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Article

Impact of the menstrual cycle phases on the movement patterns of sub-elite women soccer players during competitive matches

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Abstract: The purpose of this study was to evaluate the influence of the menstrual cycle phases on the movement patterns of sub-elite women soccer players during competitive matches over three consecutive seasons. Individual movement data were analyzed and compared in eight players from the second French League at the early follicular (EF), late follicular (LF) and mid luteal (ML) phases of their menstrual cycle determined by the calendar method. The movement patterns, expressed as meters per minute, were recorded during competitive matches using devices placed on the player's ankle. Our results showed significantly lower distances covered at moderate and high velocity in the EF phase than in the LF and ML phases (Cohen's d effect size = 1.03 and 0.79, respectively). The total distance covered during matches and the number of sprints also were reduced during EF compared with LF (d = 0.78 and 0.7, respectively). Overall, total distance and distance covered at low velocity were significantly lower during the second half-time of the matches (d = 1.51), but no menstrual cycle phase*game period interaction was noted. In conclusion, our study suggests that EF may impact the movement pattern of sub-elite women soccer players during competitive matches, without any modulation of this effect by the playing time. Despite the low sample size, these results can be useful for coaches and support staff to modulate training load and player rotation during soccer games.

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1. Introduction

The menstrual cycle follows a biological rhythm with large cyclic fluctuations in endogenous sex hormones, including estrogen and progesterone. It can be divided into different phases in function of the sex hormone production and consequently, their concentrations in the body. The follicular phase starts with the onset of menstruation until ovulation. During the early follicular (EF) phase, estrogen (E2: 17β-estradiol) and progesterone (P4) plasma concentrations are low. In the late follicular (LF) phase, E2 progressively increases and reaches a peak before ovulation at LF end, while P4 remains low. The luteal phase starts with ovulation and is associated with the elevation of P4 concentration. Studies in rodent models (after E2 and P4 supplementation) and in humans have shown that besides their roles in the reproductive system, E2 and P4 cyclical variations influence other physiological systems, including cardiovascular, respiratory, metabolic and neuromuscular parameters that might lead to significant exercise performance alterations [1].

Women athletes regularly report menstrual cycle-related symptoms, but the real impact of the menstrual cycle phases on their performance is still debated [1,2]. It is well-

known that the different menstrual phase phases (follicular vs. luteal) can specifically influence metabolic and hormonal adaptations during exercise [3]; however, the effects of hormone fluctuations during the menstrual cycle on physical performance are still conflicting. Some studies reported enhanced performance outcomes during the EF [4-6], ovulatory [7] and mid luteal (ML) phases [8,9], whereas others did not find any difference [10-15]. Furthermore, laboratory and field data are sometimes contradictory [1,16], which make difficult to propose evidence-based guidelines for managing exercise performance.

Soccer is an intermittent sport modality characterized by endurance and power/strength loads [17]. Therefore, soccer combines aerobic and anaerobic exercises that may confound the potential influence of sex hormones on the overall performance [18]. Surprisingly, studies on the impact of the menstrual phases (i.e. sex hormone variations) on women soccer players' performance are still scarce in the literature. This is important also because many top-level sportswomen, particularly in soccer, do not take oral contraception. For example, Sundgot-Borgen et al. showed that only 35.8% of Norwegian women soccer players were using oral contraception [19]. As simultaneously still few young sportswomen use copper intrauterine devices (IUDs), hormonal intrauterine systems (IUSs) or subdermal implants, this shows the large share of women with a natural menstrual cycle [20]. Despite this fact, However, to date, only one study evaluated the impact of the menstrual cycle phases on the performance of 15 elite women soccer players during the German national championship (2015-2016) [21]. The authors did not observe any difference in the total distance covered, distance covered at low or high intensity, number of sprints performed, and sprinting distance between follicular and luteal phase, suggesting that the menstrual cycle phases do not significantly alter the aerobic and anaerobic capacities during a soccer game [21]. However, their analysis did not consider separately the EF and LF phases and this might be a limitation because the EF phase is characterized by low E2 and P4 and the LF phase by high E2 and low P2.

Therefore, the aim of this study was to determine the influence of three menstrual cycle phases (EF, LF, and ML) on the movement patterns of sub-elite women soccer players during competitive matches. We expressed the recorded running performance as the total covered distance, and also according to four standardized running speed ranges. Moreover, we quantified the number of sprints, and compared the data collected in the two halves of each match.

2. Materials and Methods

2.1. Study design

To determine whether a player's movement pattern was affected by the menstrual cycle phases, we recorded each woman's movements during competitive matches of the second French division over three consecutive competitive seasons (2018/19, 2019/20, and 2020/21). Each included soccer player participated in at least three matches for each menstrual cycle phase (3.7 matches \pm 1.2). We then compared the movement data (whole match and first and second part) for the three menstrual cycle phases.

