The influence of menstrual cycle phase on measures of recovery status in endurance athletes: The FENDURA project

Virginia De Martin Topranin[1], Tina Pettersen Engseth[2], Maria Hrozanova[1], Madison Taylor[2], Øyvind Sandbakk[1,2], Dionne A. Noordhof[1]

Original Investigation

[1]Centre for Elite Sports Research, Department of Neuromedicine and Movement Science (INB), Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology, Trondheim, Norway

[2]School of Sport Sciences, UiT The Arctic University of Norway, Tromsø, Norway

Corresponding author:
Virginia De Martin Topranin
Centre for Elite Sports Research
Department of Neuromedicine and Movement Science
Norwegian University of Science and Technology
virginia.de.m.topranin@ntnu.no

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ABSTRACT

Purpose. To investigate the influence of menstrual cycle (MC) phase on measures of recovery status i.e., resting heart rate (HR), perceived sleep quality, physical and mental readiness to train, among female endurance athletes. **Methods.** Daily data were recorded during 1 to 4 MCs (i.e., duration ≥21 and ≤35 days, ovulatory, luteal phase ≥10 days) of 41 trained to elite level female endurance athletes (mean (SD) age 27 (8) years, weekly training 9 (3) hours). Resting HR was assessed daily using a standardized protocol, while perceived sleep quality, physical and mental readiness to train were assessed using a visual analogue scale (1 – 10). Four MC phases (early follicular phase (EFP), late follicular phase (LFP), ovulatory phase (OP) and mid-luteal phase (MLP)) were determined using the calendar-based counting method and urinary ovulation prediction test. Data were analysed using linear mixed-effects models. **Results.** Resting HR was significantly higher in MLP (1.7 bpm, P=0.006) compared to EFP without significant differences between the other MC phases. Perceived sleep quality was impaired in MLP compared to LFP (-0.3, P=0.035). Physical readiness to train was lower both in OP (-0.6, P=0.015) and MLP (-0.5, P=0.026) compared to EFP. Mental readiness to train did not show any significant differences between MC phases (P>0.05). **Conclusions.** Although significant, the findings had negligible to small effect sizes, indicating that MC phase is likely not the main determinant of changes in measures of recovery status, but rather one of the many possible stressors.

Keywords: follicular phase, ovulatory phase, luteal phase, hormonal fluctuations, sleep quality, resting heart rate, readiness to train

INTRODUCTION

Training adaptations in sports are regulated through an intricate balance between training stimulus and recovery [1]. Recovery status is defined as a state of biopsychosocial balance[2] and is influenced by several factors, such as nutrition, sleep [1], and potentially the menstrual cycle (MC). The endogenous female sex hormones fluctuate cyclically over a 21 – 35-day period in an eumenorrheic MC[3]. Four phases are commonly identified based on their different concentrations of estrogen and progesterone: the early follicular phase (EFP), the late follicular phase (LFP), the ovulatory phase (OP), and the mid-luteal phase (MLP)[3]. Sex hormone fluctuations associated with the MC might influence both training tolerance and the rate of recovery through several pathways[4,5]. However, there are insufficient published original investigations with proper MC-phase verification to draw any conclusions. An improved understanding of the influence of MC phase on the recovery status of athletes would help female athletes and their support personnel to adjust training load and/or the subsequent recovery to optimize training adaptations.

Athletes, coaches, and researchers have used a variety of objective and subjective variables to monitor recovery status. A commonly used objective marker of recovery status is resting heart rate (HR). Measuring resting HR has the potential to detect training-induced changes in the autonomic nervous system, which has a crucial role in stress tolerance[6]. Although there is some recent evidence of increased resting HR in the MLP compared to the EFP[7-9], high-quality studies on exercise-trained women or athletes are missing. Only one of the aforementioned studies[8] focused on an exercise-trained population; however, this study exclusively employed the calendar-based counting method for MC phase determination. Exercising women and athletes often exhibit subtle menstrual disturbances[10], such as anovulatory MCs and luteal phase deficiency, which present with altered hormonal fluctuations compared to eumenorrheic MCs and could possibly influence the recovery patterns. These subtle menstrual disturbances are not detectable when only using the calendar-based counting method[11], and the inclusion of additional methods for the determination of MC phases (e.g., ovulation prediction test) would make the findings more reliable.

