculated by summing the severity of all symptoms, resulting in a score between 0 (no symptoms) and 54 (maximal daily presence and severity of symptoms). The daily summed score was used in the analysis as summed MSS score. The questionnaire was adapted from the Menstrual Symptoms Index (Bruinvels et al., 2021), which assesses symptom frequency and has previously been used with exercising women, though as yet it is not psychometrically validated. Additionally, the six most reported symptoms from this study were then used for analysis of individual symptom severity effects within mixed model analyses.

Sleep

Objective sleep parameters were measured through actigraphy using the Actigraph GT9X Link. The Actigraph GT9X Link is a valid alternative to polysomnography, which is the gold standard sleep measurement, with a demonstrated accuracy of 89% and sensitivity of 94%, although a lower specificity 57%, when using the Cole-Kripke algorithm for analysis (Roberts et al., 2020). Actigraphy is a practical sleep measurement which detects movement and uses an algorithm to determine sleep/wake schedules (Lehrer et al., 2022). The actigraphs were setup with the following participant details: height (cm), body mass (kg), date of birth and non-dominant wrist. The sampling frequency and epochs were set at 60Hz and 60seconds respectively. Participants were instructed to wear the watch on their non-dominant wrist, from approximately 1h prior to bedtime to after waking in the morning for three consecutive nights starting from the night prior to their team's match. Participants also had one night of familiarisation prior to the first night of monitoring. To assist in determining sleep onset and waketimes, concurrent to wearing the actigraph participants were asked the following as based on the Consensus Sleep Diary (Carney et al., 2012), which accurately assesses sleep timings (Dietch & Taylor, 2021):

- What time did you try to go to sleep?
- How long did it take you to fall asleep?
- What time was your final awakening?

Team travel dates were obtained from club staff members to account for time-zone differences when calculating bedtime and wakeup time as the actigraphs do not account for this. Additionally, subjective sleep quality was measured by a single question "How was your sleep last night?" rated on a 7-point Likert scale from 1 "Outstanding sleep" to 7 "Horrible, virtually no sleep" as based on the Hooper Index questionnaire (Hooper & Mackinnon, 1995), which participants were completing as part of the larger study. Participants answered these on Smartabase as part of their morning monitoring questionnaire on match day and the following two mornings.

Actigraph data was analysed using ActiLife (Florida, USA). The following sleep variables were obtained from the actigraphs and sleep questions (Lastella et al., 2015; Roberts et al., 2020):

- Bedtime (hh:mm): the self-reported clock time at which a participant went to bed to attempt to sleep.
- Waketime (hh:mm): the self-reported clock time at which a participant woke up and stopped attempting to sleep.
- Sleep onset latency (SOL; min): the period between bedtime and sleep onset time.
- Total sleep time (TST; h min): the total amount of sleep obtained during a sleep period.

- Sleep efficiency (SE; %): the percentage of time in bed that was spent asleep.
- Wake after sleep onset (WASO; min): the total amount of time spent awake during a sleep period.

Squad selection

Each team invited to participate in the study consisted of a minimum of 23 players, however, only 16 players were selected in each match day squad. Therefore, participants were categorised as "in squad" or "not in squad" for each match. This was recorded due to known effects of match and training schedules on sleep (Sargent et al., 2014; Sim et al., 2023).

Data management

Sleep data exported from ActiLife was aligned with the menstrual cycle and sleep quality data in an excel spreadsheet. Night-time sleep was aligned with the following morning's sleep quality data and evening menstrual symptoms data and labelled as match night (MN) i.e., MN-1 (sleep the night before matches), MN (sleep the night of matches) and MN+1 (sleep the night after match day). A minimum of one recorded sleep in at least two menstrual phases (early-follicular, late-follicular, luteal) for two or more of the nights (MN-1, MN, MN+1) was required to be included in the menstrual phase models. A minimum of two recorded sleeps aligned with menstrual symptoms data for two or more of the nights (MN-1, MN, MN+1) was required to be included in the menstrual symptom models.

Statistical Analysis

All analyses were completed in R Statistical Software (R Core Team 2020). Respective linear mixed effect models were performed to determine the association of *menstrual phase* (early-follicular, late-follicular, luteal) and *MSS score* with the sleep variables. Linear mixed models are unable to handle missing predictor variable data, thus separate models were created for *menstrual phase* and *MSS score* as the fixed effect due to final dataset differences. Additionally, analyses for the six most prevalent individual symptom severities; tiredness/fatigue, mood changes/anxiety, cravings/increased appetite, lower back pain, bloating/increased gas and joint pain, in association with the sleep variables were performed (symptom severities as fixed effects), separate to the *menstrual phase* and *MSS score* models. To examine the influence of *night* (MN-1, MN, MN+1) on sleep variables, it was included as a fixed effect in all models whilst *participant ID* was included as a random effect due to repeated within participant observations. To control for the effect of *squad selection* it was included in each model. The interaction effect of *squad selection***night* was of interest, however, due to the limited number of observations this interaction effect was not possible. Bonferroni Holm correction was applied to the p-values obtained for the main effect of *night* on all sleep variables to control for multiple testing (*night* included in both menstrual phase and menstrual symptom models). For the phase models, post-hoc pairwise comparisons were performed using estimated marginal means (emmeans package) and Tukey's adjustment for *menstrual phase* and *night,* with the difference in estimated marginal means between pairs reported e.g., early-follicular phase – late-follicular phase (reported as delta difference Δ). To avoid repeated testing of *night*, post-hoc pairwise comparisons were not performed for the symptom models. The assumptions of homogeneity and normality of residuals were assessed using residuals vs fitted plots and QQ plots respectively. Of note, SOL demonstrated heteroskedasticity and was log-transformed to improve model fit, with estimates back-transformed. Significance was set at $p < 0.05$. Marginal and conditional R^2 were calculated to explain the proportion of variance explained by the fixed effects and whole model respectively.

6.4 Results

A total of 210 from a possible 379 sleep periods (55%) were recorded via actigraphy from 21 participants. After aligning data which met the inclusion criteria, included in the final objective sleep parameters analyses were 107 menstrual phase observations (early-follicular = 20, late-follicular = 47, luteal = 40) from nine participants and 145 menstrual symptoms observations from 20 participants. The subjective sleep quality data from the larger scale study resulted in 318 menstrual phase observations (early-follicular = 78, late-follicular = 131, luteal = 109) from 15 participants and 379 menstrual symptoms observations from 23 participants. Of note, two participants reported 37-38 day cycles though reported positive LH and PdG tests for all cycles, therefore their data were retained.

Menstrual phase models

The main effects from the menstrual phase models are reported in Table 6.1, Figure 6.1 and Supplementary Table 1 (see Appendix A). Sleep variables did not significantly differ between menstrual phases ($p > 0.05$). Bedtime, waketime and TST significantly differed between nights ($p < 0.001$). Pairwise comparisons for menstrual phase and night for all sleep variables are reported in Table 6.2. Bedtime was significantly later for MN compared to MN-1 (Δ= 01:27; $p < 0.001$) and MN+1 (Δ = 01:17; $p < 0.001$). Waketime was significantly earlier for MN+1 compared to MN-1 (Δ = 00:56; $p < 0.001$) and MN (Δ = 00:58; $p < 0.001$). Significantly longer TST was reported for MN-1 compared to MN (Δ = 01:21; $p < 0.001$), and MN+1 (Δ = 00:57; $p < 0.001$).

Table 6.1 Model outputs for objective and subjective measures of sleep as related to menstrual phase and night.

Sleep measures	**Menstrual phase (p-value)**	**Night (p-value)**	**R^2m; R^2c**
Bedtime (hh:mm)	0.71	<0.0001*	0.29; 0.30
Waketime (hh:mm)	0.49	<0.0001*	0.17; 0.22
Total sleep time (hh:mm)	0.35	<0.0001*	0.24; 0.43
Sleep onset latency (min)	0.47	0.34	0.05; 0.24
Wake after sleep onset (min)	0.52	0.48	0.03; 0.49
Sleep efficiency (%)	0.29	0.34	0.03; 0.63
Sleep quality (au)	0.55	0.37	0.01; 0.19

R^2m = marginal R^2; R^{2c} = condition R^2; *indicates significant association ($p<0.05$) between menstrual phase or night and the sleep measure

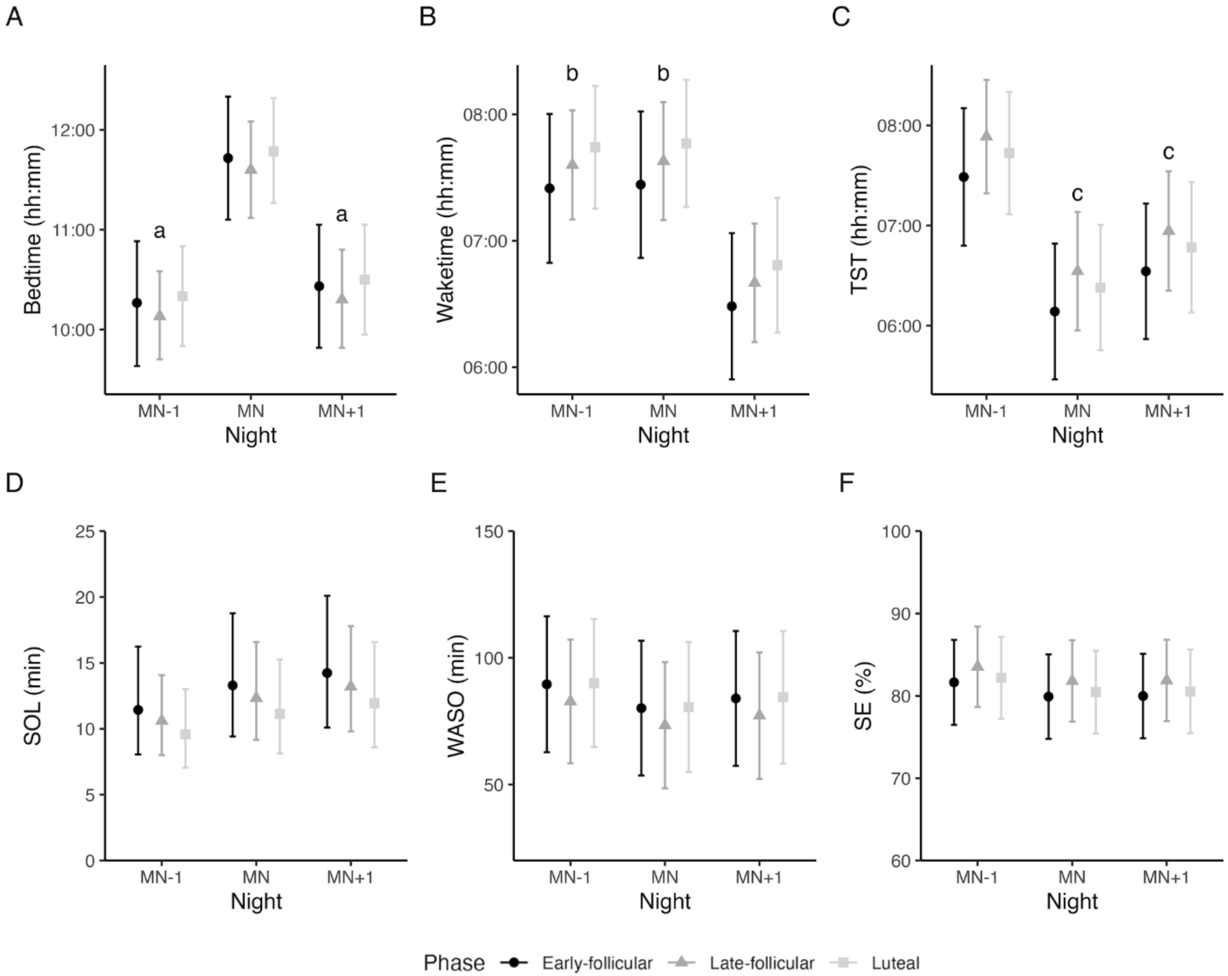

Figure 6.1 Objective sleep measures as determined by menstrual phase and night for A) bedtime, B) waketime, C) TST, D) SOL, E) WASO and F) SE. Results are estimated marginal effects and 95% confidence intervals.

TST = total sleep time; SOL = sleep onset latency; WASO = wake after sleep onset; SE = sleep efficiency.

a = significantly different from MN, b = significantly different from MN+1, c = significantly different from MN-1.

Table 6.2 Results of pairwise comparisons between nights and menstrual phases.

Sleep measures	Δ EMM (95% CI)	p value
Bedtime (min)		
MN-1 – MN	-87 (-122, -53)	<0.0001*
MN-1 – MN+1	-10 (-46, 26)	0.78
MN – MN+1	77 (39, 115)	<0.0001*
Early-follicular – late-follicular	7 (-36, 51)	0.95
Early-follicular – luteal	-4 (-48, 40)	0.97
Late-follicular – luteal	-12 (-46, 23)	0.73
Waketime (min)		
MN-1 – MN	-2 (-34, 30)	0.99
MN-1 – MN+1	56 (23, 79)	0.0003*
MN – MN+1	58 (23, 93)	0.0004*
Early-follicular – late-follicular	-11 (-51, 29)	0.79
Early-follicular – luteal	-20 (-60, 21	0.49
Late-follicular – luteal	-8 (-40, 23)	0.80
Total sleep time (min)		
MN-1 – MN	81 (49, 113)	<0.0001*
MN-1 – MN+1	57 (23, 90)	0.0003*
MN – MN+1	-24 (59, 11)	0.23
Early-follicular – late-follicular	-24 (-64, 16)	0.34
Early-follicular – luteal	-14 (-56, 27)	0.69
Late-follicular – luteal	10 (-22, 42)	0.74
Sleep onset latency (min)		
MN-1 – MN	-2 (-5, 2)	0.44
MN-1 – MN+1	-3 (-6, 1)	0.23
MN – MN+1	-1 (-5, 3)	0.86
Early-follicular – late-follicular	1 (-4, 6)	0.88
Early-follicular – luteal	2 (-3, 7	0.52
Late-follicular – luteal	1 (-2, 5)	0.67
Wake after sleep onset (min)		
MN-1 – MN	9 (-7, 26)	0.36
MN-1 – MN+1	6 (-11, 23)	0.71
MN – MN+1	-4 (-22, 14)	0.86

Table 6.2 continued

Early-follicular – late-follicular	7 (-14, 28)	0.72
Early-follicular – luteal	-0.5 (-22, 21)	1.0
Late-follicular – luteal	-7 (-24, 9)	0.54
Sleep efficiency (%)		
MN-1 – MN	2 (-1, 4)	0.25
MN-1 – MN+1	2 (-1, 4)	0.31
MN – MN+1	-0.1 (-3, 3)	1.0
Early-follicular – late-follicular	-2 (-5, 1)	0.36
Early-follicular – luteal	-1 (-4, 3)	0.92
Late-follicular – luteal	1 (-1, 4)	0.43
Sleep Quality (au)		
MN-1 – MN	-0.2 (-0.5, 0.1)	0.36
MN-1 – MN+1	-0.2 (-0.6, 0.1)	0.28
MN – MN+1	-0.02 (-0.4, 0.3)	0.98
Early-follicular – late-follicular	0.01 (-0.4, 0.4)	1.0
Early-follicular – luteal	-0.1 (-0.5, 0.3)	0.7
Late-follicular – luteal	-0.1 (-0.5, 0.2)	0.6

CI = confidence interval; ΔEMM = difference in estimated marginal means between pairs; MN-1= night prior to match, MN = night of match; MN+1 = night following a match; * indicates significant difference ($p<0.05$) between pairs

Menstrual symptoms

From the 379 menstrual symptoms observations from 23 participants, a total of 1479 symptoms were reported, of which 69% were rated as 1 (mild), 26% as 2 (moderate) and 5% as 3 (severe). The median number of symptoms per player per day was 3 out of 18 (IQR 1 - 6) and MSS score was 4 out of 54 (IQR 1 - 7). The main effects for the menstrual symptom models are reported in Table 6.3 and Figure 6.2. For every one unit increase in MSS score TST increased by 3.1min ($p = 0.03$), representing longer sleep duration, and waketime increased by 3.2min ($p = 0.03$), representing a later waketime. Bedtime ($p < 0.0001$), waketime ($p = 0.0002$) and TST ($p = 0.001$) significantly differed between nights. The six most prevalent menstrual symptoms reported were 1) tiredness/fatigue, 2) mood changes/anxiety, 3) cravings/increased appetite, 4) lower back pain, 5) bloating/increased gas and 6) joint pain. Holding other individual symptom severity variables constant, waketime was increased with increased lower back pain severity ($p = 0.048$, coefficient = 21.1min). Additionally, TST was increased with increased mood changes/anxiety severity ($p = 0.009$, coefficient = 32.8min). Bedtime, SOL, WASO, SE and sleep quality were not significantly associated with symptom severities ($p > 0.05$).