2.2. Participants

Forty-two sub-elite women soccer players from the second French division agreed to participate in the study. Participants taking hormonal contraception (n = 13, only pill or implant in our population), goalkeepers (n = 3) and participants who were unable to play at least 3 matches in each phase of their cycle (injury, non-selection, substitute, n = 18) were excluded from the analysis. Thus, only eight players met the following inclusion criteria: eumenorrheic women soccer players, no use of hormonal contraception (i.e. pill, contraceptive implant) during the last 6 months, and regular menstrual cycle (25-40 days of length). These eight players were included in the study, and their anthropometric and menstrual cycle characteristics are shown in Table 1. All procedures conformed to the standards of the Declaration of Helsinki. All participants provided a written, voluntary

informed consent before participation. This study was approved by the relevant ethics committee (Comité de Protection des Personnes Ile de France V, n°19.04.24.44735).

Table 1. Women soccer players' characteristics (n=8).

	Mean ± SD (CV%)
Age (years)	25.7 ± 3.3 (12.8%)
Height (cm)	167.3 ± 7.2 (4,3%)
Body mass (kg)	58.9 ± 6.3 (10.7%)
Body fat (%) ^a	23.0 ± 2.0 (8.7%)
Menstrual cycle length (days)	30.0 ± 2.6 (8.7%)

^a Body fat percentage measured from the skinfold method [22]
Coefficient of Variation (CV%) = (Standard Deviation / Mean) * 100

2.3. Estimation of the menstrual cycle phases

As weekly measures of urinary luteinizing hormone and serum E2 and P4 concentrations were not possible due to the long study period (3 years) [23-25], we determined the participants' menstrual phase at each match using the calendar-based counting method. During the three seasons, each woman recorded the first day of each cycle (day 1 of the menses). Then, for the first three consecutive menstrual cycles, we determined each participant's mean cycle length as the number of days before the menstruation onset. We assumed that participants had a regular ovulatory menstrual cycle with a 'classical' physiological hormone fluctuation pattern, if the standard deviation of each cycle duration was lower than 3 days. Based on the menstruation initiation day and cycle length, we retrospectively classified the matches played by each participant in: EF phase (menstruation, day 1 – 4), LF phase (day 10 – 13), and ML phase (day 20 – 23). The days were based on the average 28-day cycle [11].

2.3. Contextual-related variables

As contextual-related variables may affect the soccer players' movement patterns [26], we recorded game location (match at home or away), match outcome (won, drawn, or lost), and quality of opposition (i.e. the differences in ranking and points between the player's team and that of her opponent) (Table 2).

2.4. Movement patterns of each player

During competition games, players wore on the ankle an inertial measurement unit (Goaltime-Kerilab©, Paris, France) that included a 100 Hz accelerometer and a 100 Hz gyroscope. In this type of device, triaxial accelerometers measure three-dimensional movements, and have been used to quantify external load in team sports [27,28]. Accelerometry workload provides a measure of the total distance and a measure of loads in sports with frequent directional changes [29,30]. The pre-marketing device was carefully tested by the manufacturer. Compared with known distances, its measurement accuracy was higher than 95% and the mean inter- and intra-individual differences in total distance, for each velocity range, were lower than 5%.

Each player used the same device during each recording. We expressed the recorded running performance as the total covered distance (DTOT; m.min⁻¹) and in the four standardized velocity ranges predefined by the device: low velocity (LowV; <7 km.h⁻¹), moderate velocity (ModV; 7 km.h⁻¹ – 14 km.h⁻¹), high velocity (HighV; 14 km.h⁻¹ – 19 km.h⁻¹) and sprinting (SprintV; >19 km.h⁻¹). We also counted the number of sprints (1 sprint

corresponded to at least 4 strides at >21 km.h-1). We expressed the collected data i) for each velocity range as distance covered per minute (m.min-1), and ii) as the number of sprints per minute [31]. We then averaged the data for each phase (EF, LF, ML), for the whole match and for each half match. We used data originating from recording that lasted ≥80 minutes.

2.5. Statistical analyses

We presented data as the mean ± SD and coefficient of variation (CV%). We checked the data normality using the Shapiro-Wilk’s test. We determined whether game location and match outcome varied during the menstrual cycle phases (EF, LF, ML) using the Chi-square (χ²) test. We used linear mixed models to compare the player’s movement patterns and quality of opposition in function of the menstrual cycle phases (EF, LF, ML) and game period (first, second part). We modeled menstrual cycle phases, game period and their interaction as fixed effects, and soccer players as random effect. When we detected a significant effect, we adjusted for multiple comparisons using the Tukey’s method and computed the Cohen’s d effect size (0.2: small effect; 0.5: moderate effect; 0.8: large; and 1.3 very large effect) [32]. We set the statistical significance at p < .05. For all statistical analyses, we used the R software (version 4.0.5), and the lme4, nmlr, and multcomp packages for the linear mixed models [33].

3. Results

3.1. Context of games and menstrual cycle phase

Game location and outcome, and quality of opposition did not differ between games from the three menstrual cycle phases (p > 0.05, Table 2).

Table 2. Contextual-related variables of soccer games.

