

Menstrual Cycle and Sport: effects on the performance and metabolism of the athlete woman Ciclo menstrual y deporte: efectos sobre el rendimiento y el metabolismo de la mujer deportista

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Abstract. There are difficulties planning female training. The aim of this meta-analysis work is to know results obtained in studies on the relationship between the menstrual cycle (MC), diet, metabolism and performance in sportswomen. This work began in January-2022 looking differences in performance depending on the MC phase; exclusion criteria after 2015, non-experimental articles with quality indexes >Q2. We finally worked on 11 articles. Perception of the majority of sportswomen is that MC does have an impact on sports performance, as they are affected both physically and psychologically depending on the MC phase. Participant characteristics, such as training history, may also contribute to the variety of responses observed in studies. MC phase where performance may be reduced is in the Early Follicular Phase and may improve in the other MC phases. The effects found maybe of most relevance to female athletes.

Keywords: menstrual cycle, sportswomen, performance, nutrition

Resumen. Existen dificultades para planificar el entrenamiento femenino. El objetivo de este trabajo de meta-análisis es conocer los resultados obtenidos en los estudios sobre la relación entre el ciclo menstrual (CM), la dieta, el metabolismo y el rendimiento en mujeres deportistas. Este trabajo se inició en enero-2022 buscando diferencias en el rendimiento en función de la fase del CM; criterios de exclusión posteriores a 2015, artículos no experimentales con índices de calidad >Q2. Finalmente se trabajó con 11 artículos. La percepción de la mayoría de las deportistas es que la CM sí tiene un impacto en el rendimiento deportivo, ya que se ven afectadas tanto física como psicológicamente dependiendo de la fase de la CM. Las características de las participantes, como el historial de entrenamiento, también pueden contribuir a la variedad de respuestas observadas en los estudios. La fase de MC en la que puede reducirse el rendimiento es en la fase folicular temprana y puede mejorar en las demás fases de MC. Los efectos encontrados pueden ser más relevantes para las atletas.

Palabras clave: ciclo menstrual, mujeres deportistas, rendimiento, nutrición

Introduction

At present, there is difficulty in planning female training, since it is planned with models adapted to the male sex, without adapting the training to the physiological needs that the female sex demands. Diet and training have a lot to do with the state of hormones and metabolism (Vázquez Franco et al. 2020; Aguilar Macias et al. 2017).

The female sexual cycle consists of morpho-functional changes that occur periodically in the ovary and uterus. The cycles are regulated by complex interactions of the hypothalamic-pituitary axis, the ovaries, and the genital tract. Both positive and negative psychological and physiological variations occur that affect women in the practice of physical activity (Davidsen, Vistisen & Astrup, 2007). In athletes, cycles with 28 days are observed in 60% of cases, cycles of 21 days, in 28%, and those of 30-35 days, in just 10-12% (Vázquez Franco et al. 2020; Volkov 2002).

Women produce gametes every 28 days on an average cyclical basis (menstrual cycle). This will be affected by the

changes that occur at the follicular level (ovarian cycle) and endometrial (uterine cycle). To explain it, we will divide the menstrual cycle into three parts:

Follicular Phase (FF) (from day 1 to 14 of the menstrual cycle): formation of follicles (structures involved in the development of ova). It is comprised of two sub-phases:

a) *In the early phase*, there is a high secretion of gonadotropins that induce the growth and development of new follicles, especially FSH. During this phase, there will be a detachment of the endometrium, a phenomenon known as menstruation. b) *In the late phase* marked by maximum concentrations of estrogens, which generate a signal to the endometrium by which it begins to grow, increasing the number of cells and their irrigation through angiogenesis processes that will allow the necessary nutritional supply in such a way that during This phase will gradually build the endometrium.