Table 6.3 Model outputs for objective and subjective measures of sleep as related to menstrual symptoms and night.

Sleep measures	Menstrual symptoms		Night	R^2m; R^2c
	p value	**Coefficient (95% CI)**	**p value**	
Bedtime (hh:mm)	0.44	-1.11 (-3.93, 1.68)	<0.0001*	0.17; 0.30
Waketime (hh:mm)	0.03*	3.19 (0.48, 5.89)	0.0002*	0.15; 0.30
Total sleep time (hh:mm)	0.03*	3.10 (0.4, 5.8)	0.001*	0.13; 0.19
Sleep onset latency (min)	0.87	-0.002 (-0.02, 0.02)#	0.99	0.001; 0.20
Wake after sleep onset (min)	0.51	0.46 (-0.89, 1.81)	0.83	0.01; 0.33
Sleep efficiency (%)	0.91	-0.02 (-0.27, 0.25)	0.40	0.01; 0.40
Sleep quality (au)	0.26	-0.02 (-0.04, 0.01)	0.40	0.01; 0.29

CI = confidence interval; R^2m = marginal R^2; R^{2c} = condition R^2; #estimates are on the log scale; * indicates significant association ($p<0.05$) between menstrual symptoms or night and the sleep measure

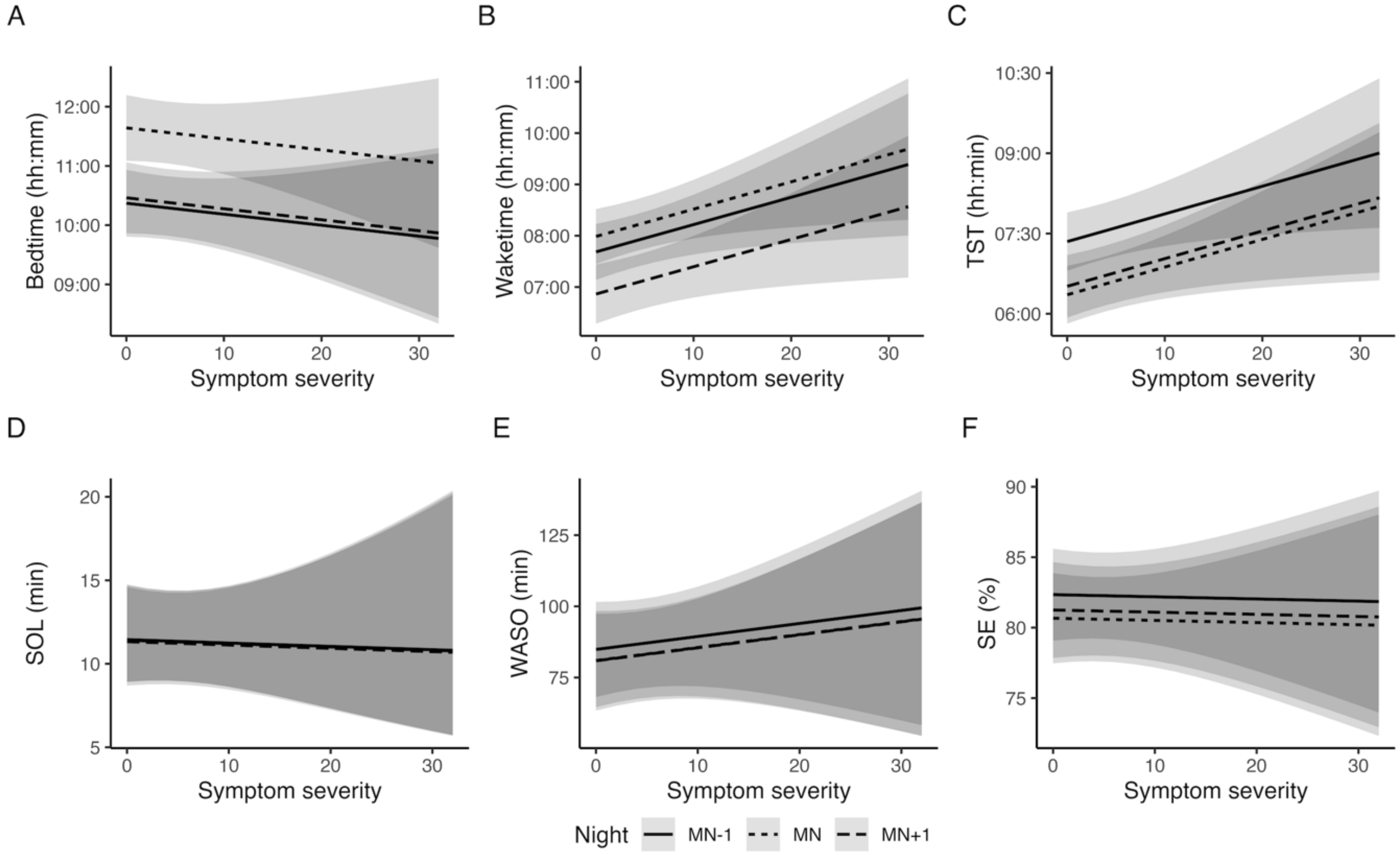

Figure 6.2 Objective sleep measures as determined by menstrual symptoms severity score and night for A) bedtime,

Results are marginal effects (lines) and 95% confidence intervals (shaded areas). Higher symptom severity score represents a higher number and/or severity of symptoms. TST = total sleep time; SOL = sleep onset latency; WASO = wake after sleep onset; SE = sleep efficiency.

6.5 Discussion

This study examined the relationship between menstrual phase and symptoms with the objective and subjective sleep of professional footballers on nights around matches. As expected, the night related to the match had a significant effect on bedtime, waketime and TST, resulting in longer TST the night before a match (MN-1). Menstrual phase (early-follicular, late-follicular, luteal) was not related to any objective sleep variables or subjective sleep quality the nights prior (MN-1), of (MN) or the following (MN+1) the match. Increasing MSS score and lower back pain severity was associated with later waketime, whilst increasing MSS score and mood/anxiety changes severity was associated with longer sleep durations (TST). Overall, this study highlights female footballers' sleep is influenced by matches more so than menstrual phase, though monitoring menstrual symptoms may improve understanding of players' sleep.

To provide initial context, and as supported by the current literature (Fullagar et al., 2015a; Sargent et al., 2014; Sim et al., 2023), the night of sleep related to matches had a significant effect on the timings of sleep (bedtime and waketime) and sleep duration (TST), though no relationship was evident with other objective sleep measures or subjective sleep quality. Bedtime was ~1h 20min later for MN than MN-1 and MN+1. This was likely an effect of evening matches as well as the high physical and cognitive loads encountered during matches (Fullagar et al., 2016b; Sim et al., 2023), though it's acknowledged match kick off times and measures of load were not included in the models. That said, not all players were part of the match day squad and previous research shows they may also have reduced sleep quality and volume on match nights (Fullagar et al., 2016a). Waketime was ~1h earlier for MN+1 than MN-1 and MN; which likely demonstrates an effect of morning training schedules (Sargent et al., 2014) reported by clubs, although were not specifically recorded or included in the models. Finally, TST was highest for MN-1, being 1h 21min and 57min greater than MN and MN+1 respectively, highlighting the effect that later bedtimes after a match (MN) and earlier waketimes for training (MN+1) have on TST. Similar results are reported in other football codes (Sim et al., 2023) and may reflect players' attempting to maximise sleep on nights prior to matches to enhance performance. The match-imposed sleep disruptions resulted in less than the recommended sleep duration (<7h) on match nights, which is commonly reported the night after competition (Sim et al., 2023), due to late matches, physical arousal and mental stimulation from match-play, post-match press and social commitments (Fullagar et al., 2015a) and may negatively affect recovery (Fullagar et al., 2016b).

In the present study, objective and subjective sleep did not differ between menstrual phases (early-follicular, late-follicular, luteal) the night prior to, night of and night following matches. Research on the influence of menstrual phase on sleep has primarily been conducted with the general population, whereby conflicting changes in objective sleep are reported, though subjective sleep quality is reportedly worse around menstruation (Alzueta & Baker, 2023). Our results concur with those of an English professional football club where subjective sleep quality on match day and the following three days (including both matches and training), was unaffected by menstrual phase (Abbott et al., 2024). However, this differs to the findings of Koikawa et al (2020) , who reported lower TST, increased SOL and lower SE during the first two nights of menstruation, compared with the mid-follicular phase for college athletes from various sports, as recorded by at home EEG during one menstrual cycle, though not related to training or match days. Additionally, Australian Rules Football athletes reported worse subjective sleep quality during the luteal than follicular phase (Carmichael et al., 2021a), however, the sample size was low (n = 5) and sleep was only assessed prior to training sessions. Perhaps in the current study the influence of matches, and the larger influence of schedules, travel, cognitive and physical load due to match demands concealed menstrual phase related changes in sleep suggested in the aforementioned studies. Thus, our findings suggest there is limited association between menstrual phase and sleep outcomes for professional footballers the night before, night of and night following matches.

For menstrual symptoms experienced, most were rated as mild (69%), though the number of symptoms experienced per player and day ranged from 0 - 18. While a significant relationship between menstrual symptoms and objective sleep was reported, there was no association between symptoms and subjective sleep quality. Specifically, around match days increased MSS score and lower back pain severity was associated with a later waketime, whilst increased MSS score and mood changes/anxiety severity was associated with a longer TST. Interestingly, tiredness/fatigue severity was not associated with any sleep variables. The findings suggest participants woke later and slept longer, which could be inferred as a self-management strategy to help cope with increased symptom severities, despite potential sleep restrictions imposed by the matches. Of note, the practical impact was likely low for most players given the median MSS score was 3, equating to +9min waketime and TST. Similar findings were reported in a professional English football club, with increased sleep duration (+21min) associated with increased number of symptoms assessed across one menstrual cycle (Halson et al., 2024). Therefore, where longer sleep durations are inhibited e.g., early morning post-match travel or trainings, recommending alternate sleep strategies to players with high symptom severity may be beneficial. In comparison, previous research reported menstrual symptoms did not affect college athletes' TST, though only a single-item symptom question was used and sleep was not assessed in relation to match or training nights (Koikawa et al., 2020). In German athletes, decreased subjective sleep quality was associated with increased menstrual symptom frequency, an association which is supported by general population studies (Alzueta & Baker, 2023; Van Reen & Kiesner, 2016). Our study did not show these findings, possibly due to a lack of sensitivity of the single-item sleep quality question used, as opposed to the validated Pittsburgh Sleep Quality Index used within the German athlete study (Kullik et al., 2024). Overall, footballers' sleep does not appear to be negatively impacted by menstrual symptoms on nights around matches, though players appear to self-manage menstrual symptoms with sleep extension strategies.

The study is not without limitations, which should be taken into consideration when interpreting the results. Firstly, serum oestrogen and progesterone hormone analysis to confirm menstrual phase was not possible due to the widespread geographical location of training sessions and matches. This could have resulted in the inclusion of players with heterogeneous hormonal profiles, however, the methods used within the current study balance practicality of researching with professional athletes whilst implementing some hormonal testing to reduce menstrual status and phase estimation errors. The lack of validity surrounding the sleep quality measure is acknowledged, however, to minimise participant burden it was decided not to ask participants to complete a separate sleep quality questionnaire, and single-item questions are common in elite sport (Jeffries et al., 2020). It should also be recognised the symptoms questionnaire is yet to be validated, though provides practitioners valuable insights. Further, several factors which could have affected participant sleep such as travel, home vs away matches and physical match load (Fullagar et al., 2015a) were not controlled for within the study. Whilst these variables were recorded, small sample sizes transpired (particularly objective sleep vs menstrual phase [n = 9]), which may have resulted in an underpowered sample size, thus the inclusion of the variables as fixed effect covariates would have resulted in overfitting, therefore simplified models were used.

6.6 Conclusion

The present study found no association between menstrual phase and objective or subjective sleep, no association between menstrual symptoms and subjective sleep and small associations between menstrual symptoms and objective sleep during the nights before and after matches for footballers. Whilst acknowledging the limited sample size, this multi-club study highlights matches affect female players' sleep more so than menstrual phase during the nights before and after matches. However, increased menstrual symptom severities were associated with longer sleep durations and later waketimes, which may suggest players utilise sleep to manage menstrual symptoms. Monitoring menstrual symptoms and implementing sleep extension or menstrual symptom management strategies to assist increased sleep could be of practical benefit to promote player recovery and performance.