		EF	LF	ML	Statistics
Game location	Home	14	14	7	χ ² (2.72) = 4.71, p = 0.10
	Away	9	12	16	
Match Outcome	Won	16	18	14	χ ² (4.72) = 3.16, p = 0.53
	Drawn	7	6	9	
	Lost	0	2	0	
Ranking difference		-4.9 ± 3.9 (-79%)	-5.08 ± 4.6 (-90%)	-5.1 ± 4.5 (-88%)	p = 0.88
Point difference		10.5 ± 9.9 (94%)	11 ± 10.2 (93%)	10.1 ± 10.1 (99%)	p = 0.73

Ranking difference = Difference between the championship ranking of the player’s team and the ranking of her opponents. Values for ranking and point difference are presented as mean ± SD (CV%). Coefficient of Variation (CV%) = (Standard Deviation / Mean) * 100

3.2. Match physical performance metrics

No menstrual cycle phase and game period interaction effect was revealed by the linear mixed model. Significant effects of the phases of the menstrual cycle were found for DTOT (m.min-1) (p=0.0097), ModV (m.min-1) (p = 0.0005), HighV (m.min-1) (p = 0.0046), and number of sprints (count.min-1, p = 0.0004) (Figure 1).

Specifically, DTOT was lower during EF than LF (p = 0.0048; d = 0.78 (moderate effect)). Similarly, ModV and HighV were significantly lower during EF compared with the LF (p < 0.001; d = 1.03 (large effect); and p = 0.0011; d = 0.79 (moderate effect), respectively) and ML phases (p = 0.04; d = 0.57 (moderate effect); and p = 0.048; d = -0.52 (moderate effect), respectively). The number of sprints was significantly higher in the LF phase than in the EF and ML phases (p < 0.001; d = 0.7 (moderate effect); and p = 0.002; d = 0.96 (large

effect), respectively). The LowV ($p = 0.12$) and SprintV ($p = 0.20$) mean values were comparable in the three phases.

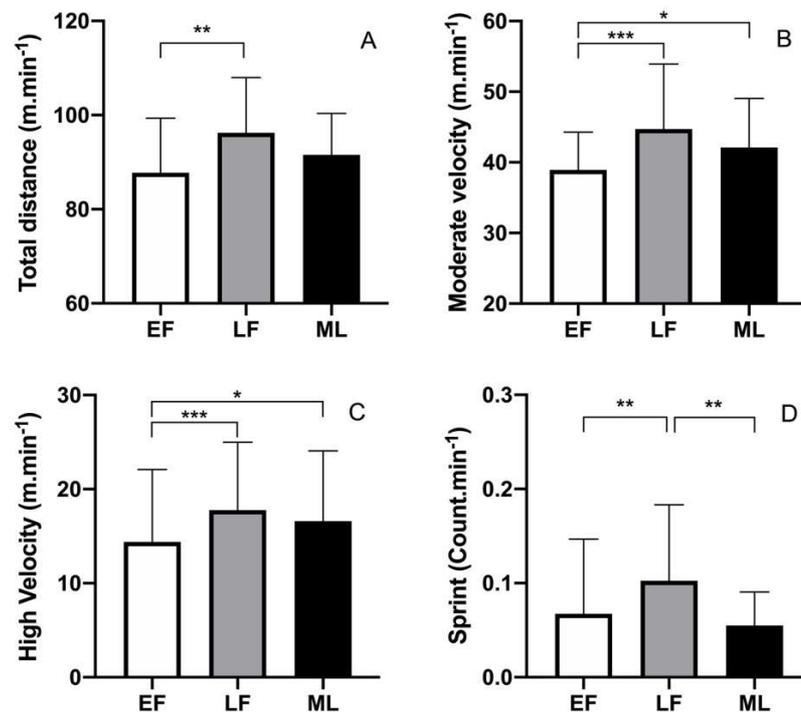


Figure 1. Effects of the menstrual cycle phases on women soccer players' movement patterns during competitive soccer matches (whole game). A) Total distance covered per minute (m.min⁻¹); B) Distance covered at moderate velocity per minute (m.min⁻¹); C) Distance covered at high velocity per minute (m.min⁻¹); D) Number of sprints per minute (count.min⁻¹). EF: early follicular; LF: late follicular; ML: mild luteal. * $p < .05$; ** $p < .01$; *** $p < .001$.

The linear mixed model also showed a significant effect of game period for DTOT ($p = 0.035$) and LowV ($p = 0.002$). DTOT and LowV were significantly lower in the second part of each game ($d = 1.51$ and $d = 1.367$, very large effects, respectively) (Table 3). Conversely, we did not observe any effect on ModV, HighV, SprintV (Table 3).



Table 3. Total covered distance per minute (D_{TOT}), distance covered per minute at low (LowV), moderate (ModV), high (HighV) velocity, and sprint velocity (SprintV) during the first (1st H) and the second half (2nd H) of competitive soccer matches.

