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THE INFLUENCE OF MENSTRUATION ON TRAINING SCHEDULES IN WELL-TRAINED AND ELITE FEMALE MOUNTAIN BIKE, ROAD AND CYCLOCROSS ATHLETES

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ABSTRACT

Female physiology is unique and driven by fluctuations in sex hormones that regulate the menstrual cycle. These hormones present myriad mechanisms that may influence physiological systems, potentially implicating exercise performance. However, research exploring the MC in athletes is limited. This study investigated if training status (well-trained/elite) influenced MC-related symptoms, training schedules, sleep quality, arousal, and alertness of elite and well-trained female mountain bike, road, and cyclocross athletes. Fifteen well-trained (n= 7) and elite (n= 8) cyclists (age: 29 ± 7yrs, height: 1.7 ± 0.1m, body mass: 61.9 ± 7.7kg) tracked their MC symptoms, basal body temperature, body mass, sleep, arousal, and alertness measures daily for three months. The MC was split into two phases, follicular and luteal, and participants were provided ovulation kits to identify the phases. The most reported symptoms were fatigue, bloating, abdominal pain, and cramping. Athletes' BBT was significantly greater (p<0.05) in the LP compared to the FP (0.4 ºC, p=0.01, d=0.4). No significant differences (p>0.05) in body mass, sleep duration and quality, alertness and arousal were observed between well-trained and elite athletes. Further, no significant differences between statuses for any training variables, average or maximum heart rate, training load (bTRIMP), average or maximum speed, and rate of perceived exertion were observed. The MC did not influence physiological responses and training variables in well-trained and elite mountain bike, road, and cyclocross female athletes. Nevertheless, individual fluctuations were present, and it is recommended that athletes monitor their own MC to optimize training and ultimately performance.

Keywords: *menstruation, females, mountain biking, training schedules, athletes*

INTRODUCTION

Over the past five years, there has been a significant increase in female participation in cycling, and this upward trend has subsequently led to an increase in competitive opportunities. In fact, in 2021, an equal number of Union Cycliste Internationale (UCI) races were available for female and male elite cyclists (UCI, 2019). The influence of the menstrual cycle (MC) on training and performance remains unclear. Mountain biking, cyclocross, and road cycling are high-intensity disciplines that elicit unique physiological demands (Impellizzeri & Marcora, 2007). Mountain biking encompasses a range of physical demands on the rider requiring endurance, strength, and technical skills (Impellizzeri et al., 2007), while cyclocross is a mix of mountain biking and road cycling with high energy expenditure, muscle power, and endurance demands (Carmichael et al., 2017). Road cycling is characterized by short and long durations and requires high anaerobic and aerobic thresholds (Martin et al., 2001).

The MC is an essential biological process for females that involves a repeating pattern of sex hormone production and secretion (Marsh & Jenkins, 2002). Each phase is regulated by sex hormones which influence many physiological systems, and research has proposed a myriad of mechanisms that could affect exercise performance (Hackney, 1999; Marsh et al., 2002; Hashimoto et al., 2014). The follicular phase (FP) can be split into three sub-phases: early, mid and late FP. During the early FP, where menses occur, estrogen and progesterone are low. Over the FP, estrogen subsequently increases through the mid-FP, yielding the greatest concentration during the late FP (Marsh et al., 2002). The increase in estrogen influences energy metabolism, increasing muscle glycogen storage and uptake and benefiting short-term high-intensity exercise (Hackney, 1999; Oosthuyse et al., 2005). For most cycling disciplines endurance plays a key role and increased estrogen levels associated with the MC may promote greater reliance on free fatty acids as a fuel source and thus enhance performance (Hackney et al., 2022). In contrast, progesterone offsets estrogen's effect during the luteal phase (LP) and increases fat oxidation (Hackney et al., 2022). This leads to a more significant thermogenic effect and an elevation in body temperature, which may negatively impact prolonged performance and increase the onset of fatigue (Janse de Jonge, 2003; Charkoudian & Stachenfeld, 2016).

Research investigating the MC in elite populations is limited, with only a small proportion (6%) of studies including exclusively female athletes (Mujika & Taipale, 2019). Consequently, most MC research has focused on untrained females or recreational athletes across various disciplines, and the research methodology used is often poorly designed to monitor the MC in these populations accurately (Emmonds et al., 2019). There has been a lack of guidance about what defines an «elite» status. However, a recent study by McKay et al. (2022) has proposed a new framework for determining the training status of athletes (Mckay et al., 2022).

It is evident that cyclic fluctuations in estrogen and progesterone influence physiological systems. However, the influence on performance is equivocal (Janse de Jonge, 2003; Oosthuyse et al., 2005; Middleton & Wenger, 2006; Vaiksaar et al., 2011; Charkoudian & Stachenfeld, 2016; Julian et al., 2017). Elite female cyclists endure high-intensity training schedules year-round and to date no research has determined how the MC influences elite female cyclists' training schedules. The lack of longitudinal studies within MC research has previously been highlighted as a limitation (Elliot-Sale et al., 2020). Following the British Association of Sport and Exercise Sciences (BASES) expert statement, it was recognized that monitoring at least three menstrual cycles is required to better understand the MC's influence on athletes' performance (Elliot-Sale et al., 2020; 2021). The aim of this study was to investigate if training status (well-trained/elite) influences MC-related symptoms and also, if training status and MC phase influence perceptual and training outcomes. The findings from this study have the potential to provide insights into more effective training schedules that take into account unique physiological demands and hormonal fluctuations experienced by female cyclists, ultimately optimizing athletic performance.

METHODS

Participants and study design

Fifteen female (n = 15) cyclists with a regular MC participated in the three-month observational study. From training history, athletes were deemed well trained (n = 7; > 8-15 hrs and > three days per week, competing at the national level) and elite (n = 8; > 17 hrs and > five days per week, competing at the international level) (McKay et al., 2022). Females were injury-free and had not used hormonal contraceptives for at least six months (Casazza et al., 2004). Participants provided full written consent and the study was conducted in accordance with the Declaration of Helsinki and was granted approval by Edinburgh Napier University Ethics Committee.