Chapter 7: Discussion

7.1 Overview

Ongoing concerns exist regarding female athlete menstrual health and the effects of the menstrual cycle on athlete performance and recovery, which is particularly evident in football (Hirschberg, 2022; Moore et al., 2023; Nassis et al., 2022). However, females are underrepresented in sport and exercise research, which has led to a lack of knowledge surrounding female athlete-specific concerns such as the menstrual cycle (Costello et al., 2014; Mujika & Taipale, 2019; Okholm Kryger et al., 2021). The menstrual cycle's potential influence on performance, recovery and sleep is multi-factorial, including the impact of menstrual health-associated abnormalities, menstrual phases as related to hormonal fluctuations and menstrual symptoms. From a health perspective, several menstrual abnormalities exist that are known to impair athlete health, performance and recovery, for example menstrual dysfunctions associated with REDs (Mountjoy et al., 2023), and HMB (Bruinvels et al., 2016; Hinton, 2014). Additionally, performance and recovery may fluctuate between menstrual phases in individuals with healthy menstrual cycles where contrasting concentrations and ratios of oestrogen and progesterone exist (Bernstein & Behringer, 2023; McNulty et al., 2020). Further, during menstruation, the presence of bleeding and menstrual symptoms may also be associated with changes in performance and recovery (Bruinvels et al., 2022). As menstrual symptoms may be experienced regardless of a healthy menstrual cycle, the influence of menstrual symptoms on performance and recovery should also be considered independently of menstrual phases. Therefore, the potential implications for the menstrual cycle on performance and recovery are multi-faceted and require attention to best support female football players.

Therefore, the aims of this thesis were:

1. Understand the menstrual health, symptomatology and perceived effects of the menstrual cycle on performance in elite junior and senior football players (Study 1).
2. Explore the effects of menstrual cycle phase and symptoms on physical match performance in elite football players (Study 2).
3. Explore the influence of menstrual cycle phase on perceptual measures and recovery timeline of perceptual measures in elite football players around matches (Study 3).
4. Explore the relationship of menstrual cycle phase and symptoms with objective and subjective measures of sleep for elite football players around matches (Study 4).

7.2 Menstrual health

Menstrual abnormalities, inclusive of abnormal uterine bleeding disorders (e.g., amenorrhea and HMB) and symptom-related conditions, can be harmful to athlete health, performance, and recovery, and hence an understanding of menstrual health is important (Elliott-Sale et al., 2020; Klingenberg, 2022; Mountjoy et al., 2018). Concerns for athlete menstrual health are heightened by the normalisation of menstrual dysfunction in sport and historically the menstrual cycle being viewed as a taboo (Brown et al., 2021; Solli et al., 2020; Verhoef et al., 2021). Providing further insight on menstrual health of football players within Australia can help guide the development of menstrual health monitoring, education, and management strategies for female football practitioners.

The prevalence of menstrual abnormalities amongst football players varies significantly between studies based on the type of menstrual abnormality, methodology, terminology and cohort (Mkumbuzi et al., 2021; Molnár et al., 2016; Parker et al., 2022; Prather et al., 2016; Read et al., 2021). The findings from Study 1 (Chapter 3) reported one case of primary amenorrhea (absence of menstruation ≥15y) from 199 players (0.5%), whilst 26% of players reported age of menarche ≥15y (16% aged 15y, 20% aged ≥16y), suggesting historical cases of primary amenorrhea. Interestingly, only one other study has reported on current and historical primary amenorrhea for football players which found no current or historical cases, (defined as absence of menstruation ≥16y), amongst elite players in Hungary (n = 65) (Molnár et al., 2016). Amenorrhea is the most severe menstrual dysfunction (Reed et al., 2015), and amongst athletes is commonly caused by problematic low energy availability, which in turn causes impairments to health, performance and wellbeing as explained by REDs (Mountjoy et al., 2023). The low number of primary amenorrhea cases reported here is reassuring (Taim et al., 2023), though it is estimated a quarter of players in this cohort have previously experienced primary amenorrhea. Given the number of historical cases of primary amenorrhea as well as the concerning association between amenorrhea and REDs (Mountjoy et al., 2023), perhaps education and screening or monitoring of menstrual health amongst adolescent football players would be beneficial for early detection and treatment of primary amenorrhea.

Players were primarily non-HC users, as only 18% of players used HCs. Amongst non-HC users, 1.5% (n = 3/163) were experiencing secondary amenorrhea and from individuals who reported their cycle length, 19% (n = 24/125) were classified as oligomenorrheic (irregular cycle length or cycle length >35 days). The prevalence of secondary amenorrhea is lower than that reported amongst professional football players in England (11%, n = 6/54), though similar to the prevalence of oligomenorrhea reported (15%, n = 8/54) (Parker et al., 2022). The combined prevalence of secondary amenorrhea and oligomenorrhea amongst players in Norway's top two domestic leagues was 30% (n = 8/60; Dasa et al., 2024), which is higher than our findings. Differences between studies could be attributed to the cross-sectional nature of surveys, which determines the prevalence of menstrual dysfunction at one point in time. Given the intraindividual variability in menstrual health and the influence of training load (Baranauskas et al., 2023; Bull et al., 2019), perhaps future research should conduct repeated observations over an entire season, capturing pre-season, in-season and end of season to make more meaningful conclusions about the menstrual health of football players. Overall, the presence of secondary amenorrhea was low whilst the higher presence of oligomenorrhea suggests frequent screening or ongoing monitoring of menstrual cycle length would be beneficial for football players.

Whilst the reporting of menstrual abnormalities is an important first step in understanding female player health, the surveys and questionnaires used to identify menstrual dysfunctions are based on cycle length (e.g., oligomenorrhea, amenorrhea), and cannot detect subtle menstrual disturbances (e.g., anovulation and luteal phase defect; Janse de Jonge et al., 2019). Subtle menstrual disturbances are experienced by 50% of exercising women (De Souza et al., 2009), though this is not specific to football players or elite athlete populations. Subtle menstrual disturbances were detected amongst 24% (n = 8/33) of elite football players when tested as part of selection criteria for a menstrual phased-based performance study (Julian et al., 2020). From the players who participated in Studies 2 to 4 of this thesis, subtle menstrual disturbances were detected in 26/61 menstrual cycles (42%). The higher prevalence compared to Julian et al. (2020) could be due to the accuracy of different progesterone measurements used (serum progesterone vs urine progesterone metabolite) or that Julian et al. (2020) only conducted hormonal testing for the first menstrual cycle for each player. Regardless, the percentage of subtle menstrual disturbances is concerning, as whilst menstrual changes may be unnoticeable to the individual, energy-related menstrual disturbances are a sign of suboptimal psycho-physiological functioning, which is unlikely to support training and performance goals for athletes (Ihalainen et al., 2024a; Mountjoy et al., 2023). Additionally, when combined with the percentage of HC users (~20%), and individuals with oligomenorrhea (~20%) it highlights that hormone-related phase-based changes in performance and recovery are potentially relevant to <50% of players in a football team.

Heavy menstrual bleeding refers to the flow and duration of menstruation, which can cause impairments to athletic performance (Bruinvels et al., 2016; Hinton, 2014) and wellbeing (Vannuccini et al., 2020). Study 1 found 11% of players were experiencing HMB. The reported prevalence is similar to professional African footballers (12%, n = 5/42) (Mkumbuzi et al., 2021), though lower than competitive Australian athletes (Armour et al., 2020), and British track and field athletes (Jones et al., 2024) being 30% (n = 37/124) and 31% (n = 40/128) respectively. Each of these studies used simple terminology such as “heavy periods”, creating a more subjective perception of HMB than the stricter criteria used within this thesis (Fraser et al., 2015), which may have attributed to the lower prevalence reported here. Heavy menstrual bleeding is concerning due to the increased the risk of iron deficiency which can impair submaximal endurance performance (Bruinvels et al., 2016; Hinton, 2014), the association with increased stress and decreased perceived wellbeing (Vannuccini et al., 2020) and the negative impact on training and competition availability (Ekenros et al., 2022). However, research specific to the impact of HMB for football players does not exist and is an area for future research. Additionally, practitioners and researchers should work towards standardisation of terminology and classification criteria for HMB to allow for comparisons between studies, and to guide practitioners working with athletes as to when to refer players for help.

Hormonal contraceptives, which are commonly used for contraception (Clarke et al., 2021; Ekenros et al., 2022), suppress endogenous hormones by introduction of exogenous oestrogen and/or progesterone (Sims & Heather, 2018). A systematic review found oral contraceptives may slightly reduce exercise performance (endurance, strength, power, speed) due to the exogenous hormone influence, although large variability and trivial effects existed across studies (Elliott-Sale et al., 2020). Study 1 found 18% of players used HCs, which is low compared to professional footballers and Australian athletes (28-58%) (Clarke et al., 2021; Larsen et al., 2020; Martin et al., 2018; McNamara et al., 2022; Parker et al., 2022), though higher than South African National Team footballers (10%) (Mkumbuzi et al., 2021). Differing sports, sociocultural and geographical norms may contribute to the varied prevalence of HC use between these studies. The main reasons reported for HC use in Study 1, which are similar to previous research, were contraception, reducing period pain, reducing heaviness of bleeding and controlling cycles (e.g., avoiding menstruation during competition) (Clarke et al., 2021; McNamara et al., 2022; Oxfeldt et al., 2020). Indeed, menstrual symptom management is a benefit of HCs and may outweigh any trivial reductions in performance caused by HC use (Elliott-Sale et al., 2020). However, 30% of players reported negative HC side effects, which should be considered when assessing individual's HC use. Reassuringly, no player reported using HCs as treatment for absence of menstruation, as HCs mask rather than treat menstrual dysfunction (Cheng et al., 2021). Given HCs masks menstrual dysfunction, the prevalence of menstrual dysfunction is likely higher than reported in athletic populations. Understanding footballers' HC use can help minimise negative effects and maximise positive effects of HCs.

Overall, the menstrual health of female footballers is an important part of ensuring healthy players who optimally perform and recover for the increasing demands of modern football. The current findings of this thesis may provide some reassurance to practitioners working with professional football players (aged 17 – 35) within the Australian football landscape given the low prevalence of severe menstrual dysfunction (amenorrhea). Of note, a partial response bias may have occurred, as voluntary participation by the domestic league players may have attracted players with menstrual health conditions (e.g., HMB) while players without a menstrual cycle (i.e., amenorrhea) may have considered the survey irrelevant, potentially leading to an underrepresentation of amenorrhea cases. However, attention to menstrual health education and monitoring strategies would still be beneficial given the considerable percentages of players who previously experienced primary amenorrhea and were experiencing oligomenorrhea, in addition to the potentially high percentage of players with subtle menstrual disturbances, and the known normalisation of menstrual dysfunction amongst athletic populations (De Souza et al., 2009). These results support the need to prioritise player menstrual health and provide alternate solutions to menstrual cycle management for players where hormone-related menstrual phase-based comparisons are unsuitable, such as menstrual symptom management.

7.3 Menstrual symptomatology

Menstrual symptoms can be associated with health conditions (e.g., premenstrual syndrome) and can be experienced irrespective of HC use and menstrual dysfunctions (McNulty et al., 2023; Taim et al., 2023). Athletes should be supported to manage symptoms across their menstrual cycle, regardless of the presence of menstrual dysfunction (e.g., oligomenorrhea), highlighting the need to better understand menstrual symptomatology amongst athletes. This is particularly important given the high prevalence of menstrual symptoms combined with normalisation of menstrual symptoms and lack of athlete-coach communication regarding the menstrual cycle (Brown et al., 2021; Findlay et al., 2020; Hook et al., 2021; Solli et al., 2020). Furthermore, previous research suggests menstrual symptoms prevent some football players from attending training (Parker et al., 2022) and athletes generally perceive a negative effects of menstrual symptoms on performance (Armour et al., 2020; Bruinvels et al., 2021; Findlay et al., 2020).

Menstrual symptoms are common in most females, though severe symptoms can cause significant personal and functional impairment (Biggs & Demuth, 2011), thus it's important to understand their prevalence and impact for athletes. The findings from Study 1 (Chapter 3) demonstrated almost all players (97%) experience one or more menstrual symptoms. In comparison, for English football club players, negative menstrual symptoms were experienced by 40% and 74% of HC and non-HC users as based on a survey (Parker et al., 2022), and 100% (n = 15) of players as based on semi-structured interviews (Read et al., 2021). Given the similar cohorts, different results may be attributed to methodologies (surveys vs interviews), as well as question wording (e.g., number of symptoms examined) (Oester et al., 2024).

As reported in Study 1, 40% of players with menstrual symptoms reported an interference of symptoms with their ability to train/play, work or study. Dysmenorrhea, associated with pelvic pain during menstruation, was not explicitly examined within this thesis. Instead, we evaluated the overall burden of symptoms (i.e., 40% reported symptom interference), rather than focusing solely on pelvic pain, as this was considered crucial for supporting players. Whilst the timing, number and severity of symptoms were not assessed within the survey, the combined knowledge of these findings (presence plus impact) warrants further menstrual symptomatology research for football players.

The median number of symptoms experienced was 5 [IQR 3-7] per player. The most prevalent symptoms being pelvic pain (71%), mood changes/anxiety (58%), tiredness/fatigue (56%), backpain (51%) and cravings/increased appetite (47%). Whilst the use of a survey inherently leads to recall bias (Althubaiti, 2016), a longitudinal study of a national league second division French football team found 95% of players reported one or more menstrual symptoms per cycle, averaging four symptoms per cycle (Dupuit et al., 2023). The most prevalent symptoms were tiredness (53%), mood change (37%), and stomach cramps (37%) (Dupuit et al., 2023). These collective findings are similar to a study of German exercising women and athletes, which reported the same four out of the five most frequently reported symptoms: cravings/increased appetite, mood changes/anxiety, backpain and tiredness/fatigue (Kullik et al., 2024). Similarly, the study where the current menstrual symptoms list originated from also reported four out of the five same most frequently reported symptoms: mood changes/anxiety, cravings/increased appetite, tiredness/fatigue, stomach cramps (Bruinvels et al., 2021). Whilst there are similarities amongst the most frequently experienced menstrual symptoms, the number, type, timing and severity of symptoms varies between athletic populations (Dupuit et al., 2023; Kullik et al., 2024) and likely requires individualised management. In accord, a multidisciplinary approach to menstrual symptom management has previously been suggested (Abay & Kaplan, 2019) and in principle may include: 1) nutritional (cravings/appetite), 2) cognitive/psychological (mood/anxiety), 3) lifestyle (tiredness/fatigue) and 4) pharmacological (pain) management strategies. The commonality of symptoms may also help guide prioritisation of menstrual management strategy education and resources for practitioners, clubs and football federations (Badenhorst, 2024; Carmichael et al., 2024). Overall, individualised and multi-disciplinary management of menstrual symptoms is recommended given the individual variability in the number, type, timing and severity of symptoms (Abay & Kaplan, 2019; Green et al., 2017).