In addition to objective measures, subjective indicators, such as perceived fatigue and readiness to train, are commonly used to assess recovery status[1] and are able to identify non-functional states[12]. Subjective measures appear to be more sensitive and consistent than objective markers for monitoring the training-induced changes in athletes well-being[13]. However, there is limited research on the influence of the MC on subjective recovery measures in athletes. Cook et al.[14] showed significant variations in motivation to train across the MC among athletes involved in a range of different sports, but this study only employed the calendar-based counting method for determination of MC phases. Perceived sleep quality is another subjective measure with the potential to provide useful indications about recovery status. Although perceived sleep quality has been shown to be impaired in the days preceding the bleeding phase (i.e., late luteal phase) and during the bleeding phase (i.e., EFP) in healthy women[15,16], there are currently no robust findings about the influence of the MC on perceived sleep among female athletes.

A combination of objective and subjective measures of recovery status that are time-efficient, easy-to-collect, and non-invasive are widely used by athletes and their support staff. Knowledge about the influence of MC phase on such recovery measures could be important for interpreting recovery status in female athletes. Altogether, the aim of this study was to investigate the influence of MC phase on measures of recovery status, such as resting HR, perceived sleep quality, and physical and mental readiness to train among female endurance athletes.

METHODS

Study design. The present study was part of the Female Endurance Athlete (FENDURA) project, which investigates the influence of female-specific aspects on training and performance among female endurance athletes. The study was pre-approved by the Norwegian Social Science Data Services (NSD) (409326). All participants were given written information about the study and provided their written informed consent before participation.

Participants. Participants were invited to enroll in the project if they: 1) were 18 years old or older, 2) were naturally menstruating, 3) reported to have a regular menstrual bleeding, 4) were exercising at least 6 times per week, and 5) were a recreational or professional athlete within an endurance sport (see Figure 1; team sports excluded). Participants could not take part in the study if they: 1) were amenorrheic), 2) were using hormonal contraceptives at the time of recruitment, 3) reported having a menstrual disturbance at the time of enrollment, 4) reported having sleep disorders or severe medical conditions. Of the 61 athletes who consented to participate, 49 completed the study (see Figure 1). Eight participants were retrospectively excluded because all their MCs during the study period presented with a menstrual disturbance, i.e.: a) absence of a positive ovulation test (anovulatory cycles), b) luteal phase shorter than 10 days[17], and/or c) MC duration shorter than 21 or longer than 35 days[3] (Figure 1). Participants were included in the analysis when they had at least one MC without menstrual disturbances. Considering the self-reported history of regular menstrual bleeding and the fact that exercising women are likely to have menstrual disturbances [10], this was regarded as a sufficient criterion for including MCs in the analysis. Details about prevalence of menstrual disturbances within each participant during the study period are reported in Supplementary material (Table 8). Thus, 1 to 4 MCs (n = 107) per participant (n = 41) were included in the final analysis. Their characteristics were collected via an enrolment questionnaire (see Table 1). Participants were classified based on their training volume and performance level[18] in 1) Tier 2, trained/developmental (n = 16), 2) Tier 3, highly trained/national level (n = 18) and 3) Tier 4, elite/international level (n = 7).

Insert Table 1 about here.

Insert Figure 1 about here.

Menstrual cycle phase determination. MC phases were determined using the calendar-based counting method and a urinary ovulation prediction test. The first day of menstrual bleeding was identified as day 1 and MC length was defined as the number of days from day 1 up to and including the day before day 1 of the following MC.