MC Tracking

To determine MC regularity, participants reported their menstruation start dates and lengths for the previous three months (Schaumberg et al., 2017). The average cycle length was calculated, and the ovulation day was estimated. This estimate was subsequently confirmed by ovulation predictor strips (Ovulation test strips, 20mlIU/mL kit tests, width 3.5mm, One Step, UK), which detect the luteinizing hormone (LH) peak occurring between 16-32 hours before ovulation. From this day, participants were required to collect daily urine samples until a positive result was observed. If a positive result was not obtained, a fourth data collection cycle was completed (Schaumberg et al., 2017).

Participants began on the first day of their MC (first day of bleeding) and recorded any symptoms they experienced. Symptoms included stomach cramps, abdominal pain, headaches, back pain, mood changes, tender breasts, bloating or increased gas, tiredness or fatigue, diarrhea, and constipation. Additionally, participants were provided with a thermometer (Basal Digital Ovulation Thermometer (Celsius), One Step, UK) to measure basal body temperature (BBT) daily upon waking and before getting out of bed. Based on their waking time, participants were instructed to take their temperature at the same time each morning between 6 - 8 am. Daily self-reported body mass was recorded at the same time each day (between 6 am and 8 am) before voiding the bladder. No body mass scales were provided; all participants used the same personal scale daily.

Riders' training

All athletes were provided access to training and competition data, including non-cycling data such as strength training, running, and swimming. Data including heart rate (HR), duration of training, distance covered, elevation gain, and speed were uploaded from the athletes' preferred GPS tracking system (Strava, Garmin, Polar). Athletes also recorded their session rating of perceived exertion (RPE) using the Borg scale (Borg, 1982) for each session. Athletes completed daily Likert-style questions upon waking to monitor arousal, alertness, and perceived sleep quality and duration. Arousal is a psychological state of alertness that readies the body for action (Arent & Launders, 2003) and was measured on a 1 to 7 scale, with one being 'feeling active, vital, alert and awake to 7 being 'almost in reverie, sleep onset soon, lost struggle to remain awake' (Hoddes et al., 1973). Alertness was measured on a Likert scale of 0 to 10, where a mark to the extreme left indicates 'as tired as I've ever felt', and the extreme right indicates 'as alert as I've ever felt'. Similarly, perceived sleep duration was measured on a Likert scale of 0 to 10. Perceived sleep duration was determined as the predicted number of hours of sleep the participant attained.

Training load was calculated using Banister's TRIMP model (bTRIMP) (Banister, 1991). Due to the remote nature of this study, the bTRIMP model was selected. bTRIMP was calculated based on training duration, HR, and a weighting factor using the following formula:

$$bTRIMP = time\ (minutes) \times \Delta HR \times 0.861.6x$$

Where:

$$\Delta HR = (HR_{ex} - HR_{rest}) / (HR_{max} - HR_{rest})e$$

equals the base of the Napierian logarithms, and 0.86 equals a generic constant for females. HRex = exercising heart rate, recorded as one average value every 5 s, HR_{rest} = resting heart rate, and HR_{max} = maximum heart rate. To obtain resting heart rate (HR_{rest}), athletes were requested to rest supine for 5 minutes wearing an HR strap, and record their results. The lowest 5-second HR was recorded as their HR_{rest}. If participants knew HR_{max} from previous laboratory testing, this HRmax was used. Otherwise, a peak heart rate from a training session was considered HRmax. However, if this was not known, a calculation was used by applying the following formula to estimate HRmax; 216 – 1.09 × age (Whyte et al., 2008).

Statistical analysis

All data analysis was performed using R (R Core Team, 2020) in RStudio (Rstudio Team, 2020). All data were checked for normality, Levene's tests for the equality of variances were all non-significant ($p > .05$), normality assumption was not violated, and equal variances were assumed. A repeated measures analysis of variance (ANOVA) assessed the effect of MC and training variables during the study by identifying an MC phase (phase) versus training status (status) interaction effect (phase; FP/LP x status; elite/well-trained). The magnitude of the effect was reported using Cohen's *d*, where 0.2, 0.5, and >0.8 represent small, medium, and large effects, respectively (Cohen, 1992).

RESULTS

The characteristics of well-trained and elite athletes are presented in Table 1. There were no significant differences observed between well-trained and elite athletes in terms of mean age (p = .96), height ($p = .82$), and body mass ($p = .38$). Additionally, no significant differences were found between the groups in MC characteristics, such as cycle length ($p = .83$), as well as phase lengths (FP; $p = .93$, LP; $p = .79$). When comparing the different cycles within both groups, there were no significant differences in cycle length ($F(1, 36) = 0.057$, $p = .812$) and phase length (FP; $F(1, 36) = 0.334$, $p = .567$, LP; $F(1, 36) = 0.371$, $p = .546$) across the three measured cycles. These results indicate a consistent pattern of MC characteristics across multiple cycles for both well-trained and elite athletes.

Table 1. *MC length and breakdown for participant group (n= 15).*

Variables	Well-trained	Elite
Age (yrs)	26.4 ± 7.1	31.1 ± 8.1
Height (m)	1.7 ± 0.1	1.7 ± 0.1
Body mass (kg)	65 ± 5.2	60 ± 9.4
Full Cycle (days)	25.2 ± 2.4	26.6 ± 4.4
Bleed length (days)	4.0 ± 0.9	3.9 ± 1.2
FP (days)	12.8 ± 2.5	13.3 ± 3.4
LP (days)	12.4 ± 2.4	13.5 ± 3.1
Age of menarche (yrs)	13.0 ± 1.4	13.0 ± 1.7
# of bleeds per year	11.0 ± 1.2	11.0 ± 1.3

Age of menarche; age when MC started, FP; follicular phase, LP; luteal phase, number; #

Figure 1 presents the number of reported symptoms during menses for well-trained and elite. No significant main effect of training status was found for any MC symptoms (p = .435). However, two participants reported missing a race due to the severity of abdominal pains and stomach cramps.