Menstrual symptoms were explored further in Studies 2 and 4 (Chapters 4 and 6), where the severity of menstrual symptoms on match days and the following two days were monitored. From the data included in Study 4, a low proportion of menstrual symptoms were rated as severe (5%), whilst a quarter were rated as moderate (26%). The low prevalence of severe menstrual symptoms is encouraging though it's acknowledged the questionnaire used for Studies 2 and 4 is not validated. It's also possible the days where severe menstrual symptoms were experienced weren't captured given the limited monitoring days (MD to MD+2), or given the small sample size resulting in exclusion of individuals with more severe symptoms. Regardless, future research should consider longitudinal tracking across a season (not restricted to MD to MD+2) with larger sample sizes. Currently there is a lack of research exploring the severity of menstrual symptoms amongst athletes, with many studies relying only on the presence or number of symptoms to inform athlete menstrual symptomatology (Ihalainen et al., 2024b; Kullik et al., 2024; Roffler et al., 2024). The maximum MSS (sum of severity of menstrual symptoms) reported in this thesis was 31, thus the potential cumulative effect of menstrual symptoms, and not simply the number or severity of symptoms should be considered (McNulty et al., 2023).

Overall, this thesis highlighted the need to improve our understanding of menstrual health and symptomatology and to further consider menstrual symptoms when examining menstrual related changes in performance and recovery. However, it should be acknowledged that the focus of menstrual symptoms throughout the thesis was negative, and positive menstrual symptoms can exist along the menstrual cycle which is a limitation of the thesis (Taim et al., 2023).

7.4 Player perceptions of the effects the menstrual cycle on training and competition

Regardless of the health-related or physical effects of the menstrual cycle, how athletes perceive the menstrual cycle is important to their behaviours and actions within and outside of sport. Understanding whether football players within Australia perceive negative effects of the menstrual cycle on competition or training performance is necessary to provide appropriate support, inform menstrual monitoring and management practices and guide future research. As evidence, previous research reports the percentage of athletes perceiving a negative effect of the menstrual cycle on performance varies from 0 to 100% (Oester et al., 2024); thus it cannot be assumed that an athlete perceives their menstrual cycle will negatively affect them. This thesis therefore also examined the perceived effects of the menstrual cycle on training and competition for football players within Australia.

Study 1 (Chapter 3) found 40% of players perceived the menstrual cycle to disrupt their training and/or competition performance. This falls within the range of previous football specific research where 24% to 100% of football players perceived a negative effect of the menstrual cycle, or menstruation, on performance (Matsumoto et al., 2023; Mkumbuzi et al., 2021; Read et al., 2021). The range in response may stem from variations in sociocultural contexts, competition level demographics and the methodologies employed across the different studies. We found increasing number of menstrual symptoms, experiencing HMB and pelvic pain increased the likelihood of players perceiving the menstrual cycle to disrupt their performance. This aligns with previous research where athletes (not including footballers) who experienced three or more symptoms were twice as likely to report their performance was negatively affected by their menstrual cycle (McNamara et al., 2022). Additionally, elite athletes with HMB were more likely to report the menstrual cycle impacted their training and performances than those without HMB (69% vs 39%) (Bruinvels et al., 2016). Such findings warrant the need to better understand how menstrual symptoms and HMB affect performance and recovery. It may also be beneficial for practitioners to screen and treat players for menstrual symptoms, HMB and pelvic pain to minimise possible performance effects.

7.4.1 Perceived timing of menstrual effect

Understanding when players feel most affected by their menstrual cycle can guide menstrual monitoring practices as to when to monitor. Based on the players who perceived a negative effect of the menstrual cycle on training and competition, 89% of players identified menstruation as the time where performance was most disrupted, followed by prior to menstruation (44%), and middle of the cycle (8%), whereas no players selected after menstruation. This aligns with previous research where athletes most often report menstruation as the phase perceived to affect training and performance, followed by the days prior to menstruation (Armour et al., 2020; Ekenros et al., 2022; Martin et al., 2018; Solli et al., 2020). Menstruation (early-follicular phase) being perceived as the most disruptive phase also aligns with the finding of increasing menstrual symptoms, HMB and pelvic pain, increasing the likelihood of perceiving a negative impact of the menstrual cycle given symptoms most frequently occur during menstruation (Martin et al., 2018; Parker et al., 2022), whilst HMB also occurs during menstruation. The low oestrogen and progesterone levels during menstruation may also contribute to players reporting worse perceived performance during this phase (McNulty et al., 2020). As explanation of this assumption, oestrogen and progesterone affect multiple physiological systems, therefore fluctuating oestrogen and progesterone across the menstrual cycle may result in variations in performance (McNulty et al., 2020). However, some players identified middle of the cycle as most disruptive, highlighting the need to support players across their entire cycle and for research to examine multiple phases or time-points. Additionally, positive effects of the menstrual cycle on training and competition were not assessed, though a minority of athletes have previously reported positive effects (Armour et al., 2020), highlighting a limitation of Study 1. Overall, players feel most affected by their menstrual cycle during menstruation, thus practitioner attention to this time of the cycle may enhance player performance, though variability in perceived timing of effects also underscores the need for individualised management.

7.4.2 *Perceived aspects of training and competition affected by the menstrual cycle*

Identifying the aspects of training and competition players feel are affected by their menstrual cycle can also help inform menstrual monitoring and management strategies. Based on players who perceived a negative impact of the menstrual cycle, the most commonly affected responses reported in Study 1 were energy levels (87%), followed by endurance (61%), soreness (56%) and strength (44%). These findings are comparable to other research where fatigue/endurance was most commonly affected, followed by energy levels, concerns for bleeding, strength and speed as reported by a mix of Australian athletes (Armour et al., 2020). Similarly, aerobic fitness and strength were identified as aspects of performance affected by the menstrual cycle amongst Swedish and Norwegian mixed-sport athletes (Ekenros et al., 2022). The least frequently selected aspects of performance disruption in Study 1 were coordination (8%), decision making (11%), ability to recovery (29%) and concentration (30%). Of note, players were provided a pre-defined list of aspects to select from which limits our understanding of the aspects of training and competition perceived to be disrupted by the menstrual cycle. For example, semi-structured interviews with professional football players revealed physical (e.g., power, fatigue, reaction time), psychological (e.g., confidence, focus) and social (e.g., communication) impacts on performance (Read et al., 2021). This qualitative study also identified several match preparation or recovery factors impacted by the menstrual cycle, including appetite, sleep, readiness, recovery and aches (Read et al., 2021). Whether players' perceived impact of the menstrual cycle, the timing of impact and aspects of performance impacted, translates to measurable menstrual-related differences in football performance and recovery is relatively unknown. However, practitioners need to employ strategies that help players feel physically and psychologically prepared to perform across their cycle.

7.5 Relationship between menstrual phase, symptoms and match running

Football match performance is composed of physical, technical, and tactical performance (Morgans et al., 2024). Match running, as measured by GPS devices, provides an indication of physical performance and is one aspect of contributing to the overall match performance of a player and team (Modric et al., 2022). During a match, players cover ~10km (Datson et al., 2014; Griffin et al., 2020; Vescovi et al., 2021) with many high-intensity actions such as sprints, accelerations, decelerations and changes of direction (Caldbeck & Dos'Santos, 2022). These high intensity actions can be associated with key match actions such as goal scoring opportunities, defensive scenarios and attacking phases of play (Martinez-Hernandez et al., 2023; Rhodes et al., 2021; Schulze et al., 2022). Hence, match running performance requires a high level of speed, power and aerobic fitness to perform repeated high-intensity actions over a prolonged period and minimise fatigue-related declines (Datson et al., 2014). Theoretically, the menstrual cycle may affect physical performance due to fluctuating hormones between menstrual phases (McNulty et al., 2020) and the presence of menstrual symptoms (Antero et al., 2023; McNulty et al., 2023), which in turn can influence match running outcomes. As such, a key concern for practitioners is to optimise match running and manage physical performance decrements. Whilst there is a perceived effect of menstrual phase and symptoms on performance for some football players in Australia (as observed in Study 1), it’s important to identify whether objective changes in performance occur. Identifying objective menstrual related changes will aid management and optimise performance across the menstrual cycle.

Current research as based on systematic reviews and meta-analyses suggest possible differences in physical performance between menstrual phases, in particular trivial decreases in physical performance during the early-follicular phase when oestrogen and progesterone are low (McNulty et al., 2020; Meignie et al., 2021). However, the numerous outcome measures assessed (e.g., strength, speed, endurance), heterogeneity in participant demographics (e.g., recreational to elite, age, type of sport) and methodological shortcomings (i.e., poor menstrual phase classification methods) of the included studies make any conclusion on the effect of menstrual phase on performance challenging. The reviews also lack specificity to football players, though as discussed within the literature review of this thesis (Chapter 2), research on the influence of the menstrual cycle on football players' physical capacities is inconclusive, particularly for speed (i.e., sprint performance) and endurance performance, thus necessitating further high-quality research with larger sample sizes. Additionally, menstrual symptoms (e.g., pelvic pain, tiredness/fatigue) may also influence performance, though limited longitudinal and objective data exists. To date, most research has focussed on changes to isolated physical capacities as related to the menstrual phases, with limited research on physical match performance changes (Igonin et al., 2022; Julian et al., 2020) and no research on physical match performance changes related to menstrual symptoms. Whilst performance in discrete physical capacity tests indicates capacity for physical match performance, competitive match play is affected by tactical and technical performance, in addition to contextual factors like position, match outcomes and weather (Augusto et al., 2022; Griffin et al., 2020; Trewin et al., 2017). Indeed, physical match performance is multifaceted, thus the influence of menstrual phase and symptoms should be examined in ecologically valid contexts.

7.5.1 Does menstrual phase influence physical match performance?

Menstrual phase-related changes in physical performance are suggested to occur due to differing hormonal profiles between phases, given the influence of oestrogen and progesterone on various physiological functions (Bernstein & Behringer, 2023; Janse de Jonge, 2003; McNulty et al., 2020). Thus, comparing performance between accurately identified phases without direct measurement of oestrogen and progesterone concentrations can provide an indirect indication of hormone associated changes to performance.

As observed in Study 2 (Chapter 4), significant differences in match running as determined by GPS measures were observed between menstrual phases. Specifically, significantly higher relative total distance was reported during the late-follicular phase compared to early-follicular and luteal phases. Igonin et al. (2022) also reported greater total distance in the late-follicular than early-follicular phase, whilst Julian et al. (2020) found no difference between the follicular and luteal phases, though didn't distinguish between early- and late-follicular. Additionally, this thesis found significantly greater relative high-speed running distance (18-25 km·h^{-1}) during the late-follicular phase compared to the early-follicular and luteal phases. This contrasts with previous research where Julian et al. (2020) reported more running at ~17-20km·h^{-1} in the luteal than follicular phase and no difference in running >20km·h^{-1} between menstrual phases. Igonin et al. (2022) found no difference in running >19km·h^{-1} between menstrual phases, though less distance was covered at 7-14km.h^{-1} and 14-19km.h^{-1} in the early-follicular compared to late-follicular and mid-luteal phases. These lower speed thresholds (<18km.h^{-1}) were not examined in Study 2, thus comparisons are unable to be drawn.

Encouragingly, some similarities between our findings and those by Igonin et al. (2022) are evident, such as the lower physical match outputs during the early-follicular phase compared to late-follicular phase. However, differences also exist which may be attributed to the previous research (Igonin et al., 2022; Julian et al., 2020) using calendar-based counting phase estimations which increase the risk of sampling heterogeneity (increased risk of including anovulatory and luteal phase deficient cycles) and menstrual phase misclassification (Elliott-Sale et al., 2021), in addition to the different phases examined and GPS speed thresholds used. Future studies should consider using more robust menstrual phase measures (Beato et al., 2024; Elliott-Sale et al., 2021; Smith et al., 2022), though acknowledging serum hormone analysis, which is considered part of the gold standard method for menstrual phase identification and verification (Elliott-Sale et al., 2021), was not performed within this thesis due to players training and competing in matches across multiple states. This prevented further sub-phase classification and increased the possibility of including players with anovulatory or luteal phase deficient cycles, which is a limitation of Study 2 as well as Studies 3 and 4. However, Study 2 was the first to conduct LH and PdG urine testing concurrent to physical match performance measures, which builds upon previous research (Igonin et al., 2022; Julian et al., 2020) and balances accuracy of menstrual phase detection with practicality and feasibility.

The influence of menstrual phase on relative total distance and high-speed running distance in this thesis equated to approximately 500m more total distance and 100m more high-speed running distance during the late-follicular than early-follicular and luteal phases. The typical within-player SD for elite female footballers match distance is: total distance of 259m (90% CI = 239 - 277m), >20km·h^{-1} distance of 73m (90% CI = 68 - 78m) and 16-20 km.h^{-1} distance of 160m (90% CI 148 – 171m) (Baptista et al., 2022).

This suggests a practically significant effect of menstrual phase on total distance and to a lesser extent high-speed running may have been observed in this thesis, though whether this difference is a concern for practitioners must be considered in the context of the player, opposition and match. However, large within and between player variability was evident when examining individual differences in total and high-speed running distance as based on menstrual phase as evidenced by the standard deviation for *player* within the total distance model (5.6m·min^{-1}) being similar to the estimated relative total distance difference between menstrual phases (5.1-5.8m·min^{-1}). Additionally, whilst the variance explained by menstrual phase for total and high-speed running distance was higher than that explained for all other GPS measures, it was still relatively low (marginal $R^2 = 0.08 – 0.10$), demonstrating the limited influence of menstrual phase. This highlights the need for individualised monitoring and management of potential menstrual phase effects with respect to physical match performance. It is also essential to consider that contextual factors which are known to influence match running, though often trivial effects are reported, such as match outcome, opposition quality and environmental conditions (Trewin et al., 2017), were not controlled for in Study 2 which could have influenced the results and is a limitation of the study.

Menstrual phase did not significantly affect relative very-high speed running, peak speed, relative acceleration count or relative deceleration count in this thesis. The high match-to-match variability that exists for higher speed thresholds (Baptista et al., 2022) may account for the lack of difference observed for relative very-high speed running between menstrual phases and highlights the need for larger studies that can control for the various confounders. Further, the amount of variance explained by menstrual phase for relative very-high speed running, peak speed, relative acceleration count and relative deceleration was low ($R^2 = 0.01 - 0.05$), highlighting the limited influence of menstrual phase. Of note, this thesis is the first to examine the influence of menstrual phase on peak speed, accelerations and decelerations in football matches. In comparison, a greater magnitude of accelerations and decelerations during the late-follicular than early-follicular, mid-follicular or luteal phases were reported amongst basketball players (Arenas-Pareja et al., 2023). Additionally, amongst football players max sprint speed (10m, 20m, 30m) was fastest during the late-follicular than early-follicular and mid-luteal phases (Igonin et al., 2024). These findings (Arenas-Pareja et al., 2023; Igonin et al., 2024) align with the increased match performance (total distance and high-speed running) observed during the late-follicular phase in this thesis. However, several studies have also reported no menstrual phase effect on max speed (Campa et al., 2022; Sánchez et al., 2022; Villaseca-Vicuña et al., 2024). Considering a total of 30 football players' match running in relation to menstrual phase has been examined across this thesis and the previous two studies (Igonin et al., 2022; Julian et al., 2020), the scarcity of research in this area and the explorative stage in which this research remains, it's challenging to draw firm conclusions. The small number of studies that exist and small sample sizes that transpired in Studies 2 to 4, which may have resulted in underpowered sample sizes, should be considered throughout this discussion.