Ovulation (from day 14 to 16 of the menstrual cycle): it is the phase in which the follicle unloads the ovum that is captured by fimbriae of the fallopian tubes to be transported to the uterus. High levels of estrogens make the anterior pituitary gland more sensitive to the gonadotropin-releasing hormone, so there will be a peak

in the release of FSH and LH hormones in this period, with LH having the function of breaking down the mature follicle that will allow the release of the ovum from the follicle. Collagenase also acts in the release of the ovum from the follicle, which it does is degrade collagen (it is part of the connective tissue that holds the follicular cells together), thus causing the follicle to rupture. Estrogen concentrations will decrease as the luteal phase progresses.

Luteal phase (LP) (from day 17 to 28 of the cycle): it is the period in which the uterus begins to prepare an optimal environment for the fertilization of the ovum and implantation of the zygote. Also comprised of two sub-phases: a) *Early subphase:* the gluteal body is generated in the ovule from the fusion of cells that comprised part of the follicle. This corpus luteum acts as a hormonal signal for the secretion of estrogens and, above all, progesterone that allows the correct and complete development of the endometrium. This generates a negative feedback signal due to 'feedback' to the production of gonadotropins. b) *Late sub-phase:* if pregnancy does not occur 12 days after the formation of the gluteal body, the production of progesterone and estrogens decreases, in such a way that the secretion of gonadotropins increases again. The blood vessels that nourish the endometrium contract, again leading to the detachment of the endometrium (menstruation). During menstruation, the superficial layers of the uterine endometrium will be expelled due to the fall in hormonal levels. Menstrual flow is comprised of a volume of 50-150 ml of blood, interstitial fluid, mucus, and endometrial epithelial cells (Reed & Carr, 2018; Bonen & Keizer, 1984).

The aim of this work is to know and contrast the results obtained in the different selected studies on the relationship between the phase of the menstrual cycle, the diet followed, metabolism and performance in high-intensity athletes in different sports.

Material and method

The preparation of this meta-analysis work begins in January 2022, with a search for articles through different databases: Pubmed and Web of Science. For the first part of the research, we sought an answer to the differences in performance depending on the phase of the menstrual cycle, due to the basic principles on which our systematic review is based, the search was restricted to scientifically proven publications that reported findings in eumenorrhic professional athletes, in the last 7 years. The search terms entered in the databases were 'menstrual cycle', 'performance', 'athlete', and the connector was 'AND'. Following the Cochrane Reviews Methodology,

which bases its findings on the results of studies that meet certain quality criteria, a series of inclusion criteria were established.: 1. Studies focused on groups of elite athletes. 2. The follow-up of the athletes has been at least one complete menstrual cycle. 3. Athletes with regular menstrual cycles (eumenorrhic). 4. Athletes without any hormonal contraceptive treatment.

Regarding the exclusion criteria that have been taken into account for the development of this study, the following stand out: 1. Articles after 2015. 2. Articles published in journals with quality indices > Q2. 3. Non-experimental articles (Figure 1).

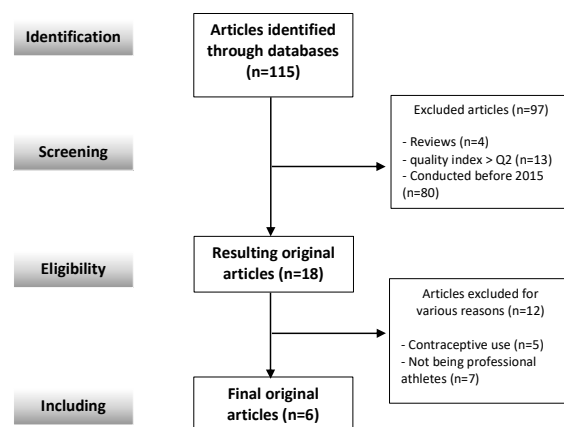


Figure 1. Initial results, inclusion and exclusion criteria, articles selected for review. (Part 1)