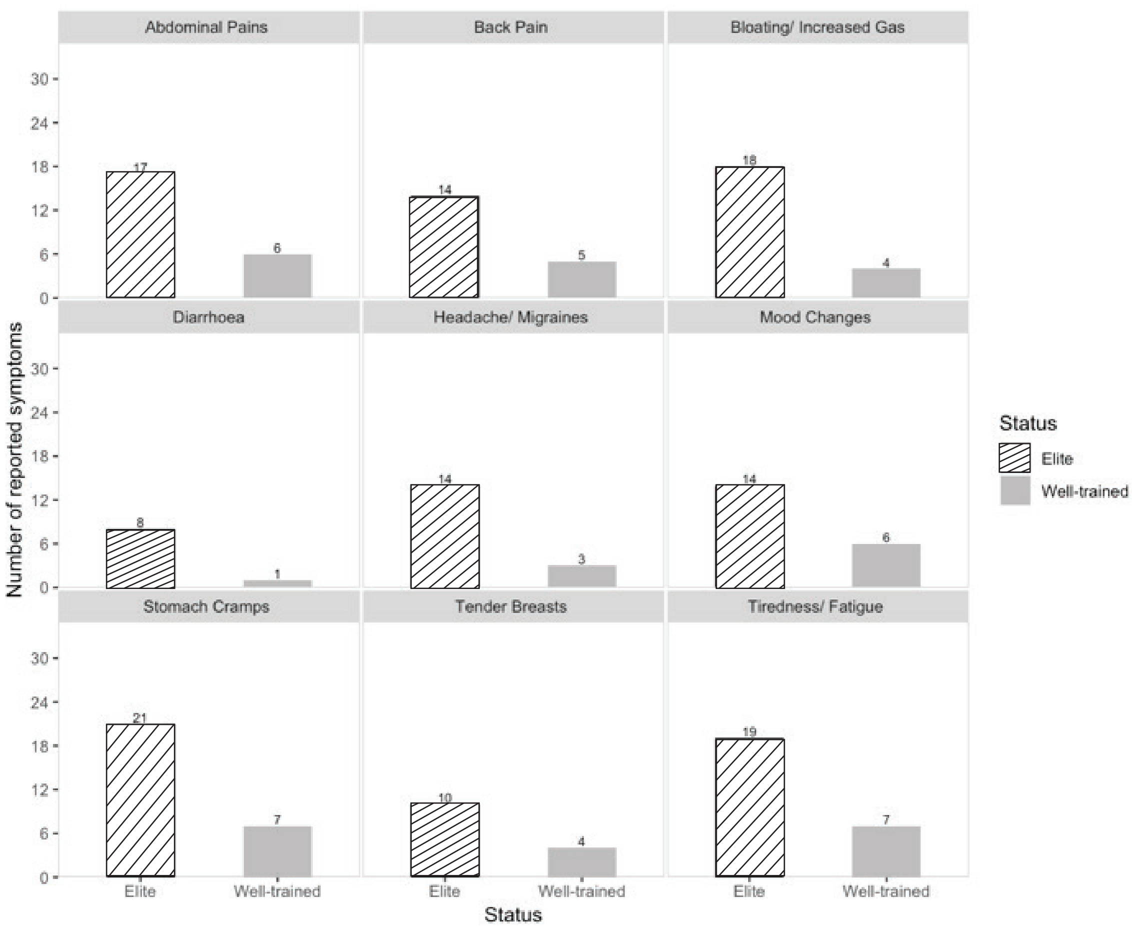

Figure 1. *Total number of participants who reported symptoms during menses for each cycle grouped by well-trained and elite*

There was no significant interaction (MC phase x training status) in BBT (F(1, 11) = 4.23, *p* = .06). The analysis of the main effects of phase revealed that BBT was significantly higher in the LP for both well-trained athletes (F(1, 11) = 3.32, *p* = .04) and elite athletes (F(1, 11) = 2.12, *p* = .03; Figure 2). The main effects of training status did not significantly affect BBT (F(1, 11) = 1.32, *p* = .12).

There was no significant interaction (phase x status) in body mass (F(1, 11) = 2.47, *p* = .09). The analysis of the main effects of phase and status revealed no significant differences (phase; F(1, 11) = 2.12, *p* = .14, status; F(1, 11) = 3.12, *p* = 0.12; Figure 3).

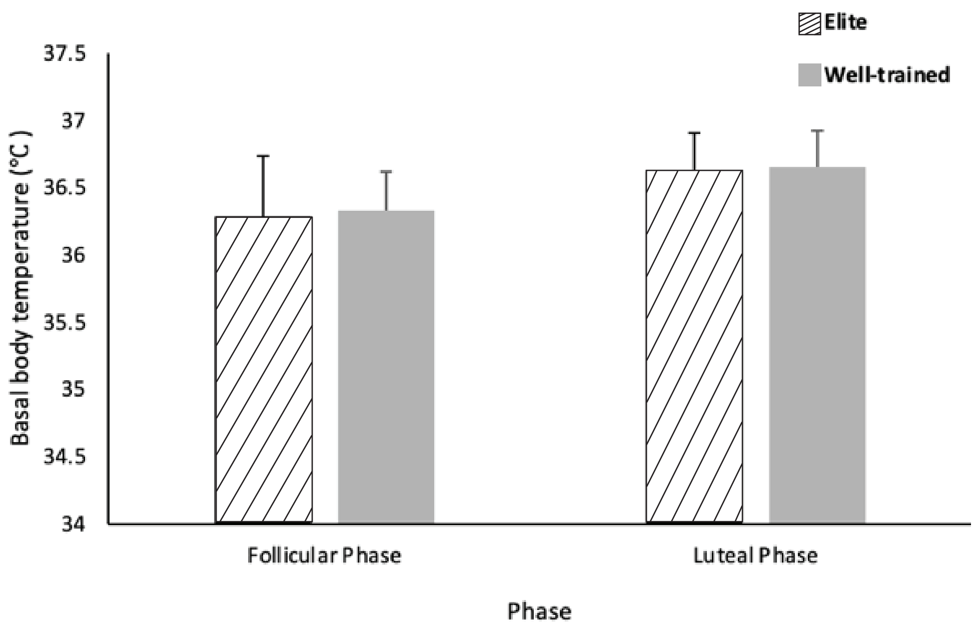

Figure 2. *Mean (±SD) basal body temperature across two menstrual phases in well-trained and elite athletes. *Significant from the Luteal phase p < .05*