In summary, menstrual phase was observed to have a statistically significant effect on match running in Study 2, though context and individual variability needs to be considered when applying these findings in practice. We observed significantly greater relative total distance and high-speed running distance during the late-follicular phase compared to early-follicular and luteal phases, though large intra- and inter-individual variability was present within the small sample size. Therefore, the early-follicular phase and luteal phase may appear the likely menstrual phases of concern with respect to match running, particularly for the less intense match actions (total distance and high-speed running) rather than high-intensity actions (very-high speed running, peak speed, accelerations, decelerations). Future research may wish to replicate this research, whilst also exploring management strategies to minimise decrements in match running performance across the menstrual cycle detected for affected individuals.

7.5.2 Do menstrual symptom influence match running?

Changes in match running across the menstrual cycle may also be related to the presence of menstrual symptoms. Survey-based studies have highlighted an association between increased menstrual symptoms and greater perceived performance disruption (McNamara et al., 2022). However, few longitudinal studies exist that assess physical performance concurrent to menstrual symptom tracking, limiting our understanding to subjective observations and recall bias. Exploring the influence of menstrual symptoms on match running may offer practitioners and athletes a logistically feasible and effective method of monitoring and managing menstrual effects.

In Study 2 (Chapter 4) we explored the influence of MSS score, a daily combined score of 18 menstrual symptoms individually rated in severity from 0 (none) to 3 (severe), on physical match performance. We observed a decline in relative accelerations in association with increasing MSS score, however, large individual variability existed and the variance explained was low ($R^2 < 0.02$). No other studies have specifically examined the influence of menstrual symptoms on match running variables in any sport, however, reduced lower body power (as measured by jump height and Wingate test) was associated with higher levels of self-reported pain, without an effect of menstrual phase, in active females (Dam et al., 2022). Menstrual symptom severity score did not affect relative total distance, relative high-speed running distance, relative very-high speed running distance, peak speed or relative deceleration count in this thesis. Speculative reasoning for the lack of effect could relate to the transient state of many menstrual symptoms (e.g., cramps), which may minimise the negative effects on performance. Further, players may manage symptoms well using painkillers and anti-inflammatory medication (Armour et al., 2020; Findlay et al., 2020), or it's possible we did not capture players with, or matches when, players experienced high symptoms. Additionally, selective attention during matches may supersede symptom distraction and effects on performance (Findlay et al., 2020), plus the competitive drive and need to perform regardless of menstrual symptoms experienced as supported by 4-13% of professional footballers (Parker et al., 2022; Read et al., 2021) compared to 27% of amateur footballers (Pinel et al., 2022) missing training or competition due to severe symptoms. Research suggests an association between daily tracked menstrual symptoms and perceived reduction in physical performance for recreational to trained athletes (McNulty et al., 2023), thus demonstrating possible misalignment between athlete perception and objective findings. However, it should be acknowledged that the MSS score is yet to be validated.

Menstrual symptoms are concerning due to their potential impact on performance, as some athletes report refraining from training or playing because of these symptoms (Ekenros et al., 2022; Pinel et al., 2022), highlighting their harmful effect. In football team settings, monitoring symptoms may offer a practical alternative to accurately measuring hormone-related menstrual phases, which requires frequent urine and/or blood tests. This approach is also inclusive of all players, including those using HCs or experiencing menstrual abnormalities. Our research showed minimal effects of menstrual symptoms on physical match performance, with an increase in MSS score linked to a decrease in relative acceleration count, and no effects on other GPS measures. However, as this is the first study to examine the influence of menstrual symptoms on physical match performance, further research is needed to confirm these findings and with potential focus on performance in training.

7.6 Relationship between menstrual phase and perceptual recovery

Optimising post-match recovery is essential to prepare players for ensuing training and competition (Carling et al., 2018; Thorpe et al., 2017). The importance of player recovery is heightened by the increasing frequency of multi-match weeks in women's football (FIFPRO, 2023). Practitioners are therefore interested in understanding the factors which may enhance or delay recovery (Kellmann et al., 2018; Thorpe et al., 2017). It has been suggested that recovery may vary across the menstrual cycle due to the fluctuations of oestrogen and progesterone concentrations affecting physiological responses that are related to post-exercise recovery (Hackney et al., 2019; Romero-Parra et al., 2021). For example, oestrogen has antioxidant and anti-inflammatory properties, which may reduce inflammation and exercise induced muscle damage (Enns & Tiidus, 2010; Kendall & Eston, 2002), thus when oestrogen levels are low, such as during the early-follicular phase, recovery may be slower, which was inferred from a recent systematic review and meta-analysis (Romero-Parra et al., 2021). The various populations studied (sedentary individuals to professional athletes), exercise protocols employed and outcome variables measured should be taken into consideration when interpreting the review's findings (Romero-Parra et al., 2021), which limits the specificity to football populations. Whether the menstrual cycle influences post-match recovery in football is relatively unknown, though knowledge of an effect could help practitioners plan recovery strategies based on menstrual phase if appropriate.

Perceptual measures (athlete self-reported) are often used in football to monitor recovery due to their ease of use, and sensitivity in response to training load (Moalla et al., 2016; Saw et al., 2016). According to a systematic review and meta-analysis, menstrual phase has limited influence on perceptual responses, though variability in populations, menstrual phase classifications and outcome variables of the included studies makes generalisable conclusions challenging (Paludo et al., 2022). Additionally, the review did not include training load or schedule data, which should be accounted for when exploring the influence of menstrual phase on perceptual responses to training and competition. Indeed, *perceptual responses* on the days following a match (e.g., rating of perceived recovery or fatigue) can provide an indication of player response to match loads (Jeffries et al., 2020; Thorpe et al., 2017). However, *recovery* refers to the timeline of restoration of disturbed psychophysiological states (Kellmann et al., 2018), thus an indication of post-match recovery is the change in perceptual measures in the days following a match (e.g., from MD to MD+2). Currently, football studies exploring the influence of menstrual phase on perceptual responses are limited to specific timepoints (e.g., at 24h post-match) (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024), as opposed to examining differences in the time-course of perceptual recovery. Understanding changes in perceptual responses and recovery across menstrual phases may support development of phase-based management strategies.

7.6.1 Does menstrual phase influence perceptual responses?

In Study 3 (Chapter 5) we observed limited association between menstrual phase and perceptual responses (PRS, fatigue, soreness, sleep, stress, total wellness) on MD, MD+1 and MD+2. Specifically, menstrual phase did not significantly affect any perceptual measure on MD, MD+1 or MD+2. However, during the early-follicular phase, moderate ESs were reported for worse PRS on MD and MD+2, and better sleep quality on MD+2. It is possible that low oestrogen and progesterone, or menstrual symptoms, which are common during the early-follicular phase (Bernstein & Behringer, 2023; McNulty et al., 2023), contributed to the moderate ES of worse PRS during this phase. However, it should be acknowledged that the study was likely underpowered, and there is risk associated with placing emphasis on effect sizes when statistical significance is not reached. Additionally, there was no effect of menstrual phase on total wellness, fatigue, soreness or stress on any Day. In comparison, worse fatigue was reported 48h following a match during the luteal compared to follicular phase for professional footballers in one national team, though no difference in fatigue at 24h and 72h, nor soreness or sleep 24-72h post-match were observed (Scott et al., 2024). Menstrual phase did not impact fatigue, soreness, sleep, stress or mood on match day or the following three days for professional football players throughout a season (Abbott et al., 2024). Additionally, weekly sum scores for fatigue, soreness, sleep and stress did not differ between menstrual phases for academy football players (Juillard et al., 2024). Although there were subtle differences in the questionnaires utilised, and the previous studies did not perform any hormonal testing to determine menstrual phase (Abbott et al., 2024; Juillard et al., 2024; Scott et al., 2024), the findings are similar to this thesis and demonstrate minimal influence of menstrual phase on perceptual measures. Of note, the lack of validity surrounding single-item questionnaires (e.g., wellness items) (Jeffries et al., 2020) and small sample sizes could have contributed to these results.

Our findings demonstrate limited influence of menstrual phase on perceptual measures on MD and the subsequent days. This is somewhat surprising given football players have previously reported perceptions of worse sleep and recovery during the pre-menstrual (late-luteal) and menstrual (early-follicular) phases (Read et al., 2021). However, our findings support the previously discussed systematic review and meta-analysis which demonstrated limited effect of menstrual phase on perceptual responses (Paludo et al., 2022). Therefore, it appears practitioners do not need to consider menstrual phase when interpreting perceptual responses on match day or the following days.

7.6.2 Does menstrual phase influence the recovery timeline of perceptual responses?

The time taken for the return of perceptual markers to pre-match levels provides an indication of the perceptual recovery timeline to the imposed match demands. Study 3 demonstrated a fatigue-recovery response to the match loads encountered (inferred from THSRD). All perceptual measures, except for stress, were worse on MD+1 than MD, then improved from MD+1 to MD+2, though many perceptual measures were not fully recovered by MD+2. This contrasts the findings of a systematic review and meta-analysis of female footballers' post-match fatigue and recovery, which reported most perceptual measures are recovered after 48h (i.e., MD+2) (Goulart et al., 2022). However, this review highlights the limited amount of research (i.e., only seven perceptual recovery studies) and lack of consideration for, or control of, menstrual phase within the studies. As such, the current research was the first to examine the influence of menstrual phase on post-match perceptual recovery timelines in football. As outlined in detail below, we observed differences in the recovery timelines between menstrual phases, depending on the perceptual scale (PRS, total wellness, fatigue, soreness, sleep, stress) and match load (THSRD).

Study 3 examined the time-course of recovery at lower (-1SD) and higher (+1SD) match loads as indicated by the THSRD. Whilst differences in recovery timelines existed between menstrual phases, evidence for consistently impaired or improved recovery in one menstrual phase did not exist. Given the multitude of results, this section will focus on the recovery timeline following higher match loads (+1SD) where an increased fatigue response was evident, and therefore increased recovery demands are expected that would be of greater importance for practitioners and players. Significant improvements in PRS, total wellness, fatigue and soreness were observed from MD+1 to MD+2 during the late-follicular and luteal phases, with no differences observed during the early-follicular phase. This suggests recovery from MD+1 to MD+2 may be impaired during the early-follicular phase. Conversely, PRS and fatigue were recovered on MD+2 (not significantly different from MD) during the early-follicular phase and luteal phase respectively, signifying slower recovery of these variables during the late-follicular phase. Of note, although recovery of PRS appeared better during the early-follicular phase this may have been offset by the lower (worse) PRS scores on match day. Furthermore, total wellness and soreness were not recovered by MD+2 in any menstrual phase, thus menstrual phase may not affect the recovery of total wellness and soreness or perhaps longer monitoring (e.g., MD+3) is required to differentiate the influence of menstrual phase. Our findings do not align with a recent systematic review and meta-analysis which suggested slower recovery during menstruation (early-follicular phase) due to greater delayed onset muscle soreness and strength losses during this phase (Romero-Parra et al., 2021). However, interpretation of these results has been cautioned due to methodological heterogeneity, high heterogeneity of the outcome variables, few studies having examined more than one phase and only 58% of studies included sex hormone analysis (Colenso-Semple et al., 2023).

Overall, the recovery timelines differed depending on the perceptual scale (PRS, total wellness, fatigue, soreness, sleep, stress), match load, and menstrual phase. Whilst differences in the recovery timelines between menstrual phases were observed, a consistent effect of impaired or improved recovery in one menstrual phase was not evident, thereby preventing any general phase-based recovery recommendations. However, we did not monitor or control for the use of recovery strategies by players, which could have been employed to manage menstrual-related effects on recovery and may have influenced the results. Additionally, contextual factors such as match outcome and environmental conditions, which could affect perceptual responses were not controlled for. Furthermore, the amount of variance in the perceptual scales explained by the fixed effects (menstrual phase, Day, THSRD) was relatively low for all models (R^2 = 0.02 - 0.19). Perhaps other markers of recovery (e.g., biomarkers) are more sensitive to the menstrual cycle, or a more controlled environment (e.g., lab-based study) may be more conducive to examining menstrual phase effects on recovery given the variability that exists within field-based studies. Lastly, whilst urinary hormonal testing was used, this could have resulted in the misclassification of menstrual phase or status compared to the gold standard serum-testing (Noordhof et al., 2024). Nevertheless, the current study found a variable influence of menstrual phases on perceptual recovery in football team settings offering new insights into the expected post-match perceptual recovery patterns as based on menstrual phase.

7.7 Relationship between menstrual phase, symptoms and sleep

Sleep is inherently important for athletes to prepare for, and recover from, competition (Querido et al., 2022). However, athlete sleep is often partially disrupted the night prior to and night following competition (Fullagar et al., 2015a; Fullagar et al., 2015b). Monitoring and managing factors that affect athlete sleep is therefore important to practitioners, particularly around competition. It is suggested that the menstrual cycle may affect sleep patterns, behaviours and perceptions (Power et al., 2024) due to phase-related fluctuations in hormones (oestrogen and progesterone) as well as the presence of menstrual symptoms (Alzueta & Baker, 2023; Baker & Lee, 2018). Changes in objective measures of sleep (e.g., sleep duration) across the menstrual cycle are often equivocal, whilst changes in subjective sleep quality (i.e., self-reported) during and prior to menstruation and for women experiencing menstrual symptoms are more frequently reported (Alzueta & Baker, 2023; Baker & Lee, 2018).

Study 4 (Chapter 6) monitored the sleep of players the night prior to (MN-1), night of (MN) and night following (MN+1) matches to explore the association between menstrual phase and sleep, as well as menstrual symptoms and sleep. As context to the players' sleep around matches, we observed significantly later bedtime for MN, significantly earlier waketime for MN+1 and significantly longer TST for MN-1. Later MN bedtime likely reflected the impact of afternoon match schedules and match loads encountered (Fullagar et al., 2016b; Sim et al., 2023), though acknowledging match schedules and load were not included in the statistical analysis. Earlier MN+1 waketime likely reflected an effect of morning training schedules (Sargent et al., 2014) as reported by clubs, though acknowledging training times were not specifically recorded nor included in the statistical models. Longer MN-1 TST demonstrated the negative effect that later MN bedtime and earlier MN+1 waketime had on TST, and that players may attempt to increase sleep prior to matches to improve performance (Sim et al., 2023). Indeed, sleep is influenced by various factors such as match and training schedules in addition to travel, home vs away matches and physical match load (Fullagar et al., 2015a). These confounding variables were not controlled for within Study 4, which should be considered when interpreting the association between the menstrual cycle and sleep.