For the second part of the research, we sought an answer to the differences in the metabolism of athletes depending on the phase of the menstrual cycle, due to the basic principles on which our systematic review is based, the search was restricted to scientifically proven publications that reported findings in eumenorrhic professional athletes, in the last 20 years. The search terms entered in the databases were 'menstrual cycle', 'performance', 'metabolism', 'glucose kinetics', and the connector was 'AND'. Following the Cochrane Reviews Methodology, which bases their findings on the results of studies that meet certain quality criteria, a series of inclusion criteria were established: 1. Studies focused on groups of athletes, trained and moderately trained. 2. The follow-up of the athletes has been at least one complete menstrual cycle. 3. Athletes with regular menstrual cycles (eumenorrhic). 4. Studies that take into account athletes without contraceptive treatment. Regarding the exclusion criteria that have been taken into account for the development of this study, the following stand out: 1. Articles after the year 2000. 2. Articles published in journals with quality indices > Q2. 3. Non-experimental articles (figure 2).

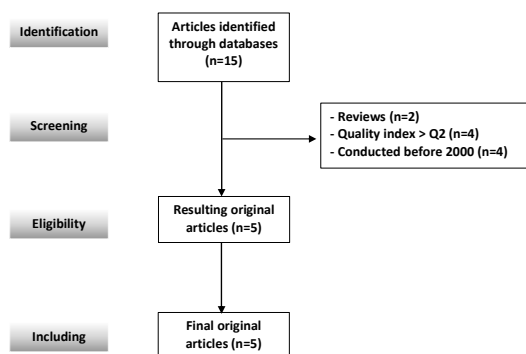


Figure 2. Initial results, inclusion and exclusion criteria, articles selected for review. (Part 2)

Results

The relationship between the menstrual cycle and sports performance is present among the latest researches on female sports, trying to contribute to a better preparation process for women in the different sports modalities and prevent possible disorders of menstrual

function. According to a study published in the Journal of Pediatric and Adolescent Gynecology in 2017, 41.7% of women who practice exercise regularly, believe that their menstrual cycle hurts physical training (Oleka, 2017). We will try to review the most recent bibliography to know how the menstrual cycle affects sports performance in different high-level modalities (Table 1).

According to researchers (Findlay et al., 2020; Brown et al., 2021; Solli et al., 2020) there is no doubt that the periodic changes related to the menstrual cycle leave a mark on the functional state of athletes, and particularly, on the state of mind. Furthermore, Shakhlina et al., 2016 affirm with analytical tests that the sports performance of women varies in the different phases of the menstrual cycle. Findlay et al., 2020 interviewed 15 elite Rugby players to find out their past and current perceptions of the menstrual cycle and their impact on athletic performance. 93% of the athletes reported symptoms related to the menstrual cycle, both physically and psychologically, and in performance.

Table 1. Relationship to menstrual cycle phase and sports performance.