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	1 st H			2 nd H			Linear Mixed Effect: <i>p</i>		
	EF	LF	ML	EF	LF	ML	MC	GP	MC*GP
D_{TOT} (m.min ⁻¹)	89.1 ± 13.7 (15.4%)	98.5 ± 11.9 (12.1%)	92.5 ± 8.3 (9.0%)	85.3 ± 10.3 (12.1%)	91.8 ± 12.3 (13.3%)	89.4 ± 9.7 (10.9%)	0.01	0.03	0.73
LowV (m.min ⁻¹)	34.6 ± 3.1 (9.0%)	34.3 ± 3.4 (9.9%)	33.1 ± 3.5 (10.6%)	33.2 ± 1.8 (5.4%)	31.9 ± 2.0 (6.3%)	31.9 ± 2.9 (9.1%)	0.13	0.004	0.61
ModV (m.min ⁻¹)	39.5 ± 6.2 (15.7%)	45.7 ± 9.2 (20.1%)	42.4 ± 6.8 (16.0%)	37.9 ± 5.0 (13.2%)	42.6 ± 9.3 (21.8%)	41.0 ± 7.0 (17.1%)	0.001	0.053	0.77
HighV (m.min ⁻¹)	14.0 ± 7.4 (52.9%)	17.0 ± 6.5 (38.2%)	15.8 ± 6.7 (42.4%)	13.3 ± 6.8 (51.1%)	15.9 ± 6.1 (38.4%)	15.3 ± 6.9 (45.1%)	0.005	0.26	0.93
SprintV (m.min ⁻¹)	0.64 ± 0.86 (134.4%)	1.12 ± 1.31 (117.0%)	0.95 ± 1.35 (142.1%)	0.60 ± 0.82 (136.7%)	1.06 ± 1.27 (120.0%)	0.92 ± 1.31 (142.4%)	0.21	0.85	0.99

Values are presented as mean ± SD (CV%). Coefficient of Variation (CV%) = (Standard Deviation / Mean) * 100. Significant values are in bold. EF: early follicular; LF: late follicular; ML: mild luteal; MC: menstrual cycle effect; GP: game period effect; MC * GP: menstrual cycle x game period interaction.

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4. Discussion

Our study suggests that independently of contextual-related variables (i.e. game location, match outcome and quality of opponents), the EF phase of the menstrual cycle (i.e. the period of the menses) may negatively impact the women soccer players' movement patterns during competitive matches. Indeed, ModV and HighV were lower during the EF than the LF and ML phases, leading to a decrease of the DTOT covered during this period. Moreover, the number of sprints was also reduced during EF compared with LF. As expected, overall DTOT and LowV were lower during the second half of the game, but the match duration did not modify the EF phase influence on women soccer players' performance.

Performance-based research in women soccer players is scarce and to our knowledge, only one previous study was performed in "ecological" conditions. In this study on 15 elite German women soccer players, the authors compared the impact of the follicular and luteal phases on physical performance during match-play over a 4-month period [21]. Their results suggest that the menstrual cycle phases do not significantly influence the match physical performance, but their conclusions should be interpreted with caution because they did not consider separately the EF and LF phase, and therefore, the potential influence of menstruation was not analyzed separately. Our study is the first to establish that physical performance evaluated during competitive matches may be affected in women soccer players during the menstruation period.

Women soccer players are exposed to specific physical demands during matches that vary according to the game level/standard. Overall, a woman soccer player generally covers around 10 km per match [34], highlighting that soccer athletic performance requires good aerobic capacities. Helgerud et al. [35] demonstrated that the increase of maximal oxygen consumption (VO₂max) in men elite junior soccer players is correlated with the distance covered, work intensity level, number of sprints, and number of involvements with the ball during matches. Besides aerobic endurance, strength, agility, speed and repeated sprint capacity also are important for high level performance in a soccer match [36]. Speed can be described as the ability to cover a distance in a short time. High-intensity running and sprints are crucial component in soccer because they represent 22 to 28% of the total distance covered in a match [37], although large fluctuations are noted due to playing position, level of play, surface, or team tactics [38]. Therefore, we decided to calculate the total distance covered during the whole match and during each half period. We also distinguished four velocity ranges to cover simultaneously the aerobic and anaerobic capacities. As the women soccer players did not always play for the entire duration of the match (95 minutes), we expressed the results as meter per minute or counts per minute (for the number of sprints).

Female sex hormone (E2 and P4) fluctuations during the menstrual cycle may potentially modulate the energy stores, neuromuscular function, fatigability, and recovery. E2 and P4 are both low in the EF, only E2 is high in the LF, and both E2 and P4 are high in the ML phase [3,5]. P4 is known to counteract E2 effect. Muscle glycogen content in vastus lateralis at rest is higher in the mid-luteal phase than in the mid-follicular phase [39]. After a glycogen depletion session (90min cycling at 60% of VO₂max followed by four 1-min sprints at 100% VO₂max), muscle glycogen content remains higher during the luteal than follicular phase [40]. These findings suggest that the elevated E2 and P4 plasma concentrations in the luteal phase might promote muscle glycogen storage and sparing during exercise, and this might delay the fatigue onset and facilitate recovery [3,41,42]. Conversely, low E2 and P4 levels (EF) and high E2 level alone (LF) do not induce such effects [3,41,42]. However, as soccer requires also high intensity running and sprints, the women's performance could be improved by a large capacity to use glycolysis during the match (if H⁺ and Pi production are well regulated). In our study, we did not detect any difference between the LF and ML phases for any of the measured distances (whatever

the velocity range) during the whole match and in two halves. This suggests that the capacity to induce muscle glycogen storage and sparing during the match in the luteal phase was not efficient, or that the glycolysis activity during LF did not significantly improve performance. This conclusion is in accordance with previous studies that did not observe any significant performance difference between the follicular and luteal phases in women soccer players [43].