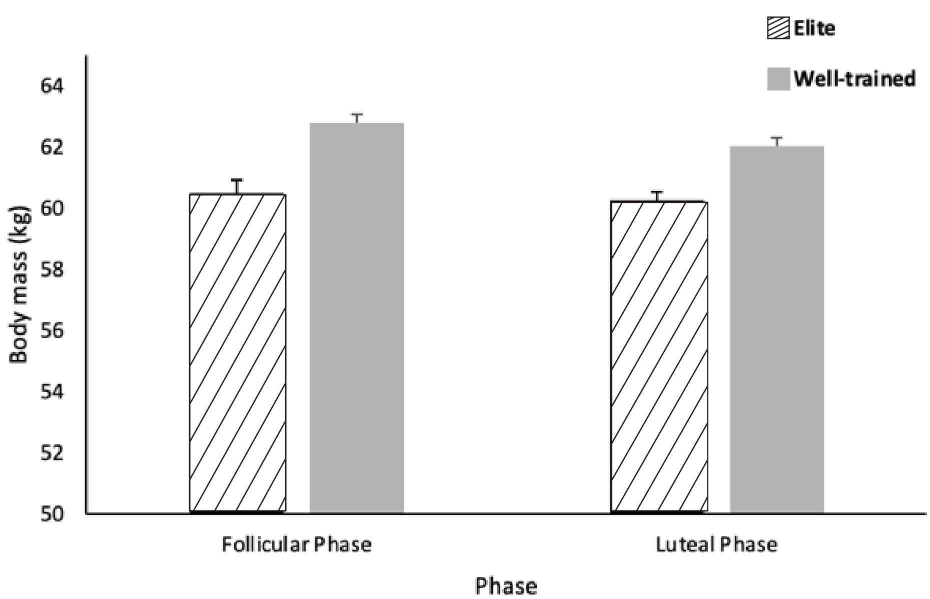

Figure 3. *Mean (±SD) body mass across two menstrual phases in well-trained and elite athletes.*

No significant interaction effect (phase x status) was found for arousal (F(1, 11) = 0.07, *p* = .78), alertness (F(1, 11) = 0.78, *p* =.393), sleep length (F(1, 11) = 1.79, *p* = .475), and perceived sleep quality (F(1, 11) = 0.12, *p* = .393). Similarly, no significant main effects of phase were observed for arousal scores (F(1, 11) = 0.00, *p* =.99), alertness scores (F(1, 11) = 0.67, *p* = .46), sleep length (F(1, 11) = 1.236, *p* = .45), and perceived sleep quality (F(1, 11) = 0.28, *p* = .37). Training status also did not have a significant main effect on arousal scores (F(1, 11) = 0.55, *p* = .47), alertness scores (F(1, 11) = 0.38, *p* = .76), sleep length (F(1, 11) = 0.06, *p* = .94), and perceived sleep quality (F(1, 11) = 0.07, *p* = .94).

Table 2. *Perceptual Likert scales for each phase between well-trained and elite athletes.*

Variable	Well-trained		Elite	
	FP	**LP**	**FP**	**LP**
Arousal	3 (1-8)	4 (1-9)	3 (1-8)	4 (1-8)
Alertness	6 (2-9)	7 (2-10)	6 (2-10)	6 (1-9)
Sleep quality	7 (1-10)	7 (1-10)	7 (2-10)	7 (3-10)
Sleep duration	8 (4-11)	8 (4-10)	8 (4-11)	8 (4-10)

Values presented as median (lower quartile and upper quartile range)

The total training load was determined via bTRIMP and was grouped by training status in Figure 4 below. There was no significant interaction (phase x status) for total bTRIMP (F(1, 20) = 0.19, *p* = .66). The analysis of the simple main effects showed no main effect of phase (F(1,20)= 0.12, *p*= .74, *d* = 2.5), or status (F(1,20)= 9.33, *p*= .01). Participants 12 and 13 were removed from Figure 2, as bTRIMP data were not collected and 11 and 31 were removed as they did not provide training data for cycle 3.