Author	Year	Quality of the journal	Title	Type	Objectives	Results
Findlay et al.	2020	Q1 1/85 IF:12.68	How Menstrual Cycle and menstruation affect sporting performance: experiences and perception of an elite female rugby player	Experimental	To explore athletes' past and current experiences and perceptions of the menstrual cycle about its impact on athletic performance (n=15).	93% of female athletes reported symptoms related to the menstrual cycle. 33% reported heavy menstrual bleeding and 67% felt that these symptoms affected their performance. 2/3 of athletes self-medicated to relieve symptoms.
Brown et al.	2021	Q1 14/85 IF:3.255	Elite female athletes' experiences and perceptions of menstrual cycle on training and sport performance	Experimental	To examine 17 elite multi-sport athletes' experiences of their menstrual cycle, with a focus on the impact on training performance and menstrual cycle-related communication with coaching and support staff (n=17).	The results revealed that the athletes presented with physical symptoms along with mood disturbances and reduced motivation to train. The decision to actively manage the menstrual cycle was often triggered by a desire to reduce the effect on competition, reduce anxiety about weight requirements or reduce distraction during competition.
Solli et al.	2019	Q1 13/85 IF:3.528	Changes in Self-Reported Physical Fitness, Performance, and Side Effects Across the Phases of the Menstrual Cycle Among Competitive Endurance Athletes	Experimental	To investigate changes in 140 female athletes competing in biathlon or cross-country skiing on fitness, performance, and side effects across the phases of the menstrual cycle in competitive endurance athletes. (n=140)	Most athletes reported their worst fitness (47 %) and performance (30 %) during menstruation. The post-bleeding phase was considered the best phase for perceived fitness and performance. Only 8% of participants reported sufficient knowledge about the Menstrual Cycle.
Shakhlina et al.	2016	Q1 41/235 IF:1.872	Physical performance during the menstrual cycle of female athletes who specialize in 800 m and 1500 m running.	Experimental	To determine the physical exercise dynamics and functional capacity of athletes in 800 m and 1500 m races during the menstrual cycle. (n=13)	They found that the physical performance of an aerobic test is better during the post-menstrual and post-ovulatory phases.
Köse et al.	2018	Q2 110/263 IF:1.172	Analysis of the Effect of Menstrual cycle phases on Aerobic-Anaerobic Capacity and Muscle Strength	Experimental	To examine the effect of menstrual cycle phases on aerobic-anaerobic and muscular capacity in 10 kickboxing athletes. (n=15)	Hormonal changes in the mid-follicular and luteal phases during the menstrual cycle did not affect the women in terms of performance. It was reported that the menstrual cycle did not influence peak power, average power, and lactate intensity.
Julian et al.	2017	Q2 IF:2.806	The effects of menstrual cycle phase on physical performance in female soccer players	Experimental	Nine female association football players (age 18.6 ± 3.8 years; height 161.2 ± 6.6 cm; weight 59.0 ± 7.6 kg) were recruited. (n=9)	We found that performing an aerobic test between days 5-9 (follicular phase 3288 ± 800 m) results in a 14% increase compared to performing it between days 21-22 (luteal phase 2833 ± 896 m) of the menstrual cycle. However, these results were not significant (p=0.07).

The most prevalent physical symptoms, especially in the days before and at the beginning of menstruation, are identified as abdominal pain (80% of the players), reduced energy levels, and generalities of discomfort. On a psychological level, the most frequent symptoms that we find are concerns associated with menstruation and the distraction it caused. Athletes expressed the less perceived impact of their menstrual cycle in their daily life (33%) than in training or during competition. We found a study of 17 elite athletes from different sports, where Brown et al., 2021 wanted to know the experiences and knowledge about the menstrual cycle of athletes. Most female athletes reported that during menstruation and PMS they felt slower in training and often unmotivated. They report feeling uncomfortable completing specific techniques, for example, in weightlifting, when the bar hits the lower abdomen in the snatch when it is swollen. In addition, most of the participants stated that they preferred to do lower intensity sessions in the premenstrual phase, however, during menstruation they were only uncomfortable with bleeding.

Solli et al., 2020 published an experimental study of 140 participants who competed in Biathlon and Cross-Country Skiing at an international level, to know the possible impact of the menstrual cycle on performance. 71% of the participants perceived a reduction in physical fitness, coinciding with the menstruation phase. The post-bleeding phase was considered the best for perceived fitness and performance. Also, only 8% of the participants reported having sufficient knowledge about the menstrual cycle and only 27% told the coach they were in the menstruation phase. The results of these studies show that in elite eumenorrhic women there is a relationship between a decrease in the perception of sports performance according to the phase of the menstrual cycle, coinciding with the early follicular phase (menstruation) and the late luteal phase (premenstruation).