Interestingly, our study showed that the EF phase negatively influenced the women soccer players' movement pattern with lower ModV and HighV values compared with the LF and ML phases, leading to a decrease of the DTOT. The number of sprints also was lower during the EF than the LF phase. High-intensity running and repeated sprint abilities rely not only on glycogen availability and glycolytic enzyme activities, but also on neuromuscular features and fatigability. Ovarian hormone fluctuations during the menstrual cycle may influence the neural drive, skeletal muscle contractility and fatigability. Studies in animal models reported that E2 binds to muscle α estrogen receptors (ER α) [44] and limits skeletal muscle fatigue in soleus muscles [45]. In humans, it has been shown that neuromuscular function and fatigability of the knee extensors vary during the menstrual cycle, possibly influencing the exercise performance, as indicated by the higher voluntary activation (assessed by transcranial magnetic stimulation and motor nerve stimulation) during the LF phase and the longer time to task failure during the ML phase [46]. Moreover, the luteal phase has been associated with decreased knee joint valgus angles, suggesting that progesterone might influence knee kinematics and the associated injury risk [47]. However, a recent review reported conflicting results on fatigability during the menstrual cycle [48]. Indeed, half of the studies found that fatigability was lower during the luteal phase, and the other half during the follicular phase. These inconsistencies could be explained by differences in the methodologies used and the skeletal muscles investigated (upper/lower extremities). Concerning the lower extremities, where knee extensors are the muscles more often evaluated, only one study examined the time to task failure in the EF, LF and ML phases, and did not find any significant difference [6]. However, it highlighted a clear trend ($p = 0.061$) for higher maximal voluntary contraction in the EF than ML phase. Thus, it is difficult to explain our results indicating that low E2 and P4 concentrations may negatively impact soccer performance during competitive matches. However, our findings are in accordance with the meta-analysis by McNulty et al. [1] showing that exercise performance might be slightly reduced during the EF phase of the menstrual cycle, compared with all the other phases. They are also in agreement with other studies in which women athletes stated that their performance is altered during the menstruation days [49,50]. Motivation, pain, discomfort, disturbed mood are some psychological factors that should be taken into account to explain the lower performance during the EF phase [51,52].

Finally, overall, our findings showed a decrease of the DTOT and of the LowV during the second half period (vs. the first one), but without any menstrual cycle phase*game period interaction, meaning that the EF negative effect on performance is not counterbalanced by the match duration. This result is in accordance with the recent study by Krustrup et al. [53] showing that match playing in elite women soccer players results in significant glycogen depletion in both muscle fiber types, which may explain fatigue in the last part of the match. Furthermore, repeated sprint capacity was associated with muscle metabolite perturbation [53].

4.1. Limitations

One of the limitations of this study concerns the absence of sex hormone measurements to validate the different menstrual cycle phases. Although the "calendar cycle tracking method" is the most common method for a long follow-up period, it is not optimal to confirm that women are in the expected menstrual phase [24]. Furthermore, we might have included women with anovulatory cycle in our study because no ovulation test was

carried out [54]. In addition, the limited number of participants and the long study period might restrict our conclusions.

4.2. Future Directions

This study deserves to be reinforced by a larger sample size with women followed over a sporting season. The use of connected devices incorporating GPS could provide additional information. Beyond the 3 phases studied in this work, the addition of the ovulatory phase could complete these results due to a higher E2/P4 ratio and its impact on energy metabolism and neuromuscular function. Lastly, as many female soccer players use oral contraceptives, a comparative population could complement these data.

5. Conclusions

This study was the first to analyze women players' movement pattern during soccer games according to three menstrual cycle phases (early follicular, late follicular, and mid luteal phases). Our results suggest that the early follicular phase (i.e. menstruation days) may negatively affect performance in sub-elite women soccer players during competitive matches by decreasing the distances covered at different velocities and the sprint number. The playing duration did not modify this effect. These results can be useful for coaches and conditioning staff to optimize training load and performance in high-level women soccer players.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

- McNulty, K.L.; Elliott-Sale, K.J.; Dolan, E.; Swinton, P.A.; Ansdell, P.; Goodall, S.; Thomas, K.; Hicks, K.M. The Effects of Menstrual Cycle Phase on Exercise Performance in Eumenorrhic Women: A Systematic Review and Meta-Analysis. *Sports Med* **2020**, *50*, 1813–1827, doi:10.1007/s40279-020-01319-3.
- Larsen, B.; Morris, K.; Quinn, K.; Osborne, M.; Minahan, C. Practice does not make perfect: A brief view of athletes' knowledge on the menstrual cycle and oral contraceptives. *J Sci Med Sport* **2020**, *23*, 690–694, doi:10.1016/j.jsams.2020.02.003.
- Boisseau, N.; Isacco, L. Substrate metabolism during exercise: sexual dimorphism and women's specificities. *European journal of sport science* **2021**, 1–21, doi:10.1080/17461391.2021.1943713.
- Campbell, S.E.; Angus, D.J.; Febbraio, M.A. Glucose kinetics and exercise performance during phases of the menstrual cycle: effect of glucose ingestion. *Am J Physiol Endocrinol Metab* **2001**, *281*, E817–825, doi:10.1152/ajpendo.2001.281.4.E817.