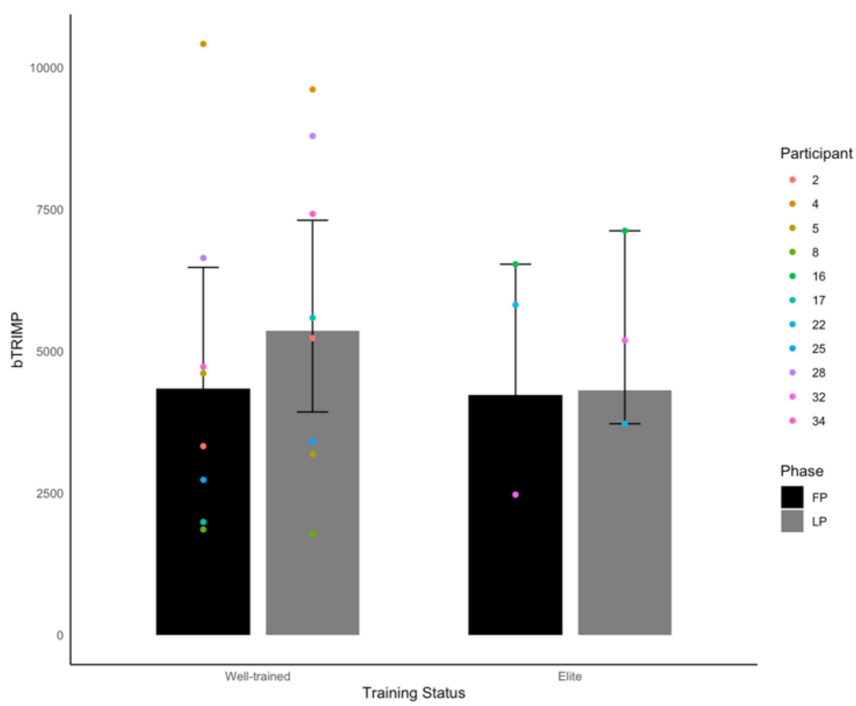

Figure 4. *Training load (bTRIMP) between well-trained and elite athletes for each phase*

In Table 3 we can see that no significant interaction (phase x status) was observed for average HR (F(1, 24) = 0.26, p = .87, d = 9.39), maximum HR (F(1, 24) = 0.01, p = .92, d = 9.59), average speed (F(1, 24) = 0.01, p = .92, d = 3.63), maximum speed (F(1, 24) = 1.79, p = .19, d = 7.57), bTRIMP (F(1, 12) = 1.93, p = .18, d = 3.59) and RPE (F(1, 24) = 0.22, p = .88, d = 12.74).

Table 3. *Training variables for phase (FP/LP) x status (well-trained/elite) interaction and combined group results*

Variables	Well-trained (n = 7)		Elite (n = 8)	
	FP	LP	FP	LP
Average HR (bpm)	133 ± 34	130 ± 41	123 ± 39)	125 ± 34
Max HR (bpm)	166 ± 36	159 ± 50	156 ± 56	158 ± 51
Average speed (km/hr)	20.6 ± 20.7	19.2 ± 8.8	19.2 ± 8.7	20.3 ± 9.2
Max speed (km/hr)	41.5 ± 19.5	41.6 ± 16.5	48.4 ± 24.4	44.1 ± 18.5
RPE	13.7 ± 2.7	13.6 ± 3.2	12.8 ± 2.7	13.2 ± 2.8
bTRIMP (A.U.)	154 ± 150.3	210.8 ± 196.6	191 ± 145.4	167.5 ± 98.8

Values presented as mean ± SD, A.U.; arbitrary units

DISCUSSION

This study aimed to determine if different phases of the MC influenced training schedules, sleep quality, alertness, and arousal of female mountain bike, road, and cyclocross athletes. The study revealed a significant increase ($p < .05$) in BBT during the LP in both well-trained and elite athletes, aligning closely with the general population's BBT response. However, between the FP and LP, there were no significant differences ($p > .05$) between well-trained and elite athletes for body mass, arousal, alertness, perceived sleep quality or duration, and any of the training outcomes (HR, bTRIMP, RPE).

The mean values for the MC characteristics are presented in Table 1. There were no significant differences between well-trained and elite athletes ($p > .05$). To the best of the author's knowledge, no prior research has provided data on MC lengths in well-trained or elite cyclists. Notably, comparable cycle lengths have also been observed among elite football (28 ± 3 days) and rugby (28 ± 5 days) athletes (Carmichael et al., 2021; Findlay et al., 2019). Similar findings have been observed in non-athletic populations, with a large-scale survey (n = 124,648) showing an average FP length (16.9 ± 5.3 days) was longer compared to the LP (12.4 ± 2.4 days; Bull et al., 2019). These findings collectively suggest that, on average, training status does not significantly influence MC characteristics such as cycle length and phase length. Consequently, for athletes with a regular MC, athletic training does not appear to have a notable impact on their MC lengths. This finding enables athletes to monitor their MC individually and apply data from non-athlete research, as the MC characteristics seem consistent across athletic and non-athletic populations.

Fatigue, bloating, abdominal pain, and cramping were commonly reported symptoms during menses (Figure 1). While elite athletes reported more symptoms than well-trained athletes, training status did not significantly affect any reported symptom ($p > .05$), possibly due to the small sample size. However, previous research has shown a wide range of prevalence and severity of MC-related symptoms, including stomach cramps, headaches, breast tenderness, and fatigue (Findlay et al., 2019; Armour et al., 2020). In this study, two participants reported missing a race due to severe abdominal pain and cramping, highlighting the potential impact of MC symptoms on athletic performance. Therefore, instead of relying on group averages, it is recommended that athletes monitor their own MC symptoms and develop strategies for optimal exercise performance.

Individual fluctuations in body mass were also present between participants. However, on average, no significant differences between training statuses were observed ($p > 0.05$). Specific to cyclists, body mass and body composition are critical in hill-dominated disciplines such as cross country (XC), marathon, and enduro, and unexpected fluctuations in body mass may have affected performance through alterations in the power-to-weight ratio (Impellizzeri et al., 2007). Previous studies have also reported no change in average body mass for physically active (Middleton et al., 2006; Tsampoukos et al., 2010; Rael et al., 2021), well-trained (Lamberts & Davidowitz, 2014; Julian et al., 2017) and elite cyclists (Haakonssen et al., 2016). Although due to individual fluctuations, it is recommended that athletes should track their MC to monitor body mass and mitigate negative effects on performance.

An increase in progesterone triggers a rise in BBT (Driver et al., 1996; Shechter et al., 2010). The average values increased significantly during the LP by 0.4ºC for well-trained and elite athletes. These findings also agree with previous research (Driver et al., 1996; Shechter et al., 2010; Händel et al., 2019). However, no changes in training measures were observed during the LP, suggesting that an increase in BBT does not influence daily training for the current group. Nevertheless, former research has demonstrated that an increase in BBT (0.4 ºC) has been associated with psychological measures such as a rise in arousal and alertness (Wright et al., 1999; Wright et al., 2002; Grant et al., 2020).