Studies like Shakihlina et al., 2016 evidence this perception of the athletes with the following analytical tests. This study aimed to investigate the dynamics of physical performance and functional capacity of women who specialize in running 800m and 1500m during the menstrual cycle. The physical work capacity of these

athletes was measured with 4x400 m tests with 5-minute breaks. The study lasted two months and divided the different phases of the menstrual cycle (MC) as follows: phase I - menstrual (on days 1 to 5 of the cycle); phase II - postmenstrual (on days 6 to 12); phase III - ovulatory (on days 13 to 15); phase IV - postovulatory (on days 16 to 24); phase V - premenstrual (on days 25 to 27). In Table 2 we find differences in the results in seconds in every 400 m stretch according to the phase of the menstrual cycle. The results show that the athletes were faster in the postmenstrual and postovulatory phases, confirming the changes in the performance of the athletes who specialize in medium distance running according to the phase of the menstrual cycle, being able to confirm the anabolic effect of estrogens, whose concentration in the blood is higher in these phases.

On the other hand, research such as Köse et al., 2018 and Julian et al., 2017 show that insufficient evidence has been found to affirm that MC can significantly affect the performance of trained athletes. Köse et al. aimed to investigate the effect of the phases of the menstrual cycle on aerobic-anaerobic capacity and muscular strength in 10 kickboxing athletes, in three different phases of MC. The first test to analyze was the maximum strength test (1RM) with the bench press and the second strength endurance test was also in the bench press until they were exhausted with 65% of 1RM (table 3). According to the authors, the changes were not significant enough to determine that the phases of the menstrual cycle can interfere with the strength and anaerobic performance of kickboxing athletes. Julian et al., 2017 investigated the potential effects of the menstrual cycle phase on performance in specific soccer tests in nine sub-elite soccer players, during the early follicular phase (FP) and mid-luteal phase (LP) where the greatest difference found is hormonal. The tests of the present study were: an intermittent endurance test (Yo-Yo IET), countermovement jump (CMJ), and 3x30m sprints. Yo-Yo IET performance was considerably lower during the mid-luteal phase (2833 ± 896 m) compared to the early follicular phase (3288 ± 800 m) ($p = 0.07$). For the CMJ test in the early follicular phase (20.0 ± 3.9 cm) and in the middle luteal phase (29.6 ± 3.0 cm) ($p = 0.33$). And finally in the sprint

Table 2.
Time in seconds by 400 m segment and Menstrual Cycle Phase (Shakihlina et al. 2016)

Segment 4 x 400	Seconds Phase MC I	Seconds Phase MC II	Seconds Phase MC III	Seconds Phase MC IV	Seconds Phase MC V
1	74.87 ± 5.91	72,64 ± 5.78	73.01 ± 5.61	72.42 ± 5.72	73.77 ± 5.06
2	74.32 ± 5.61 *	72,23 ± 5.11	73.50 ± 5.70	71.51 ± 5.03	72.87 ± 8.01
3	74.21 ± 5.43	73.21 ± 7.05	73.71 ± 5.55	71.85 ± 5.67	74.29 ± 5.53
4	75.31 ± 7.81 *	71.25 ± 6.38	72.28 ± 5.69	70.53 ± 5.06	73.48 ± 5.97

*($p < 0.05$) real changes in outcomes compared to the post-ovulatory phase.