5. Pallavi, L.C.; UJ, D.S.; Shivaprakash, G. Assessment of Musculoskeletal Strength and Levels of Fatigue during Different Phases of Menstrual Cycle in Young Adults. *Journal of clinical and diagnostic research : JCDR* **2017**, *11*, CC11-CC13, doi:10.7860/JCDR/2017/24316.9408. 338-340
6. Tenan, M.S.; Hackney, A.C.; Griffin, L. Maximal force and tremor changes across the menstrual cycle. *Eur J Appl Physiol* **2016**, *116*, 153-160, doi:10.1007/s00421-015-3258-x. 341-342
7. Bambaiechi, E.; Reilly, T.; Cable, N.T.; Giacomoni, M. The isolated and combined effects of menstrual cycle phase and time-of-day on muscle strength of eumenorrheic females. *Chronobiology international* **2004**, *21*, 645-660, doi:10.1081/cbi-120039206. 343-344
8. Oosthuysen, T.; Bosch, A.N.; Jackson, S. Cycling time trial performance during different phases of the menstrual cycle. *Eur J Appl Physiol* **2005**, *94*, 268-276, doi:10.1007/s00421-005-1324-5. 345-346
9. Ekenros, L.; Hirschberg, A.L.; Heijne, A.; Friden, C. Oral contraceptives do not affect muscle strength and hop performance in active women. *Clin J Sport Med* **2013**, *23*, 202-207, doi:10.1097/JSM.0b013e3182625a51. 347-348
10. Dibrezzo, R.; Fort, I.L.; Brown, B. Dynamic strength and work variations during three stages of the menstrual cycle. *J Orthop Sports Phys Ther* **1988**, *10*, 113-116, doi:10.2519/jospt.1988.10.4.113. 349-350
11. Janse de Jonge, X.A. Effects of the menstrual cycle on exercise performance. *Sports Med* **2003**, *33*, 833-851, doi:10.2165/00007256-200333110-00004. 351-352
12. Janse de Jonge, X.A.; Boot, C.R.; Thom, J.M.; Ruell, P.A.; Thompson, M.W. The influence of menstrual cycle phase on skeletal muscle contractile characteristics in humans. *J Physiol* **2001**, *530*, 161-166, doi:10.1111/j.1469-7793.2001.0161m.x. 353-354
13. Janse, D.E.J.X.A.; Thompson, M.W.; Chuter, V.H.; Silk, L.N.; Thom, J.M. Exercise performance over the menstrual cycle in temperate and hot, humid conditions. *Med Sci Sports Exerc* **2012**, *44*, 2190-2198, doi:10.1249/MSS.0b013e3182656f13. 355-356
14. McLay, R.T.; Thomson, C.D.; Williams, S.M.; Rehrer, N.J. Carbohydrate loading and female endurance athletes: effect of menstrual-cycle phase. *Int J Sport Nutr Exerc Metab* **2007**, *17*, 189-205, doi:10.1123/ijsnem.17.2.189. 357-358
15. Vaiksaar, S.; Jurimae, J.; Maestu, J.; Purge, P.; Kalytka, S.; Shakhlina, L.; Jurimae, T. No effect of menstrual cycle phase and oral contraceptive use on endurance performance in rowers. *J Strength Cond Res* **2011**, *25*, 1571-1578, doi:10.1519/JSC.0b013e3181df7fd2. 359-360
16. Billaut, F.; Bishop, D. Muscle fatigue in males and females during multiple-sprint exercise. *Sports Med* **2009**, *39*, 257-278, doi:10.2165/00007256-200939040-00001. 362-363
17. Stolen, T.; Chamari, K.; Castagna, C.; Wisloff, U. Physiology of soccer: an update. *Sports Med* **2005**, *35*, 501-536, doi:10.2165/00007256-200535060-00004. 364-365
18. Archiza, B.; Andaku, D.K.; Beltrame, T.; Libardi, C.A.; Borghi-Silva, A. The Relationship Between Repeated-Sprint Ability, Aerobic Capacity, and Oxygen Uptake Recovery Kinetics in Female Soccer Athletes. *Journal of human kinetics* **2020**, *75*, 115-126, doi:10.2478/hukin-2020-0042. 366-368
19. Sundgot-Borgen, J.; Torstveit, M.K. The female football player, disordered eating, menstrual function and bone health. *Br J Sports Med* **2007**, *41 Suppl 1*, i68-72, doi:10.1136/bjism.2007.038018. 369-370
20. Henderson, Z.J.; Scribbans, T. Intrauterine Contraception and Athletic Performance: Where is the Data? *The Health & Fitness Journal of Canada* **2020**, *13(2)*, 37-45, doi:<https://doi.org/10.14288/hfjc.v13i2.308>. 371-372
21. Julian, R.; Skorski, S.; Hecksteden, A.; Pfeifer, C.; Bradley, P.S.; Schulze, E.; Meyer, T. Menstrual cycle phase and elite female soccer match-play: influence on various physical performance outputs. *Science and Medicine in Football* **2020**, *5*, 97-104, doi:10.1080/24733938.2020.1802057. 373-375
22. Durnin, J.V.; Womersley, J. The relationship between skinfold thickness and body fat in adults of middle age. *J Physiol* **1969**, *200*, 105P-106P. 376-377