The main findings of this research were that perceived arousal and alertness scales did not significantly change between training status or phase of the MC ($p > .05$; Table 2). Previous research in non-athletic populations has indicated increases in BBT during the LP of the MC increased agitation. Wright et al. (1999) and Grant et al. (2020) conducted surveys with non-athletic populations. Well-trained and elite athletes may possess enhanced cognitive performance that enables them to control alertness and arousal before and during training or competition, regardless of alterations to BBT (Ludyga, Gronwald & Hottenrott, 2016; Mehrsafar et al., 2020). Moreover, using solely Likert scales to assess arousal and alertness may not be sufficient, and future research could focus on more comprehensive and specific tests to monitor these variables in athletes across the MC.

In addition, there were no significant differences between the phases or training status for perceived sleep quality or duration ($p > .05$). There is limited research investigating sleep outcomes across the MC. However, five elite female Australian footballers attained a significantly poorer perceived sleep quality during the LP than the FP (Carmichael et al., 2021), which was postulated as a potential consequence of a rising body temperature (Driver et al., 1996). There is sufficient evidence to indicate that elite athletes experience poorer sleep quality than the recommended sleep guidelines for athletes (Leeder et al., 2012; Halson et al., 2014). In a cohort of 175 elite athletes across a wide array of sporting disciplines, including mountain biking and road cycling, athletes achieved an average of 6.7 hours of sleep a night and 72% of the athletes did not achieve the required 8.3 hours a night to feel rested (Sargent et al., 2021). However, the lack of significant difference in perceived sleep quality and duration may be due to limitations in the measurement methods used in this study. Future studies should consider more objective measures to assess the MC's influence on these outcomes.

Training volumes in female well-trained and elite mountain bikers are lacking, and there are only a handful of studies based on female elite road cyclists (Van Erp et al., 2019; Barreto et al., 2021). Athletes' training load was measured with bTRIMP to determine the frequency and intensity of the athletes' training (Saunders et al., 2017). No significant differences were observed between the FP and LP or between highly trained and elite, indicating that training variables did not differ regardless of training status. However, extreme outliers were observed between participants in the elite group, which may be attributed to differences in training level or cycling discipline, given the varying types of training between disciplines and the number of training sessions and competitions completed.

Athletes' training load was also measured through exercising HR and RPE. No significant differences were observed between the MC phases for average HR, HRmax, and RPE. Previous research has also detected no change in RPE between the FP and LP for well-trained and elite athletes (Julian et al., 2017; Carmichael et al., 2021) and several studies have also detected no change in average HR or HR_{max} between the FP and LP in untrained and active (Lebrun et al., 1995; Abdollahpor et al., 2013; Stone et al., 2020), well-trained (Julian et al., 2017) or elite females (Vaiksaar et al., 2011). The phases of the MC and training status did not significantly influence any of the training variables during their regular training schedules. Nevertheless, this study is the first to observe the influence of the MC in a typical training environment and provide a realistic picture of training for female well-trained and elite mountain bike, road, and cyclocross athletes. Individual variation was present, and as a result, athletes and their coaches may benefit from monitoring the MC and adjusting training load and intensity accordingly to optimize performance and reduce the risk of injury or overtraining. Overall, this study highlights the importance of considering the MC in the training of female athletes and the need for further research in this area.

Due to the online nature of this study, determination of ovulation via urinary ovulation kits, BBT, and manual MC tracking were the three methods used to determine the MC phase. Thus, one limitation of this study was that hormonal verification via blood serum could not be conducted. Consequently, sub-phases of the MC could not be identified, and it is essential to recognize the intricate variations in estrogen concentrations throughout the FP. Measuring only one phase may not comprehensively capture variations in estrogen in this phase. Furthermore, the study was underpowered, requiring a larger cohort to determine more significant values.

One of the critical findings that confirmed previous research was the rise in BBT during the LP, which was discussed throughout as its sole effect on several other factors, such as HR, sleep, RPE, arousal, and alertness. Although previous research has observed mixed findings, it is recommended that future research consider the influence on exercising body temperature and subsequent performance, specifically in challenging environmental conditions. This is the first study investigating MC responses during daily training across various cycling disciplines. While the MC did not appear to impact the training regimens of experienced mountain bike, road, and cyclocross athletes as a group, and no differences were observed between training statuses, it is essential to note that individual variations still exist. Therefore, coaches and athletes are advised to monitor their MC status throughout their training program.

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REFERENCES

Abdollahpor, A., Khosravi, N., & Zahra, N. R. (2013). Effects of the menstrual cycle phase on the blood lactate responses and exercise performance in active women. *European Journal of Experimental Biology, 3*(3), 206-210. Retrieved from www.pelagiaresearchlibrary.com

Arent, S.M., & Landers, D.M. (2003). Arousal, Anxiety, and Performance: A Reexamination of the Inverted-U Hypothesis, *Research Quarterly for Exercise and Sport, 74*(4), 436–444, 10.1080/02701367.2003.10609113

Armour, M., Parry, K. A., Steel, K., & Smith, C. A. (2020). Australian female athlete perceptions of the challenges associated with training and competing when menstrual symptoms are present. *International Journal of Sports Science & Coaching, 15*(3), 316–323. https://doi.org/10.1177/1747954120916073.