in the early follicular phase (4.7 ± 0.1 s) and the middle luteal phase (4.7 ± 0.1 s) ($p = 0.96$). Indicating that there is a potential reduction in the maximum endurance performance in the middle luteal phase, contrary to what we could expect, which would be a reduction in the performance in FP (menstruation). During exercise, the use of the substrate plays an important role in performance and disease prevention. The contribution of fat and carbohydrates to energy expenditure during exercise is modulated by several factors, including intensity and duration of exercise, age, training and, still diet, but also sex. Because the levels of sex hormones change throughout a woman's life (about puberty, the menstrual cycle, the use of oral contraceptives, and menopause), the female population must be considered specifically in terms of the use of substrates and metabolic and hormonal responses to exercise. Before puberty, there is no difference between males and females in regards to substrate oxidation during exercise. This is not the case during adulthood, as women are known to be more dependent on fat than men for the same relative intensity of exercise (Isacco, Duché & Boisseau, 2012). Studies have shown that women have a lower respiratory exchange rate (RER) during exercise than equally trained men, indicating a greater dependence on fat oxidation. Differences in estrogen concentration between men and women probably influence this sex difference. The different concentrations of estrogen and progesterone during the follicular (FF) and luteal (LF) phases of the female menstrual cycle suggest that fuel use may also vary between phases. Among adult women, the menstrual cycle may influence substrate oxidation. Although some authors have pointed out that the luteal phase of the menstrual cycle is related to higher lipid oxidation and lower glucose utilization, compared to the follicular stage, other authors have found no differences (Table 4) (Isacco, Duché & Boisseau, 2012). Suh et al., 2002 attempted to examine the effects of exercise intensity and menstrual cycle phase on glucose flow rates in 8 moderately active eumenorrheic women under conditions of rest (90 min) and exercise (60 min, leg cycle ergometer at 45 and 65% maximum oxygen consumption) during the follicular and luteal phases, concluding that glucose flow is directly related to exercise intensity regardless of the phase of the menstrual cycle. The phase of the menstrual cycle does not alter the flow of glucose at rest either in moderate-intensity exercise (45% of VO_2 max) or high-intensity exercise (65% of VO_2 max), concluding that the effects of endogenous ovarian hormones on glucose flux and overall carbohydrate

oxidation (CHO) are small compared to the much greater effects of exercise and CHO nutrition. These results were confirmed by research such as that of Tremblay et al., 2010, who studied the effects of the diet before exercise on the metabolism of the substrate during exercise in men and women. Observing that, during exercise preceded by 2 days of a mixed diet, the contribution of CHO to total energy expenditure was greater in men than in women, regardless of whether the women used Contraceptives or not. However, when women and men were fed a high-CHO diet for 2 days before exercise, and ingested glucose before and during exercise, the rate of CHO oxidation during exercise increased for both groups; there was no longer any difference between men and women. This study highlights the importance of nutritional status in research comparing men and women. On the other hand, studies such as Devries et al., 2006 aimed to determine the effect of the menstrual cycle phase and sex on glucose turnover and muscle glycogen utilization during endurance exercise. Young recreationally active women ($n = 13$) (6 were on contraceptives and 7 were not) and men ($n = 11$) underwent a 90-minute cycling test at 65% peak O_2 consumption, with muscle biopsies taken before and after, proving that women with Luteal Phase have a lower dependence on CHO sources to drive endurance exercise compared to women in Follicular Phase, as evidenced by a lower glucose Ra (rate of appearance of glucose), Rd (rate of glucose disappearance) and MCR (metabolic lengthening rate) at 90 min of exercise.

Table 3.
Repetitions of maximal strength and strength endurance (Köse, 2018)

	Follicular Phase (day 2-3 of the MC)	Middle Follicular Phase (day 8-9 of MC)	Luteal Phase (day 22-23 of the MC)	P
Bench Press (1 RM)*	41.20 ± 6.54	41.70 ± 6.40	41.65 ± 6.72	0,234
Bench press (65%)*	20.88 ± 6.45	20.55 ± 4.41	21.15 ± 6.08	0,549

*The number of repetitions of maximal strength (1RM) and strength endurance (65%) of the participants was obtained from the bench press in three different phases of the menstrual cycle.

Discussion and conclusion

To find an answer to the possible differences in performance in athletes depending on the phase of the menstrual cycle, it is necessary to study it from several approaches. Many authors agree on the importance of deepening studies on the various peculiarities of the menstrual function of athletes, for better planning of the sports training process.

Table 4.
Relationship to menstrual cycle phase and carbohydrate metabolism (CHO) and fats.