7.7.1 Does menstrual phase influence sleep?

Menstrual phase was not related to any objective sleep variable (bedtime, waketime, TST, SOL, WASO, SE) for MN-1, MN or MN+1. Studies conducted with non-athletic populations report equivocal effects of menstrual phase on objective measures of sleep (Alzueta & Baker, 2023; Baker & Lee, 2018), though athlete specific studies are limited (Power et al., 2024). Shorter TST, longer SOL and less deep sleep during menstruation compared with the mid-follicular phase were found amongst collegiate athletes, as assessed by home electroencephalogram monitoring (Koikawa et al., 2020). In contrast, longer time in bed and longer deep sleep, but no difference for TST or SOL, were reported during menstruation compared to non-bleeding days amongst junior endurance athletes, as assessed by a Somnofy monitor (Hrozanova et al., 2021). Further, no differences in sleep between menstruation and the mid-luteal phase were reported for physically active sport science students as measured by sleep diaries (Martínez-Cantó et al., 2018). Variances in the athletic populations studied, menstrual phases assessed, measurement of sleep and measurement of menstrual phases, as well as lack of training/match schedule context in these studies makes comparisons and conclusions challenging. Therefore, additional research is required to confirm the influence of menstrual phase on footballers' sleep, particularly during the nights around competition where sleep is of most importance and often disrupted (Fullagar et al., 2015a; Fullagar et al., 2015b; Lastella et al., 2014).

Menstrual phase also did not affect self-reported sleep quality on MN-1, MN or MN+1. Our findings question existing perspectives regarding worse perceived sleep quality during the premenstrual (late-luteal) and menstrual (early-follicular) phases observed for non-athletic populations (Baker & Lee, 2018). Although speculative, the specific context of which sleep was measured (i.e., nights around matches) could have influenced these results, as we observed a significant effect of the different nights on bedtime, waketime and TST, thus perhaps the context masked any observable effect of menstrual phase in this population. Additionally, we did not examine the pre-menstrual phase specifically, rather it was included within the luteal phase due to a limited number of observations, which may have contributed to the lack of menstrual phase effect. The absence of serum-hormone testing, which is more accurate yet less feasible than urinary hormonal testing, could also have influenced the results. Further, the sleep quality question analysed was a single-item Likert scale question as part of a wellness questionnaire, thus possibly lacking sensitivity to changes across the menstrual cycle. A similar sleep quality question as part of a broader wellness questionnaire was also employed by a study with a professional football club, which found no effect of menstrual phase on sleep quality on match day or the following three days (Abbott et al., 2024). In contrast, worse sleep quality was reported during the luteal compared to follicular phase amongst Australian Rules Football players, though only five players were included in the study, likely resulting in an underpowered study (Carmichael et al., 2021a). Overall, the current evidence suggests monitoring menstrual phase in relation to self-reported sleep quality using single-item questions is unlikely to improve interpretation of sleep quality around matches, however, the scarcity of research that exists warrants further research to support these findings.

7.7.2 Do menstrual symptoms influence sleep?

Menstrual symptom severity was demonstrated to be associated with two objective sleep variables. Specifically, increased MSS score was associated with longer TST and later waketime, whilst exploration of individual symptom severities revealed increased mood changes/anxiety severity and increased lower back pain severity were associated with longer TST and later waketime respectively. The findings suggest players wake later and sleep longer when experiencing increased menstrual symptom severities, which is perhaps a self-management strategy to cope with menstrual symptoms. Our findings are supported by a study conducted with a professional football club, which reported an association between increased number of menstrual symptoms and increased (longer) sleep duration, as well as increased number of menstrual symptoms and increased (later) time in bed (Halson et al., 2024). The study also found increased number of menstrual symptoms was associated with increased WASO, indicative of disturbed sleep with increased symptoms and perhaps a contributing reason for the observed increased time in bed with increased symptoms (Halson et al., 2024). Menstrual symptoms therefore appear to influence footballers' sleep behaviour given the observed later wake time in this thesis, and increased time in bed in a similar study (Halson et al., 2024). Thus, in circumstances when sleep may be restricted e.g., early morning post-match travel or trainings, consideration for alternate sleep strategies for players with high symptom severity may be useful.

Interestingly, there was no association observed between menstrual symptoms and self-reported sleep quality. Previous research has alluded to an association between increased menstrual symptoms (e.g., individuals with premenstrual syndrome and premenstrual dysphoric disorder) and worse sleep quality in non-athletic populations (Khazaie et al., 2016). Several reasons may contribute to our findings. Firstly, most symptoms were rated as mild (69%) and the median MSS score was 3 (equating to three mild symptoms, or one moderate and one mild symptom, or one severe symptom), therefore it may be speculated that more severe symptoms may result in higher MSS scores and perhaps an observed effect on sleep quality. Secondly, as referred to previously, the lack of sensitivity of the single-item sleep quality question may have contributed to the results. This is supported by a study of German athletes which found an association between increased menstrual symptom frequency and decreased sleep quality, as measured by the validated Pittsburgh Sleep Quality Index (Kullik et al., 2024; Van Reen & Kiesner, 2016). Thirdly, athletes are often accustomed to experiencing poor sleep (Walsh et al., 2021), thus perhaps the threshold for reporting poor sleep quality is higher than that of the general population.

Overall, sleep does not appear to be negatively impacted by menstrual symptoms on nights around matches in the cohort of football players monitored. The changes in sleep behaviour, leading to increased TST, in association with increased symptom severities suggests players self-manage menstrual symptoms with sleep extension strategies. Therefore, menstrual symptom monitoring and management, and sleep extension strategies, may be beneficial to maximise player recovery and performance.

7.8 Are there key menstrual phases or symptoms of concern to player performance, recovery and sleep?

To enhance understanding of the menstrual cycle's overall impact on football players, this section will 1) explore whether player perceptions of the menstrual cycle align with the measured changes, 2) discuss the overall impact of menstrual phases, and 3) summarise the overall influence of menstrual symptoms. While aligning perceived effects and objective outcomes is not an explicit aim of this thesis, it remains an ongoing consideration that is often discussed by practitioners in relation to monitoring player health and performance. Additionally, the consistency in menstrual phase classification and use of menstrual symptom assessment tool across Studies 2 to 4 (Chapters 4 to 6), and the interrelationship between performance, recovery and sleep (Fullagar et al., 2015a; Fullagar et al., 2015b), provides an opportunity to draw connections between studies, though acknowledging no statistical analyses were conducted between datasets.

For transparency, Studies 2 to 4 were part of one large data collection process. As such, 17 participants were common across Studies 2 to 4, whereby their data were included in two or more of the studies.

7.8.1 Do athlete perceptions translate to measurable menstrual-related effects?

Understanding whether players' perceptions of the menstrual cycle's impact on training and competition align with measurable changes in performance and recovery can provide novel insight on what may be important for player health and performance. Players perceived "whilst menstruating" as the most disruptive time of the menstrual cycle to training and competition, followed by "prior to menstruation", as per previous research (Armour et al., 2020; Ekenros et al., 2022; Martin et al., 2018; Solli et al., 2020). This is supported by the findings of Study 2, where relative total distance and high-speed running distance during matches were lower during the early-follicular phase (i.e., whilst menstruating) and luteal phase (i.e., prior to menstruation) for some players. Although noting, the luteal phase aligns with "prior to menstruation" and possibly "middle of cycle", depending on an individual's physiological luteal phase length and interpretation of "prior to menstruation" and "middle of cycle". Tracking the menstrual cycle and implementing interventions during the early-follicular phase/whilst menstruating and luteal phase/prior to menstruation is encouraged (Beato et al., 2024) which may help to promote more consistent, or perceptions of more consistent, physical performance across the menstrual cycle. However, some players reported perceived performance disruptions during the middle of their cycle and given the intra- and inter-individual variability in physical match performance observed, this highlights the need for individualised monitoring and management of the menstrual cycle (Bruinvels et al., 2022; Findlay et al., 2020). No studies have statistically compared the timing of perceived and objective impacts to training and competition, thus future research may consider subgroup analyses to determine whether athlete's perceived and actual timing of menstrual effects align.

Players' perceptions of disruptions to performance and recovery by the menstrual cycle were explored in Study 1, with "energy levels" and "endurance" occurring as the most frequently selected, similar to previous research (Armour et al., 2020). The perception of the menstrual cycle negatively affecting "energy levels" and "endurance" could be viewed as being supported by menstrual phase affecting relative total distance and high-speed running distance, in addition to the association between increasing MSS and decreasing relative acceleration count in Study 2, though acknowledging the large variability in match running in relation to menstrual phase. Monitoring of, and strategies targeted towards improving, energy levels and endurance performance may therefore be beneficial in supporting player match performance across the menstrual cycle.

The “ability to recover” was among the less frequently selected aspects perceived to be disrupted. This is reinforced by the inconsistent influence of menstrual phase on the post-match perceptual recovery time-course demonstrated in Study 3. This is further supported by a review which suggests limited influence of menstrual phase on perceptual responses (Paludo et al., 2022). Resources and attention to the effect of the menstrual cycle may therefore be better directed towards competition performance outcomes. However, “soreness” was the third most frequently selected aspect perceived to be disrupted by the menstrual cycle, which was not evident in the findings of Study 3. Of note, we did not monitor or control for the recovery or treatment strategies used by players that would affect self-reported recovery (Nédélec et al., 2013). Therefore, it is possible players were proactive in managing their recovery and soreness, regardless of their menstrual cycle, which could have contributed to the disparity between the perceived menstrual effect and the lack of observed difference across the menstrual cycle.

Overall, it appears there is some evidence from match running and recovery data that aligns with player perceptions of the effects of menstrual cycle phase. In particular, the most prevalent aspects of training and competition perceived to be affected by the menstrual cycle (i.e., energy levels, endurance), though the perceived effect on soreness requires further investigation. Regardless, athletes should feel supported across their menstrual cycle and individualised management still seems the most appropriate approach where possible (Bruinvels et al., 2022; Findlay et al., 2020). Currently no research exists exploring the association between athlete’s perceived and actual performance and recovery across the menstrual cycle. If perceptions did translate to measurable changes, observing athlete perceptions could provide an effective menstrual monitoring strategy.

7.8.2 Overall influence of menstrual phase

From a match performance perspective, menstrual phase had a statistically significant effect on running outcomes, with increased relative total distance and high-speed running distance during the late-follicular phase, albeit large intra- and inter-variability within a small sample size existed, and the practical impact may be limited. This partially aligns with the trivial reductions in physical performance during the early-follicular phase as reported by a systematic review and meta-analysis (McNulty et al., 2020). From a recovery perspective, menstrual phase had minimal effect on the perceptual responses, which aligns with previous football research (Abbott et al., 2024; Scott et al., 2024). Additionally, a systematic review and meta-analysis suggested recovery may be impaired during the early-follicular phase (Romero-Parra et al., 2021), however, the results of this thesis found a variable effect of menstrual phase on the recovery timeline for perceptual responses. Recovery from MD+1 to MD+2 may be impaired during the early-follicular phase, whilst recovery from MD to MD+2 (i.e., return of perceptual markers to pre-match levels) may be impaired during the late-follicular phase. Furthermore, menstrual phase did not affect the objective or subjective sleep of players the night prior to, night of or night following matches. Whilst athlete specific research is scarce, amongst non-athletic populations menstrual phase appears to have an equivocal effect on objective sleep, with worse sleep quality occurring during menstruation and pre-menstruation (Alzueta & Baker, 2023).

Interestingly, at lower match loads (-1SD THSRD), players are perceptually more sensitive to match load in the late-follicular phase as indicated by MD to MD+1 PRS and total wellness, despite being likely to run more during this phase. Additionally, at higher match loads (+1SD THSRD), recovery may be slower during the late-follicular phase, as indicated by MD to MD+2 PRS and fatigue. Given the likely higher match loads encountered during the late-follicular phase, players may be more likely to experience longer perceptual recovery timelines during this phase. However, MD to MD+2 total wellness and soreness were unaffected by menstrual phase. Additionally, impaired MD+1 to MD+2 recovery during the early-follicular phase should be considered. These findings highlight the complexities surrounding the interplay between menstrual phase, match running, perceptual responses and the perceptual recovery time-course, and relate to the individualised management required (Bruinvels et al., 2022; Burden et al., 2021; Findlay et al., 2020).

Overall, the influence of menstrual phase on match running, and variable influence of menstrual phase on perceptual recovery, were not mirrored by the influence of menstrual phase on sleep. Perceptual sleep quality and objective sleep measures MN-1 to MN+1 were unaffected by menstrual phase. A bidirectional relationship between perceived fatigue and sleep has been demonstrated amongst female football players (Moen et al., 2021). However, nuanced menstrual phase comparisons between the recovery time-course of perceptual recovery (Study 3) and objective sleep (Study 4) are tenuous due to the lack of interaction effect included between menstrual phase and Night in the Study 4 analysis. Given the importance of sleep to athlete recovery (Fullagar et al., 2015b; Walsh et al., 2021), future research may wish to examine the concurrent effects of menstrual phase on sleep and recovery to provide a more comprehensive understanding of the menstrual cycle's effect, to then guide appropriate support and education.

Currently it appears no studies have measured the influence of menstrual phases on athlete performance, recovery and sleep simultaneously. Given the interconnected relationship that exists between performance, recovery and sleep (Fullagar et al., 2015a; Fullagar et al., 2015b) such research would help provide a more comprehensive understanding of the menstrual cycle's impact on athletes. A holistic understanding would help to provide more direct management strategies for use in real-world football settings.

7.8.3 Overall influence of menstrual symptoms

In terms of match performance, menstrual symptoms had limited influence on match running. Specifically, increased MSS score was associated with a reduction in relative acceleration count only, although large variability existed. The influence of menstrual symptoms on perceptual recovery was not examined. Additionally, player sleep was not adversely affected by menstrual symptoms, rather increased symptom severities were associated with longer TST and later waketime. These findings do not support the association we observed between a higher number of symptoms reported and increased likelihood of perceiving a menstrual disruption in Study 1. However, our ecological and exploratory approach to exploring the influence of menstrual symptoms may have contributed to these findings as previously discussed (e.g., symptom management was not monitored or controlled for) and does not disregard the negative impact menstrual symptoms can have, nor the benefit that monitoring menstrual symptoms may provide. As noted above, research concurrently exploring the effects of menstrual symptoms on athlete performance, recovery and sleep is non-existent and would be beneficial to provide a holistic understanding of the menstrual cycle's impact. In particular, longitudinal observations of menstrual symptoms effects on all athlete performance and recovery aspects is lacking, including player availability.

7.9 Monitoring the menstrual cycle

The knowledge and insights gained from this thesis can contribute to our understanding and practices related to menstrual cycle monitoring in football. Although this is not a research aim of the thesis, it remains a relevant concern and area of interest for practitioners. As such, the processes used, and data collected, throughout this thesis are explored to offer additional perspectives on this important topic.