Banister E.W. (1991). *Modelling athletic performance*. In: MacDougall JD, Wenger HA, Green HJ (eds.) *Physiological testing of the high-performance athlete*. Human Kinetics, Campaign, 403–425

Barreto, G., de Oliveira, L. F., Saito, T., Klosterhoff, R., Perim, P., Dolan, E., ... & Saunders, B. (2021). Reduced Endurance Capacity and Suboptimal Energy Availability in Top-Level Female Cyclists. *International Journal of Sports Physiology and Performance, 16*(8), 1194-1203. https://doi.org/10.1123/ijspp.2020-0513

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise, 14*(5), 377–381. https://doi.org/10.1249/00005768-198205000-00012

Bull, J. R., Rowland, S. P., Scherwitzl, E. B., Scherwitzl, R., Danielsson, K. G., & Harper, J. (2019). Real-world menstrual cycle characteristics of more than 600,000 menstrual cycles. *NPJ digital medicine*, *2*(1), 1-8. https://doi.org/10.1038/s41746-019-0152-7

Carmichael, R.D., Heikkinen, D.J., Mullin, E.M., McCall, N.R. (2017). Physiological response to cyclocross racing. *Sport Exerc Med Open Journal, 3*(2): 74- 80. 10.17140/SEMOJ-3-152

Carmichael, M. A., Thomson, R. L., Moran, L. J., Dunstan, J. R., Nelson, M. J., Mathai, M. L., & Wycherley, T. P. (2021). A Pilot Study on the Impact of Menstrual Cycle Phase on Elite Australian Football Athletes. *International Journal of Environmental Research and Public Health, 18*(18), 9591. https://doi.org/10.3390/ijerph18189591

Casazza, G. A., Jacobs, K. A., Suh, S. H., Miller, B. F., Horning, M. A., & Brooks, G. A. (2004). Menstrual cycle phase and oral contraceptive effects on triglyceride mobilisation during exercise. *Journal of Applied Physiology, 97*(1), 302–309. https://doi.org/10.1152/japplphysiol.00050.2004

Charkoudian, N., & Stachenfeld, N. (2016). Sex hormone effects on autonomic mechanisms of thermoregulation in humans. *Autonomic Neuroscience, 196*, 75-80. https://doi.org/10.1016/j.autneu.2015.11.004

Cohen, S., Kamarck, T., & Mermelstein, R. (1994). Perceived stress scale. Measuring stress: A guide for health and social scientists, 10(2), 1-2.

Driver, H. S., Dijk, D. J., Werth, E., Biedermann, K., & Borbely, A. A. (1996). Sleep and the sleep electroencephalogram across the menstrual cycle in young healthy women. *The Journal of Clinical Endocrinology & Metabolism, 81*(2), 728-735. 10.1210/jcem.81.2.8636295

Elliott-Sale, K., Ross, E., Burden, R., & Hicks, K. (2020). The BASES expert statement on conducting and implementing female athlete-based research. *The Sport and Exercise Scientist,* (65), 6–7. ISSN 1754-3444

Elliott-Sale, K. J., Minahan, C. L., de Jonge, X. A. J., Ackerman, K. E., Sipilä, S., Constantini, N. W., ... & Hackney, A. C. (2021). 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 Medicine*, *51*(5), 843–861. https://doi.org/10.1007/s40279-021-01435-8

Emmonds, S., Heyward, O. & Jones, B. (2019). The Challenge of Applying and Undertaking Research in Female Sport. *Sports Med - Open 5*, 51. https://doi.org/10.1186/s40798-019-0224-x

Findlay, R. J., Macrae, E. H., Whyte, I. Y., Easton, C., & Forrest, L. J. (2020). How the menstrual cycle and menstruation affect sporting performance: experiences and perceptions of elite female rugby players. *British Journal of Sports Medicine, 54*(18), 1108–1113. http://dx.doi.org/10.1136/bjsports-2019-101486

Grant, L. K., Gooley, J. J., St Hilaire, M. A., Rajaratnam, S. M., Brainard, G. C., Czeisler, C. A., ... & Rahman, S. A. (2020). Menstrual phase-dependent differences in neurobehavioral performance: the role of temperature and the progesterone/estradiol ratio. *Sleep, 43*(2), zsz227. https://doi.org/10.1093/sleep/zsz227

Hackney, A. C. (1999). Influence of oestrogen on muscle glycogen utilisation during exercise. *Acta Physiologica Scandinavica, 167*(3), 273. https://doi-org.napier.idm.oclc.org/10.1046/j.1365-201x.1999.00605.x

Halson, S. L. (2014). Sleep in elite athletes and nutritional interventions to enhance sleep. Sports Medicine, 44(1), 13-23. https://doi.org/10.1007/s40279-014-0147-0

Hackney, A. C., Koltun, K. J., & Williett, H. N. (2022). Menstrual cycle hormonal changes: estradiol-β-17 and progesterone interactions on exercise fat oxidation. *Endocrine,* 1-3. https://doi.org/10.1007/s12020-022-02998-w

Händel, P., & Wahlström, J. (2019). Digital contraceptives based on basal body temperature measurements. *Biomedical Signal Processing and Control, 52,* 141-151. https://doi.org/10.1016/j.bspc.2019.04.019

Hashimoto, H., Ishijima, T., Hayashida, H., Suzuki, K., & Higuchi, M. (2014). Menstrual cycle phase and carbohydrate ingestion alter immune response following endurance exercise and high intensity time trial performance test under hot conditions. *Journal of the International Society of Sports Nutrition, 11*(1), 1-11. https://doi.org/10.1186/1550-2783-11-39

Hoddes, E., et al. (1973). Quantification of sleepiness: a new approach. *Psychophysiology* 10.4 431-436. https://doi.org/10.1111/j.1469-8986.1973.tb00801.x

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology.*

Impellizzeri, F. M., & Marcora, S. M. (2007). The physiology of mountain biking. *Sports medicine, 37*(1), 59-71. https://doi.org/10.2165/00007256-200737010-00005

Janse de Jonge, X. A. (2003). Effects of the menstrual cycle on exercise performance. *Sports medicine, 33*(11), 833-851. https://doi.org/10.2165/00007256-200333110-00004

Julian, R., Hecksteden, A., Fullagar, H. H., & Meyer, T. (2017). The effects of menstrual cycle phase on physical performance in female soccer players. *PloS one, 12*(3), e0173951. https://doi.org/10.1371/journal.pone.0173951

Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J., & Pedlar, C. (2012). Sleep duration and quality in elite athletes measured using wristwatch actigraphy, *Journal of Sports Sciences, 30(*6), 541-545. 10.1080/02640414.2012.660188