Author	Year	Quality of the journal	Title	Type	Objectives	Results
Suh et al.	2002	Q1 18/85 IF:3.461	Luteal and follicular glucose fluxes during rest and exercise in 3 h postabsorptive women	Experimental	To examine effects of exercise intensity and menstrual cycle phase on glucose flux rates during rest and exercise in rested and fed women (3h after absorption) in 8 moderately active, eumenorrhoeic women under resting (90min) and exercise (60min, leg ergometer cycling at 45 and 65% of maximal oxygen consumption) conditions during follicular and luteal phases. (n=8)	Glucose flow is directly related to exercise intensity. The phase of the menstrual cycle does not alter glucose flux during rest and exercise. The subtle effects of endogenous ovarian hormones on glucose kinetics are subordinate to the much greater effects of exercise and recent carbohydrate nutrition.
Devries et al.	2006	Q2 27/81 IF:3.255	Menstrual cycle phase and sex influence muscle glycogen utilization and glucose turnover during moderate-intensity endurance exercise	Experimental	To determine the effect of the menstrual cycle phase on glucose turnover and muscle glycogen utilization during endurance exercise in 13 active women (n=13).	Women in the luteal phase are less dependent on CHO sources in endurance exercise than women in the follicular phase.
Campbell et al.	2001	Q1 19/81 IF:4.209	Glucose Kinetics and exercise performance during phases of the menstrual cycle: effect of glucose ingestion	Experimental	To determine the effect of menstrual cycle phase and carbohydrate intake on glucose kinetics and performance in 8 healthy eumenorrhoeic women in a cycling test. A control (C) and a glucose trial (G) were studied during the follicular and luteal phases. (n=8)	Substrate metabolism and exercise performance are influenced by the phase of the menstrual cycle, but glucose intake minimizes these effects.
Zderic et al.	2001	Q1 18/85 IF:3.461	Glucose Kinetics and substrate oxidation during exercise in the follicular and luteal phases	Experimental	To determine whether plasma glucose kinetics and substrate oxidation during exercise are dependent on the phase of the menstrual cycle. To determine total carbohydrate and fat oxidation with indirect calorimetry. (n=6)	Plasma glucose kinetics and CHO oxidation during moderate-intensity exercise are lower during the luteal phase compared to the follicular phase in women. These differences may be due to differences in circulating oestradiol.
Tremblay et al.	2010	Q1 9/85 IF:5.098	Carbohydrate supplementation and sex differences in fuel selection during exercise	Experimental	To compare the effects of a high-CHO diet and glucose intake during exercise on fuel selection in women. (n=12)	There is no difference when CHO in the diet is increased in total CHO oxidation.

There is a high level of bias in the areas of the review since the different studies do not take into account the phases of the MC in the same way, the same parameters are not used to measure the changes and it is not taken into account whether the athletes were going through the menstruation phase with pain, heavy bleeding or not. Interindividual variations in the magnitude and timing of hormonal fluctuations require serial measurements of serum hormones to accurately determine the phase of the menstrual cycle.

To more accurately determine the effects of oestradiol on metabolic substrates during exercise, researchers should assess each hormonal status of the participants. Furthermore, as nutritional status is related to the effects of the menstrual phase on metabolic substrates, it would be important to adequately monitor these variables, since, in studies in which the diet has been monitored, fewer differences have been found between phases and between sexes. In the reviewed studies, two different methodologies have been used to determine muscle glycogen utilization during exercise: analyzing muscle biopsies for glycogen content and estimating from total CHO oxidation and Rd of glucose, with numerous assumptions and possible errors. Some studies make comparisons with men and other studies compare women

with contraceptive treatment, which could be misleading in the results.