7.9.1 Reasons for monitoring

Monitoring an athlete's menstrual cycle is important for several health-specific reasons. Firstly, menstrual abnormalities can be a health concern, or a sign of further health issues ("ACOG Committee Opinion No. 651: Menstruation in Girls and Adolescents: Using the Menstrual Cycle as a Vital Sign," 2015; Attia et al., 2023). Secondly, menstrual dysfunction is more prevalent in athletic than non-athletic populations (De Souza et al., 2009; Shangold et al., 1990). Thirdly, as menstrual dysfunction is often normalised, athletes and practitioners may not view menstrual dysfunction as an issue, and a taboo for open discussion still exists around menstruation (Verhoef et al., 2021). Hence, the studies in this thesis can provide rationale for monitoring and insight on why and what to monitor for practitioners working with a squad of players, but also for players to further understand their own individual needs and responses. The findings from Study 1 support the need to monitor the menstrual health of football players. Despite the low prevalence of amenorrhea detected, the severity of the conditions and potential health and performance consequences (Mountjoy et al., 2023), plus higher prevalence of oligomenorrhea reinforces the need to monitor menstrual health in professional footballers. Of further concern was the number of subtle menstrual disturbances (i.e., anovulation, luteal phase defect) indicated by the menstrual cycle monitoring conducted by players in Studies 2 to 4. The high prevalence of subtle menstrual disturbances, which precede the more severe menstrual dysfunctions, emphasises the menstrual health concerns that exist within football populations. Furthermore, Study 1 highlighted additional concerns unrelated to menstrual dysfunction, such as players experiencing HMB and HC users experiencing side HC effects, further highlighting the need for holistic menstrual cycle monitoring. Hence, it is recommended professional football teams have a (validated) menstrual health questionnaire to periodically assess players that is overseen by medical experts trained in female health.

Monitoring athlete's menstrual cycles with respect to menstrual-related symptoms is also crucial. Menstrual symptoms are common and often manageable, though can cause significant impairment and disruption (Biggs & Demuth, 2011; Taim et al., 2023), and negatively impact athlete training and competition availability (Dupuit et al., 2023; Ekenros et al., 2023; Parker et al., 2022). Concerns for menstrual symptoms are further emphasised because of the normalisation, stigma and societal expectation to cope with symptoms (Critchley et al., 2020; Wiggleton-Little, 2024). The prevalence and perception of symptom impact reported in Study 1 support the need to monitor menstrual symptoms amongst football players. We did not examine menstrual symptom-related health conditions specifically, or symptoms effects on player availability, however, players' perception of interference of symptoms highlights the negative impact and importance of monitoring menstrual symptoms. Additionally, whilst most symptoms experienced by players in Studies 2 to 4 were rated as mild, the maximum MSS score reported by a player was 31 which equates to approximately 10 severe menstrual symptoms on one day and further illustrates the need to individually monitor player symptoms.

Lastly, monitoring menstrual phase alongside menstrual symptoms may be beneficial for performance and recovery purposes (Bruinvels et al., 2022; McNulty et al., 2023). Individualised monitoring of menstrual phases with respect to performance is supported by the findings of Study 2. Match running performance differed between menstrual phases, and whilst variability existed, there was a distinct difference in match running between menstrual phases for some players, though the lack of control of contextual factors and magnitude of practical significance needs to be considered. Menstrual phase was also related to perceptual recovery, though with less clarity regarding impaired or improved recovery within a certain phase. Perhaps reassuringly, sleep was not associated with menstrual phase, though further research is still required. Menstrual symptoms appeared to minimally affect football performance, and did not adversely affect sleep, though as discussed throughout this Chapter there are many speculative reasons for why this may have occurred. Given the association we found between experiencing a higher number of menstrual symptoms and increasing the likelihood of perceiving a disruption of the menstrual cycle to performance, monitoring player menstrual symptoms in addition to menstrual phase is recommended. Menstrual monitoring may be individualised by implementing symptom monitoring for players reporting higher symptom frequencies and severities, as well as players with abnormal menstrual cycles or using HCs where hormone-related phases cannot be observed. Further practical recommendations as to menstrual monitoring are provided in in the following section 7.9.3.

7.9.2 Methods of monitoring

Several methods of monitoring the menstrual cycle were utilised within this thesis, which included a survey (Study 1), menstrual phase tracking via a combination of calendar-based counting and urinary hormone tests (Studies 2 to 4), and menstrual symptoms monitoring (Studies 2 and 4). For a more detailed discussion of all the available methods to classify menstrual phases, the reader is referred to section 2.1.2.1 "Measuring menstrual cycle phases" of the Literature Review (Chapter 2).

The survey used for Study 1 may be utilised by medical practitioners as a Menstrual Health in Football Screening tool to monitor the menstrual cycle for health, symptoms and (perceptual) performance purposes. Singular, or intermittent, use of screening tools are low burden to players and low cost to practitioners. Appropriately trained staff (e.g., team doctor) are required to oversee screening responses and ensure suitable referral processes are in place (Badenhorst, 2024; Carmichael et al., 2024). As demonstrated by the results of Study 1, they can provide a snapshot of players' menstrual characteristics, HC use and perceptions of the menstrual cycle's effects on training and performance. However, the results are vulnerable to recall bias which increases the risk of inaccurate results (Althubaiti, 2016). The single use of a questionnaire also doesn't capture the dynamic nature of the menstrual cycle given the intra-individual variability that exists with respect to menstrual cycle length, symptoms and bleedings (Bull et al., 2019). It may be necessary for players to complete such a questionnaire multiple times throughout the year or season, for example pre-season, mid-season and end-of season. Of note, the survey used within the study is not currently validated and future research is still required.

Monitoring the menstrual cycle for health purposes can also be achieved through calendar-based counting, as demonstrated by the longitudinal reporting conducted in Studies 2 to 4. Self-reporting menstruation to determine cycle length not only improves accuracy compared to a survey/screening tool (Small et al., 2007), but also allows for tracking cycle-to-cycle variability and the early detection of oligomenorrhea, before it could progress to secondary amenorrhea (Dupuit et al., 2023; Li et al., 2020; Zhang et al., 2023). This is particularly important, as secondary amenorrhea may remain undetected by practitioners for extended periods when infrequently using a survey/screening tool. Additionally, subtle menstrual disturbances, such as anovulation or luteal phase defects (which are precursors to oligomenorrhea and amenorrhea) cannot be identified by tracking cycle length only (Hirschberg, 2022; Janse de Jonge et al., 2019). In Studies 2 to 4, players also tested urinary LH and PdG, which can help detect anovulation and luteal phase defect. This monitoring method can offer a valuable means of early intervention before the onset of severe menstrual dysfunction and potential health consequences and performance declines (Ihalainen et al., 2024a). However, this approach involves increased costs and time demands, and cycles could be inaccurately classified as anovulatory, or luteal phase deficient if testing days are missed. Prior to collecting menstrual cycle tracking data player consent must be obtained with the option to opt-out, details regarding what will be collected, who will have access and how the data will be used must be transparent, appropriately trained practitioners should oversee the data and referral pathways should be setup in case concerns are identified (Carmichael et al., 2024). When resources and the environment do not support ethical and safe menstrual cycle tracking (Carmichael et al., 2024), prioritising player education and encouraging self-monitoring may be a beneficial alternative (McGawley et al., 2023).

Calendar-based counting to estimate menstrual phases for performance monitoring is often used in practice due to its low cost and low burden (Dupuit et al., 2023). This method assumes the timing of ovulation and a normal hormonal profile. Given the intra- and inter- individual variability in menstrual cycle length and menstrual phase timing that exist (Bull et al., 2019), this increases the risk of inaccurate phase classifications (Burden et al., 2024). This is supported by the menstrual cycle monitoring for Studies 2 to 4 where self-reporting of menstruation was supplemented by urinary LH and PdG testing, and large variability in menstrual phase timing was observed. The lack of reproducibility of menstrual phase timings alongside the high prevalence of menstrual disturbances indicated within this thesis, support the need for hormonal measurements to supplement calendar-based counting for accurate menstrual phase classification (Janse de Jonge et al., 2019; Schaumberg et al., 2017). Nevertheless, we did not employ the gold-tier method involving serum measurements for oestrogen and progesterone concentrations (Smith et al., 2022). While frequent urine sampling already poses a reasonable burden and challenge to implement in real-world football settings, regular blood tests introduce significantly higher challenges (Dupuit et al., 2023).

Monitoring and management of menstrual symptoms can provide practical information disregarding the need for the impractical hormone measurements for menstrual phases, and inclusive of all athletes who experience menstrual symptoms regardless of HC use and menstrual abnormalities. We successfully implemented a Menstrual Symptom Severity questionnaire adapted from a previous tool used with exercise participants (Bruinvels et al., 2021). While acknowledging that this questionnaire is not validated, it reflects the current lack of validated tools specifically designed for this purpose. Although speculative, daily and long-term use of the 18-item menstrual symptom severity tool in practice could cause survey fatigue (Ben-Nun, 2008). Future research could look to identify the most impactful symptoms to monitor for practical application. Further, practitioners should consider whether reported symptoms are exclusively menstrual-related, or attributed to other factors such as lifestyle and injury (D'Souza et al., 2023).

7.9.3 Practical recommendation for monitoring based on this thesis

The findings from this thesis support the need to initially focus on monitoring the menstrual cycle for health purposes, followed by the potential application to performance and recovery purposes (Carmichael et al., 2024). The desired outcomes of menstrual cycle monitoring should be considered alongside the benefit to player health and performance, accuracy and validity of monitoring, feasibility, burden to players, cost, and resources required (Beato et al., 2024; Carmichael et al., 2024; Dupuit et al., 2023). Whilst the effectiveness and feasibility of implementing menstrual monitoring strategies were not directly assessed within this thesis, the tools and processes used within the two football settings (national team vs. club) of this thesis offer meaningful insight.

A Menstrual Health in Football Screening tool may be implemented intermittently across a year or season with ease, low burden and negligible cost, provided a medical practitioner is available to oversee the responses. This method is applicable to all football levels (i.e., including amateurs), inclusive of players using HCs and with menstrual abnormalities (Beato et al., 2024). Screening provides a first step to understanding player menstrual health and perceptions of menstrual-related effects (Dupuit et al., 2023). Player responses can be used to instigate treatment, manage key concerns and guide further exploration of menstrual effects (Schulz et al., 2024; Taim et al., 2024). Screening may also direct individualisation of additional menstrual monitoring strategies.

Within a national football team environment where longitudinal monitoring is frequently disrupted (Buchheit & Dupont, 2018), accurately monitoring menstrual cycle length for health purposes and phase for performance purposes is prevented due to gaps in data. In this instance, increased reliance on a screening tool, and daily reporting of symptom severities whilst in national team camps, may be most beneficial to national team practitioners. Given players often identify menstruation as disruptive to training and competition (Armour et al., 2020; Ekenros et al., 2022; Martin et al., 2018; Solli et al., 2020), simply monitoring whether a player is menstruating may also be worthwhile, though additional research is required.

Club-settings provide a greater opportunity for menstrual monitoring. In addition to the methods applicable within a national-team setting, daily tracking of menstruation to measure menstrual cycle length is a simple method to monitor for oligomenorrhea and amenorrhea amongst non-HC users (Badenhorst, 2024). Menstrual phase may also be monitored in a club setting to aid interpretation of, or improve, performance (e.g., match running) and recovery (e.g., perceptual recovery) outcomes (Carmichael et al., 2024; Dupuit et al., 2023). Several factors should be considered prior to implementing menstrual phase monitoring including accuracy, efficiency, burden and cost of monitoring with respect to effectiveness and magnitude of impact (Beato et al., 2024; Carmichael et al., 2024). The timing of ovulation and progesterone peak varies greatly within and between individuals, therefore classification of the late-follicular phase and luteal phases based on calendar-based counting only is likely inaccurate (Burden et al., 2024; Janse de Jonge et al., 2019) and not supported by this thesis. Key menstrual phases of perceived concern for players, such as menstruation and the pre-menstrual phase, which may not require hormonal testing to identify, may still be worthwhile monitoring via calendar-based counting (Allen et al., 2016; Beato et al., 2024). Identification of additional menstrual phases would require urinary LH testing at minimum, which would improve accuracy and validity of monitoring menstrual phase effects, though increases cost and burden (Allen et al., 2016; Elliott-Sale et al., 2021; Janse de Jonge et al., 2019). However, urinary LH testing provides an additional benefit of early detection of subtle menstrual disturbances.

Overall, simple menstrual health monitoring via a survey or calendar-based tracking for player health is an evident strategy for teams to employ. Monitoring the menstrual cycle for performance benefits via menstrual phase or symptom monitoring shows promise, though is more challenging to implement. A one-size fits all approach does not currently exist, thus individualised monitoring and management of the menstrual cycle is recommended.

Chapter 8: Summary and Practical Applications

8.1 Thesis Aims

This thesis aimed to explore the menstrual health of football players, and the influence of menstrual phase and symptoms on physical match performance, post-match perceptual recovery responses and sleep around matches. The first study (Study 1, Chapter 3) aimed to assess the menstrual health, HC use and menstrual symptomatology of football players, in addition to exploring player perceptions of the menstrual cycle's effects on training and competition. The remaining studies (Studies 2 – 4, Chapters 4 – 6) explored the influence of menstrual phase (early-follicular, late-follicular, luteal) and menstrual symptom severities on performance, recovery and sleep. Specifically, Study 2 (Chapter 4) examined menstrual phase and symptoms influence on the following match running performance variables: relative total, high-speed and very-high speed running distances, peak speed, relative acceleration and deceleration counts. Following this, Study 3 (Chapter 5) examined the influence of menstrual phase on perceptual responses (PRS, total wellness, fatigue, soreness, sleep, stress) on match day and the following two days, in addition to the influence of menstrual phase on the timeline of post-match perceptual recovery. Lastly, to provide a more comprehensive understanding of the menstrual cycle's impact on football performance and recovery, Study 4 (Chapter 6) aimed to explore the relationship between menstrual phase and sleep, and menstrual symptoms and sleep. Specifically, objective sleep (bedtime, waketime, TST, SOL, WASO, SE) and perceived sleep quality were examined in relation to the menstrual cycle.

8.2 Key Findings

The key findings of each study are presented below:

Study 1:

- Ninety seven percent of players experienced one or more menstrual symptom, averaging five per player. The five most prevalent symptoms were 1) pelvic pain, 2) mood changes/anxiety, 3) tiredness/fatigue, 4) backpain and 5) cravings/increased appetite.
- Eighteen percent of players used HCs, with the primary reason being contraception.
- One player had primary amenorrhea. Amongst non-HC users the prevalence of menstrual abnormalities was: 1.5% secondary amenorrhea, 19% oligomenorrhea and 11% HMB.
- Forty percent of players perceived the menstrual cycle to disrupt training and/or competition. Menstruation was identified as the most disruptive phase, whilst "energy levels" and "endurance" were the most frequently identified aspects of performance to be disrupted.
- A higher number of menstrual symptoms, having HMB, and experiencing pelvic pain increased the likelihood of perceiving the menstrual cycle to disrupt performance.