Ludyga, S., Gronwald, T., & Hottenrott, K. (2016). The athlete's brain: cross-sectional evidence for neural efficiency during cycling exercise. *Neural Plasticity,* 2016. https://doi.org/10.1155/2016/4583674

Marsh, S. A., & Jenkins, D. G. (2002). Physiological responses to the menstrual cycle. *Sports Medicine, 32*(10), 601–614. https://doi.org/10.2165/00007256-200232100-00001

Martin, D. T., McLean, B., Trewin, C., Lee, H., Victor, J., & Hahn, A. G. (2001). Physiological characteristics of nationally competitive female road cyclists and demands of competition. *Sports Medicine, 31*(7), 469–477. https://doi.org/10.2165/00007256-200131070-00002

McKay, A. K., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., ... & Burke, L. M. (2022). Defining training and performance caliber: a participant classification framework. *International journal of sports physiology and performance, 17(2)*, 317–331. https://doi.org/10.1123/ijspp.2021-0451

Mehrsafar, A. H., Rosa, M. A. S., Zadeh, A. M., & Gazerani, P. (2020). A feasibility study of application and potential effects of a single session transcranial direct current stimulation (tDCS) on competitive anxiety, mood state, salivary levels of cortisol and alpha amylase in elite athletes under a real-world competition. *Physiology & Behavior, 227*, 113173. https://doi.org/10.1016/j.physbeh.2020.113173

Middleton, L. E., & Wenger, H. A. (2006). Effects of menstrual phase on performance and recovery in intense intermittent activity. *European Journal of Applied Physiology, 96*(1), 53–58. https://doi.org/10.1007/s00421-005-0073-9

Mujika, I., & Taipale, R. S. (2019). Sport science on women, women in sport science. International *Journal of Sports Physiology and Performance, 14*(8), 1013-1014. https://doi.org/10.1123/ijspp.2019-0514

Oosthuyse, T., Bosch, A. N., & Jackson, S. (2005). Cycling time trial performance during different phases of the menstrual cycle. *European Journal of Applied Physiology, 94*(3), 268-276. https://doi.org/10.1007/s00421-005-1324-5

R Core Team (2020). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rael, B., Alfaro-Magallanes, V. M., Romero-Parra, N., Castro, E. A., Cupeiro, R., Janse de Jonge, X. A., ... & IronFEMME Study Group. (2021). Menstrual cycle phases influence on cardiorespiratory response to exercise in endurance-trained females. *International Journal of Environmental Research and Public Health, 18*(3), 860. https://doi.org/10.3390/ijerph18030860

RStudio Team (2020). *RStudio: Integrated Development for R. RStudio*, PBC, Boston, MA

Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2021). How much sleep does an elite athlete need?. *International Journal of Sports Physiology and Performance, 16*(12), 1746-1757. https://doi.org/10.1123/ijspp.2020-0896

Saunders, D., Abt, G., Hesselink, M. K., Myers, T., & Akubat, I. (2017). Methods of monitoring training load and their relationships to changes in fitness and performance in competitive road cyclists. *International journal of sports physiology and performance, 12*(5), 668–675. https://doi.org/10.1123/ijspp.2016-0454

Schaumberg, M. A., Jenkins, D. G., de Jonge, X. A. J., Emmerton, L. M., & Skinner, T. L. (2017). Three-step method for menstrual and oral contraceptive cycle verification. *Journal of Science and Medicine in Sport, 20*(11), 965-969. https://doi.org/10.1016/j.jsams.2016.08.013

Shechter, A., Varin, F., & Boivin, D. B. (2010). Circadian variation of sleep during the follicular and luteal phases of the menstrual cycle. *Sleep, 33*(5), 647-656. https://doi.org/10.1093/sleep/33.5.647

Stone, T., Earley, R. L., Burnash, S. G., & Wingo, J. E. (2020). Menstrual cycle effects on cardiovascular drift and maximal oxygen uptake during exercise heat stress. *European Journal of Applied Physiology, 121*(2), 561–572. https://doi.org/10.1007/s00421-020-04542-y

Tsampoukos, A., Peckham, E. A., James, R., & Nevill, M. E. (2010). Effect of menstrual cycle phase on sprinting performance. *European Journal of Applied Physiology, 109*(4), 659-667. https://doi.org/10.1007/s00421-010-1384-z

UCI. (2019). *UCI cycling regulations: Part IV Mountain bike races.* Aigle: Union Cycliste Internationale. Retrieved from: https://www.uci.org/regulations/3MyLDDrwJCJJ0BGGOFzOat#part-iv-mountain-bike

Vaiksaar, S., Jürimäe, J., Mäestu, J., Purge, P., Kalytka, S., Shakhlina, L., & Jürimäe, T. (2011). No effect of menstrual cycle phase and oral contraceptive use on endurance performance in rowers. *The Journal of Strength & Conditioning Research, 25*(6), 1571-1578. 10.1519/JSC.0b013e3181df7fd2

Van Erp, T., Sanders, D., & De Koning, J. J. (2019). Training characteristics of male and female professional road cyclists: a 4-year retrospective analysis. *International Journal of Sports Physiology and Performance, 15*(4), 534-540. https://doi.org/10.1123/ijspp.2019-0320

Whyte, G. P., George, K., Shave, R., Middleton, N., & Nevill, A. M. (2008). Training induced changes in maximum heart rate. *International Journal of Sports Medicine, 29*(02), 129–133. 10.1055/s-2007-965783

Wright Jr, K. P., Hull, J. T., & Czeisler, C. A. (2002). Relationship between alertness, performance, and body temperature in humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology.* https://doi.org/10.1152/ajpregu.00205.2002

Wright, K. P., & Badia, P. (1999). Effects of menstrual cycle phase and oral contraceptives on alertness, cognitive performance, and circadian rhythms during sleep deprivation. *Behavioural Brain Research, 103*(2), 185–194. https://doi.org/10.1016/S0166-4328(99)00042-X

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