Doctors, coaches, and technical teams need awareness, knowledge, and understanding of menstrual cycle dysfunctions and menstrual symptoms, along with the appropriate available treatments, and must understand the potential impact of negative menstrual symptoms. Also, doctors should develop and facilitate educational opportunities regarding the topic of the menstrual cycle and athletic performance, to prevent potential negative health consequences and maximize health and performance.

More research is needed to fully elucidate the relationships between cyclical hormonal fluctuations, neuromuscular control, functional movement mechanics, metabolism, and risk of injury. Even though there are many publications on cyclical changes of some physiological parameters in women, few of these publications are recent and we still find controversial issues on changes in work capacity, functional capacity, metabolic and psychophysiological indices during the menstrual cycle. To reproductive function, female sex hormones are known to affect other parameters such as cardiovascular, respiratory, thermoregulatory,

and metabolic. Therefore, at each stage of the menstrual cycle, during a month of cycling, they can theoretically affect athletic performance. However, the effects of the menstrual cycle (and associated hormonal fluctuations) on athletic performance have not been largely reported. Although more studies are beginning to emerge, there are still many questions with undefined answers.

Regarding the effects of MC on metabolism, more studies and research are needed in professional athletes that take into account the oxidation of the substrate depending on the phase of the menstrual cycle, diet, and type of physical activity. Furthermore, future sex comparative studies should consider comparing men with women in both phases of the menstrual cycle to fully elucidate the effect of sex and estrogen on substrate metabolism.

The perception of the vast majority of elite athletes is that MC does have an impact on sports performance since they are affected according to the phase of MC both physically and psychologically. Participant characteristics, such as training history, could also contribute to the range of responses observed in studies on athletic performance. The phase of the MC where the performance could be reduced is in the Early Follicular Phase and could improve in the other phases of the MC. The effects found could be of greater relevance for elite athletes, where the difference between winning and losing is marginal. Metabolically, women are more dependent on fat oxidation than men. The differences in estrogen and progesterone during the follicular and luteal phases suggest that the metabolism of fats, carbohydrates, and protein may be affected. In the luteal phase, there could be a greater dependence on carbohydrate sources. Exercise and carbohydrate intake minimize the effects on the metabolism depending on the phase of the menstrual cycle. There do not appear to be significant differences between phases of MC in protein metabolism, although there may be differences in performance and adaptations to exercise between phases, increasing strength in the follicular phase compared to the luteal phase.

Medics, trainers and technical staff need awareness, knowledge and understanding of menstrual cycle dysfunctions and menstrual symptoms, along with the appropriate treatments available. Should develop and facilitate education for athletes and support staff and seek further educational opportunities regarding the topic of the menstrual cycle and sport performance. In order to prevent potential negative health consequences and maximise health and performance. More work

is needed to fully elucidate the relationships between cyclic hormonal fluctuations, neuromuscular control, functional movement mechanics, metabolism and injury risk. Although there are many publications on cyclic changes of some physiological parameters in women, few of these publications are recent and there are still controversial issues about changes in work capacity, functional capacity, metabolic and psychophysiological indices during the menstrual cycle.

Authors' contribution: The idea of this article came from MM-A; the study was designed by MM-A, and NG-B; literature search was performed by MM-A, MS, NG-B, MM-B and JAL, data were collected and analysed by MM-A, NG-B, MM-B, JAL, LC, MJJ-C, JC-P, and AL-M; data interpretation and manuscript preparation were undertaken by MM-A, LC, and AL-M; funding acquisition: MM-A.

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All authors have read and approved the final version of this manuscript.

Conflict of Interest

All authors have reviewed and approved the manuscript. None of the authors have conflicts of interest.

Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of Granada, Spain (ref. 1162/CEIH/2020).

Consent to publish (Ethics)

The results and writing of this manuscript followed the Committee on Publication Ethics (COPE) guidelines on how to deal with potential acts of misconduct, maintaining integrity of the research and its presentation following the rules of good scientific practice, the trust in the journal, the professionalism of scientific authorship, and the entire scientific endeavor.

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