23. Schaumberg, M.A.; Jenkins, D.G.; Janse, D.E.J.X.A.; Emmerton, L.M.; Skinner, T.L. Oral Contraceptive Use Dampens Physiological Adaptations to Sprint Interval Training. *Med Sci Sports Exerc* **2017**, *49*, 717-727, doi:10.1249/MSS.0000000000001171. 378-380
24. Janse de Jonge, X.A.; Thompson, B.; Han, A. Methodological Recommendations for Menstrual Cycle Research in Sports and Exercise. *Med Sci Sports Exerc* **2019**, *51*, 2610-2617, doi:10.1249/MSS.0000000000002073. 381-382
25. Elliott-Sale, K.J.; Minahan, C.L.; de Jonge, X.; Ackerman, K.E.; Sipila, S.; Constantini, N.W.; Lebrun, C.M.; Hackney, A.C. Methodological Considerations for Studies in Sport and Exercise Science with Women as Participants: A Working Guide for Standards of Practice for Research on Women. *Sports Med* **2021**, *51*, 843-861, doi:10.1007/s40279-021-01435-8. 383-385
26. Diez, A.; Lozano, D.; Arjol-Serrano, J.L.; Mainer-Pardos, E.; Castillo, D.; Torrontegui-Duarte, M.; Nobari, H.; Jaen-Carrillo, D.; Lampre, M. Influence of contextual factors on physical demands and technical-tactical actions regarding playing position in professional soccer players. *BMC Sports Sci Med Rehabil* **2021**, *13*, 157, doi:10.1186/s13102-021-00386-x. 386-388
27. Hughes, T.; Jones, R.K.; Starbuck, C.; Sergeant, J.C.; Callaghan, M.J. The value of tibial mounted inertial measurement units to quantify running kinetics in elite football (soccer) players. A reliability and agreement study using a research orientated and a clinically orientated system. *J Electromyogr Kinesiol* **2019**, *44*, 156-164, doi:10.1016/j.jelekin.2019.01.001. 389-391
28. Murray, A.M.; Varley, M.C. Technology in soccer. In *Elite Soccer Players: Maximizing Performance and Safety*, Ryan Curtis, C.B., Robert Huggins, Douglas J. Casa, Ed.; Routledge, Taylor & Francis: New York, NY 10017, 2020; pp. 37-53. 392-393
29. Boyd, L.J.; Ball, K.; Aughey, R.J. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *Int J Sports Physiol Perform* **2011**, *6*, 311-321, doi:10.1123/ijsp.6.3.311. 394-395
30. Polglaze, T.; Dawson, B.; Hiscock, D.J.; Peeling, P. A comparative analysis of accelerometer and time-motion data in elite men's hockey training and competition. *Int J Sports Physiol Perform* **2015**, *10*, 446-451, doi:10.1123/ijsp.2014-0233. 396-397
31. Carling, C.; Le Gall, F.; Dupont, G. Analysis of repeated high-intensity running performance in professional soccer. *J Sports Sci* **2012**, *30*, 325-336, doi:10.1080/02640414.2011.652655. 398-399
32. Cohen, J. *Statistical Power Analysis for the Behavioural Sciences.*; Associates, L.E., Ed.; Hillsdale, NJ, 1988. 400
33. Hothorn, T.; Bretz, F.; Westfall, P. Simultaneous inference in general parametric models. *Biom J* **2008**, *50*, 346-363, doi:10.1002/bimj.200810425. 401-402
34. Vescovi, J.D.; Jovanovic, M. Sprint Mechanical Characteristics of Female Soccer Players: A Retrospective Pilot Study to Examine a Novel Approach for Correction of Timing Gate Starts. *Front Sports Act Living* **2021**, *3*, 629694, doi:10.3389/fspor.2021.629694. 403-405
35. Helgerud, J.; Engen, L.C.; Wisloff, U.; Hoff, J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc* **2001**, *33*, 1925-1931, doi:10.1097/00005768-200111000-00019. 406-407
36. Datson, N.; Hulton, A.; Andersson, H.; Lewis, T.; Weston, M.; Drust, B.; Gregson, W. Applied physiology of female soccer: an update. *Sports Med* **2014**, *44*, 1225-1240, doi:10.1007/s40279-014-0199-1. 408-409
37. Vescovi, J.D.; Favero, T.G. Motion characteristics of women's college soccer matches: Female Athletes in Motion (FAiM) study. *Int J Sports Physiol Perform* **2014**, *9*, 405-414, doi:10.1123/IJSP.2013-0526. 410-411
38. Randell, R.K.; Carter, J.M.; Jeukendrup, A.E.; Lizarraga, M.A.; Yanguas, J.I.; Rollo, I. Fat Oxidation Rates in Professional Soccer Players. *Med Sci Sports Exerc* **2019**, *51*, 1677-1683, doi:10.1249/MSS.0000000000001973. 412-413
39. Hackney, A.C. Effects of the menstrual cycle on resting muscle glycogen content. *Horm Metab Res* **1990**, *22*, 647, doi:10.1055/s-2007-1004994. 414-415
40. Nicklas, B.J.; Hackney, A.C.; Sharp, R.L. The menstrual cycle and exercise: performance, muscle glycogen, and substrate responses. *Int J Sports Med* **1989**, *10*, 264-269, doi:10.1055/s-2007-1024913. 416-417
41. Oosthuyse, T.; Bosch, A.N. The effect of the menstrual cycle on exercise metabolism: implications for exercise performance in eumenorrhoeic women. *Sports Med* **2010**, *40*, 207-227, doi:10.2165/11317090-000000000-00000. 418-419