Study 2:

- Relative total and high-speed running distances were higher during the late-follicular phase compared to early-follicular and luteal phases, albeit large intra- and inter-individual variability existed.
- Menstrual phase did not affect relative very-high speed running distance, peak speed, relative acceleration or deceleration counts.

- Increasing MSS score was associated with decreasing relative acceleration count, though the explained variance was very low.
- Menstrual symptom severity did not affect relative total, high-speed running or very-high speed running distances, peak speed or relative deceleration count.

Study 3:

- Menstrual phase did not significantly affect any perceptual measure (PRS, total wellness, fatigue, soreness, stress, sleep) on MD, MD+1 or MD+2. However, moderate ES were reported for worse PRS on MD and MD+2, plus better sleep quality on MD+2 during the early-follicular phase.
- There was a combined effect of Day and THSRD on PRS, total wellness, fatigue, soreness and stress.
- All perceptual measures, except stress, differed significantly between Days, demonstrating a fatigue-recovery response. However, at higher match loads, on MD+2 most perceptual measures remained worse than MD levels.
- Menstrual phase influenced the recovery timeline of perceptual measures. Recovery of PRS, total wellness, fatigue and soreness MD+1 to MD+2 was impaired during the early-follicular phase, whilst recovery of PRS and fatigue MD to MD+2 was impaired during the late-follicular phase. Thus, consistently impaired or improved recovery in one menstrual phase did not exist.

Study 4:

- Sleep timings and duration varied across nights due to matches, as bedtime was later for MN, waketime was earlier for MN+1 and TST was longer for MN-1.
- Menstrual phase was not related to any objective or subjective sleep variable.

- Increased MSS score was associated with longer TST and later waketime. Increased lower back pain severity and mood changes/anxiety severity were associated with longer waketime and TST respectively.
- Menstrual symptoms were not associated with bedtime, SOL, WASO, SE or perceived sleep quality.

8.3 Practical Applications

Considering the summary of findings outlined above, the following practical applications have been identified:

- Simple surveys to screen or monitor player menstrual health, symptomatology and perceived effects are important.
- Individualised and multi-disciplinary management of menstrual symptoms is recommended. Additionally, commonality of the most prevalent symptoms can help guide prioritisation of menstrual management strategy education and resources.
- Prevalence of oligomenorrhea and subtle menstrual disturbances are relatively high. Practitioners implementing menstrual phase monitoring should be aware that hormone-related phase-based changes in performance and recovery may be applicable to <50% of the squad. Additionally, the timing of ovulation is highly variable, creating issues for accurately classifying menstrual phases using calendar-based counting only.
- Monitoring menstrual phase with respect to performance and recovery should consider balancing accuracy with practicality and feasibility, such as those employed within this thesis: self-reporting menstruation and urinary hormone tests (LH, PdG).

- Practitioners should individually monitor player match running, particularly total distance and high-speed running distance, across menstrual phases and implement management strategies in response to observed changes.
- Practitioners should monitor the number and severity of menstrual symptoms experienced by players. Individualised monitoring and management of menstrual symptoms may help minimise reductions in match running, particularly accelerations.
- Consideration for menstrual phase when interpreting perceived fatigue, soreness, stress, sleep on a MD, MD+1, MD+2 does not appear necessary, though PRS and sleep may be affected.
- Monitoring menstrual phase can improve understanding of perceptual recovery timelines, though variability in menstrual phase effects prevent any general phase-based recovery recommendations.
- For players who flag as experiencing a high number or severity of menstrual symptoms, practitioners should monitor their symptoms and implement sleep extension or symptom management strategies to promote player recovery and performance in circumstances when sleep may be restricted.

8.4 Future Research

Future research recommendations to expand upon the findings of this thesis include:

- Future research should conduct repeated menstrual health screenings over an entire season to make more meaningful conclusions about the menstrual health of football players.

- As HMB was associated with a perceived performance disruption, and the lack of HMB football-specific research that currently exists, future research should explore how HMB affects football players.
- Future research should examine the association between perceived effects and objective effects of the menstrual cycle to better support female footballers. Given the individual variability in perceptions, subgroup analyses could be beneficial.
- Repetition of these studies with larger sample sizes, and inclusion of the premenstrual phase, which was perceived as a phase of concern, would strengthen this area of research.
- To improve our understanding of the menstrual cycle's impact on performance and recovery, concurrently assessing performance, recovery and sleep would be beneficial given the strong relationship between these factors.
- Future longitudinal research examining the influence of menstrual symptoms on performance and recovery should take into consideration the menstrual symptom management strategies employed by players.
- To ensure all female football players are supported across their menstrual cycle, how the menstrual cycle affects HC users (e.g., symptoms, HC types, HC phases) should be examined.
- Future research should consider exploring other aspects of football performance and recovery related to the menstrual cycle, for example technical performance factors and neuromuscular fatigue.

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Appendices

Appendix A - Supplementary Table: Chapter 6, Study 4

Supplementary Table 1: Sleep measures by menstrual phase and night presented as estimated marginal means (95% confidence intervals).

Sleep measures	MN-1	MN	MN+1
Bedtime (hh:mm)			
Menstruation	10:16 (09:39 - 10:54)	11:44 (11:07- 12:20)	10:26 (09:50 - 11:03)
Follicular	10:09 (09:42 - 10:35)	11:36 (11:07 - 12:05)	10:19 (09:50 - 10:48)
Luteal	10:21 (09:50 - 10:51)	11:48 (11:17 - 12:19)	10:31 (09:58 - 11:04)
Waketime (hh:mm)			
Menstruation	07:25 (06:49 - 08:00)	07:27 (06:52 - 08:01)	06:29 (05:54 - 07:04)
Follicular	07:36 (07:10 - 08:02)	07:38 (07:10 - 08:06)	06:40 (06:12 - 07:08)
Luteal	07:44 (07:15 - 08:14)	07:46 (07:16 - 08:16)	06:48 (06:16 - 07:20)
Total sleep time (hh:mm)			
Menstruation	07:29 (06:48 - 08:10)	06:08 (05:28 - 06:49)	06:33 (05:52 - 07:13)
Follicular	07:53 (07:19 - 08:27)	06:33 (05:57 - 07:08)	06:57 (06:21 - 07:32)
Luteal	07:43 (07:07 - 08:20)	06:24 (05:45 - 07:00)	06:47 (06:08 - 07:26)
Sleep onset latency (min)			
Menstruation	11 (8 - 16)	13 (9 - 19)	14 (10 - 20)
Follicular	11 (8 - 14)	12 (9 - 17)	13 (10 - 18)
Luteal	10 (7 - 13)	11 (8 - 15)	12 (9 - 17)
Wake after sleep onset (min)			
Menstruation	90 (63 - 116)	80 (54 - 107)	84 (57 - 111)
Follicular	83 (58 - 107)	73 (48 - 98)	77 (52 - 102)
Luteal	90 (65 - 115)	81 (55 - 106)	84 (58 - 111)
Sleep efficiency (%)			
Menstruation	82 (76 - 87)	80 (75 - 85)	80 (75 - 85)
Follicular	84 (79 - 88)	82 (77 - 87)	82 (77 - 87)
Luteal	82 (77 - 87)	80 (75 - 85)	81 (75 - 86)
Sleep quality (au)			
Menstruation	2.3 (1.9 - 2.7)	2.5 (2.1 - 2.9)	2.5 (2.2 - 2.9)
Follicular	2.3 (2 - 2.7)	2.5 (2.1 - 2.9)	2.5 (2.2 - 2.9)
Luteal	2.5 (2.1 - 2.8)	2.7 (2.3 - 3)	2.7 (2.3 - 3.1)

Au = arbitrary units, MN-1= night prior to match, MN = night of match, MN+1 = night following a match

Appendix B - Ethics Approval Letter: Self-reported menstrual health and perceived effects of the menstrual cycle on elite female football players

Dear Applicant
Re: ETH22-7624 - "Self-reported menstrual health and perceived effects of the menstrual cycle on elite female football players"

The assigned UTS Human Research Ethics Committee has reviewed your application and agreed that this application meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7624.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).

- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat
on behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
Research.Ethics@uts.edu.au | Website
PO Box 123 Broadway NSW 2007

Ref: E13-4

Appendix C - Ethics Approval Letter: Influence of the menstrual cycle on football players' match running, fatigue, recovery, sleep and nutrition

Dear Applicant

Re: ETH22-7106 - "Influence of the menstrual cycle on football players' match running, fatigue, recovery, sleep and nutrition"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.
You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7106.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat

On behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au

Ref: E38

Appendix D - Football Australia Data Consent Letter

FOOTBALL
AUSTRALIA

6 October 2022

Human Research Ethics Committee
University of Technology Sydney
Broadway Campus, Sydney

To Human Research Ethics Committee,

As Head of Medical for Football Federation Australia, this document serves as an approval letter for Georgia Brown to conduct research using Australian Women's National Team menstrual health screening data obtained by Football Australia National Teams Unit. The data will be anonymised by internal Football Australia staff prior to sending to you to prevent release of player information. Approval is granted on the condition that participant anonymity is maintained and reasonable measures are taken to keep confidentiality of personal information. It is expected a final summary report will be provided on completion of the research project.

If you have any queries please feel free to contact me at mark.jones@footballaustralia.com.au.

Yours Sincerely,

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prior to publication.

Dr Mark Jones

Head of Medical Services

Football Australia

Appendix E – A-League Research Support Letter

6 October 2022

Human Research Ethics Committee
University of Technology Sydney
Broadway Campus, Sydney

To Human Research Ethics Committee,

As Chief Medical Officer for A-League, this document serves as a support letter for Georgia Brown to conduct menstrual health research with A-League Women's players during the 2022-23 season. As part of support for this research I will connect the research team with A-League Women's club staff to disseminate the research information in order to recruit participants for the anonymous online survey. I understand that the research will take the form of an online questionnaire, similar to that of the Football Australia menstrual health screening. I understand that the research will be published in peer-reviewed journal articles, and the results will combine the findings from A-League Women's players and Football Australia's National Team players responses. It is expected a final summary report will be provided on completion of the research project.

If you have any queries please feel free to contact me anikshawdon@gmail.com.

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Yours Sincerely,

Dr Anik Shawdon

Chief Medical Officer

A-League

Appendix F - Supplementary Table: Chapter 6, Study 4

Menstrual Health Questionnaire

1. How old are you? ___

2.Have you had your first period?
☐ Yes ☐ No → *questionnaire automatically ends*

---

3. At what age did you have your first period?
☐ ____ years old

4. Have you been diagnosed with any of the following conditions? (please tick all that apply)
☐ Endometriosis ☐ Polycystic Ovary Syndrome
☐ Primary Amenorrhoea ☐ Menorrhagia
☐ Dysmenorrhoea ☐ Pre-Menstrual Syndrome (PMS) ☐ None of the above

5. Do you have pelvic pain (between your belly button and groin) whilst or just before your period?
☐ Yes ☐ Sometimes ☐ No

6. Do you experience any of the following whilst or just before your period? (please tick all that apply)
☐Back or thigh pain ☐Headache
☐Nausea ☐ Vomiting
☐Breast pain/tenderness ☐Diarrhoea
☐Bloating/increased gas ☐Constipation
☐Temperature fluctuations ☐Joint/muscle pain/cramps
☐Mood changes/anxiety ☐Water retention
☐Poor concentration/memory ☐Tiredness/fatigue
☐Disrupted sleep ☐Cravings/increased appetite
☐Difficulties breathing ☐ No

7. Do these symptoms interfere with your ability to train, compete, study or work?
☐ Yes ☐ No

8. Have you used hormonal contraceptives (e.g., contraceptive pill, IUD, implant etc NOT including copper IUD) at any time in the last 3 months?
☐ Yes → *automatically taken to Q9* ☐ No → *automatically taken to Q14*

---

9. What type of hormonal contraceptive are you/were you using in the last 3 months?
☐ Oral contraceptives (the pill)
If you are using oral contraceptives (the pill) what brand do you use? (Type "unsure", if not sure) ____________________
☐ Hormonal IUD ☐ Hormonal implant ☐ Hormonal coil
☐ Hormonal patch ☐ Hormonal ring ☐ Other, Please specify _______

10. Approximately how long have you been/were you using hormonal contraceptives for? (Please specify years or months)

☐ ____________

11. What are your reasons for using hormonal contraceptives? (please tick all that apply)

☐ To be able to skip or shift my period ☐To make my cycle more regular
☐Contraceptive reasons ☐Reduce period pain
☐ Acne/skin problems ☐Reduce heaviness of bleeding
☐Reduce emotional changes ☐Reduce other PMS symptoms
☐ My doctor prescribed it for me because I wasn't getting my period
☐Other (please specify) ____________

12. Have you had any side effects or adverse events you think are related to being on hormonal contraceptives?

☐ Yes (please specify) ____________ ☐ No

13. Are you still on hormonal contraceptives?

☐ Yes ☐ No
→ *following Q12 automatically taken to final section, Q22*

---

14. Do you currently use a copper IUD?

☐ Yes ☐ No

15. When did you have your last period?

☐ 3 months of less ago → *taken to Q17* ☐ 4-5 months ago ☐ 6 months ago or more

16. Were your periods regular (every 21-35 days) when you were last menstruating?

☐ Yes ☐ No
→ *automatically taken to final section, Q22*

The following questions relate to the previous 3 months:

17. On average, in the previous 3 months how many days were there between the start of one period and the start of the next?

____
(If too irregular) Please specify the range ___________________

18. Have you had any menstrual cycles in the previous 3 months that were less than 21 days or more than 35 days?

☐ Yes ☐ No

19. How many days of bleeding have you had each period?

____
(If too irregular) Please specify the range ___________________

20. Do you think you have heavy menstrual flow? (please tick all that apply)

☐ Yes – pass large blood clots
☐ Yes – flood through to clothes or bedding
☐ Yes – bleeding more than 7 days
☐ Yes – changing of sanitary items (tampons or pads) every 2 hours, or 12 sanitary items per day
☐ No

21. Have you experienced bleeding or spotting between periods in the previous 3 months?
☐ Yes ☐ No

---

22. Do you feel your training and/or match performance is disrupted by your menstrual cycle?
☐ No → *questionnaire automatically ends*
☐ Yes – please tick all that apply
☐ Days/week prior to menstruating ☐ Whilst menstruating
☐ Days/week following menstruating ☐ Middle of my cycle

23. Which aspects of your training/match performance do you feel are impacted?
☐ Concentration ☐ Decision making ☐ Coordination
☐ Ability to recover ☐ Soreness ☐ Energy levels (lower)
☐ Strength (not as strong) ☐ Speed (not as fast) ☐ Endurance/fatigue more easily

End of questionnaire