42. Devries, M.C.; Hamadeh, M.J.; Phillips, S.M.; Tarnopolsky, M.A. Menstrual cycle phase and sex influence muscle glycogen utilization and glucose turnover during moderate-intensity endurance exercise. *Am J Physiol Regul Integr Comp Physiol* **2006**, *291*, R1120-1128, doi:10.1152/ajpregu.00700.2005. 420-422
43. De Souza, M.J.; Maguire, M.S.; Rubin, K.R.; Maresh, C.M. Effects of menstrual phase and amenorrhea on exercise performance in runners. *Med Sci Sports Exerc* **1990**, *22*, 575-580, doi:10.1249/00005768-199010000-00006. 423-424
44. Wiik, A.; Ekman, M.; Morgan, G.; Johansson, O.; Jansson, E.; Esbjornsson, M. Oestrogen receptor beta is present in both muscle fibres and endothelial cells within human skeletal muscle tissue. *Histochem Cell Biol* **2005**, *124*, 161-165, doi:10.1007/s00418-005-0030-z. 425-427
45. Cabelka, C.A.; Baumann, C.W.; Collins, B.C.; Nash, N.; Le, G.; Lindsay, A.; Spangenburg, E.E.; Lowe, D.A. Effects of ovarian hormones and estrogen receptor alpha on physical activity and skeletal muscle fatigue in female mice. *Exp Gerontol* **2019**, *115*, 155-164, doi:10.1016/j.exger.2018.11.003. 428-430
46. Ansdell, P.; Brownstein, C.G.; Skarabot, J.; Hicks, K.M.; Simoes, D.C.M.; Thomas, K.; Howatson, G.; Hunter, S.K.; Goodall, S. Menstrual cycle-associated modulations in neuromuscular function and fatigability of the knee extensors in eumenorrheic women. *J Appl Physiol (1985)* **2019**, *126*, 1701-1712, doi:10.1152/jappphysiol.01041.2018. 431-433
47. Cesar, G.M.; Pereira, V.S.; Santiago, P.R.; Benze, B.G.; da Costa, P.H.; Amorim, C.F.; Serrao, F.V. Variations in dynamic knee valgus and gluteus medius onset timing in non-athletic females related to hormonal changes during the menstrual cycle. *Knee* **2011**, *18*, 224-230, doi:10.1016/j.knee.2010.05.004. 434-436
48. Pereira, H.M.; Larson, R.D.; Bemben, D.A. Menstrual Cycle Effects on Exercise-Induced Fatigability. *Frontiers in physiology* **2020**, *11*, 517, doi:10.3389/fphys.2020.00517. 437-438
49. Findlay, R.J.; Macrae, E.H.R.; Whyte, I.Y.; Easton, C.; Forrest Nee Whyte, L.J. How the menstrual cycle and menstruation affect sporting performance: experiences and perceptions of elite female rugby players. *Br J Sports Med* **2020**, *54*, 1108-1113, doi:10.1136/bjsports-2019-101486. 439-441
50. Armour, M.; Hyman, M.S.; Al-Dabbas, M.; Parry, K.; Ferfolja, T.; Curry, C.; MacMillan, F.; Smith, C.A.; Holmes, K. Menstrual Health Literacy and Management Strategies in Young Women in Australia: A National Online Survey of Young Women Aged 13-25 Years. *J Pediatr Adolesc Gynecol* **2021**, *34*, 135-143, doi:10.1016/j.jpjag.2020.11.007. 442-444
51. Chrisler, J.C.; Marvan, M.L.; Gorman, J.A.; Rossini, M. Body appreciation and attitudes toward menstruation. *Body Image* **2015**, *12*, 78-81, doi:10.1016/j.bodyim.2014.10.003. 445-446
52. Schooler, D.; Ward, L.M.; Merriwether, A.; Caruthers, A.S. Cycles of shame: menstrual shame, body shame, and sexual decision-making. *J Sex Res* **2005**, *42*, 324-334, doi:10.1080/00224490509552288. 447-448
53. Krstrup, P.; Mohr, M.; Nybo, L.; Draganidis, D.; Randers, M.B.; Ermidis, G.; Orntoft, C.; Roddik, L.; Batsilas, D.; Poulos, A.; et al. Muscle metabolism and impaired sprint performance in an elite women's football game. *Scand J Med Sci Sports* **2021**, doi:10.1111/sms.13970. 449-451
54. Speroff, L.; Glass, R.H.; Kase, N.G. *Clinical gynecologic endocrinology and infertility*; Wilkins, L.W., Ed.; Philadelphia, 1999. 452
55. Elliott-Sale, K.J.; McNulty, K.L.; Ansdell, P.; Goodall, S.; Hicks, K.M.; Thomas, K.; Swinton, P.A.; Dolan, E. The Effects of Oral Contraceptives on Exercise Performance in Women: A Systematic Review and Meta-analysis. *Sports Med* **2020**, *50*, 1785-1812, doi:10.1007/s40279-020-01317-5. 453-455-456