The participants were provided with Clearblue digital ovulation test kits (Clearblue, SPD Swiss Precision Diagnostics GmbH, Geneva, Switzerland) and instructed to start using these on day 8 of the MC, to perform the test at approximately the same time each day (± 1 hour) and in standardized conditions (not having urinated for at least 4 hours before testing and to avoid excessive fluid intake before testing). The test was performed every day until a positive result occurred or until the first day of menstrual bleeding in the following MC. Participants were required to send a photograph of the test strip to the primary investigator for visual confirmation of a positive test. Four MC phases were determined based on the first day of menstrual bleeding and the day of a positive ovulation test: EFP (day 1 to day 3 of the MC), LFP (the day before and the day of a positive ovulation test), OP (the two days following a positive ovulation test), MLP (7 to 9 days following the positive ovulation test) (Elliott-Sale et al., 2021). Figure 2 provides a graphical visualization of the MC phases.

Insert Figure 2 about here.

Training parameters. Participants self-recorded their training sessions using one of two online platforms: "Olympiatoppens Treningsdagbok", the Norwegian Top Sports Centre (Olympiatoppen) training diary, or BESTR training diary (Oslo, Norway). Both the training and recovery parameters that participants recorded daily were identical in the two training diaries. Training load was calculated by multiplying total duration of the training session in minutes by the session rating of perceived exertion (sRPE) as described in Foster et al.[19]. In case of multiple training sessions on one day, the training load of those sessions was summated to obtain one training load score per day. Both endurance and strength sessions were considered for the quantification of training load, including warm-up, cool-down, and recovery intervals. Mobility and stretching sessions were excluded. Monotony was quantified as the mean of the daily training load during a given MC phase divided by its standard deviation; strain was determined as the product of training load during a given MC phase and monotony[20] (both variables were calculated for each MC phase). To account for the different length of MC phases, the mean training load was used rather than the sum[21].

Recovery measures. Participants were asked to report their objective and subjective measures of recovery status in their online training diary daily. Resting HR was assessed using an overnight-monitoring watch (mean value throughout the night). Participants that did not have such equipment used a standardized procedure upon awakening, i.e., go to the bathroom, lie back in bed in supine position and calm down, relax for five minutes, count the HR during the last minute. Participants were instructed to measure resting HR using the same method throughout the whole study period. Perceived sleep quality, perceived physical readiness to train, and mental readiness to train were assessed using a visual analogue scale (VAS) from 1 to 10 (only whole numbers)[12]. Each scale included specific verbal anchors provided in the participants native language (Norwegian): for perceived sleep quality 1 referred to "low sleep quality" and 10 to "high sleep quality". Physical and mental readiness to train were defined as the degree of how ready the athlete felt physically and mentally to complete training or competition and had to be filled out on days off as well. Participants could rate their feeling from 1 = "not ready" to 10 = "very ready". The analyses were performed using resting HR, perceived sleep quality, physical and mental readiness to train data reported on the following day respective to the MC phase day (Figure 3). Additionally, participants were asked to record the degree of negative MC-related symptoms (e.g., headache, bloating, severe bleeding, back/abdominal pain) every day on a 1-10 VAS: 1 was equal to "no symptoms" and 10 to "severe symptoms".

Statistical analysis. Daily datapoints were averaged to obtain a single datapoint for each MC phase. Data were analyzed by performing linear mixed-effects model analysis. Random intercept models were built considering a two-level structure with MCs clustered within participants (random effect) and the relationship between MC phase (main determinant) and recovery measures (outcome) was investigated. The effect of the MC phase was adjusted for potential confounders and/or effect modifiers, i.e., MC-related symptoms, daily training load (sRPE), monotony, and strain as described by Twisk[22]. EFP was defined as the reference phase for comparisons and the alpha level was set at < 0.05. The other phases were set as reference for comparisons between each phase. Visual inspection of residuals did not reveal obvious deviations from normality or homoscedasticity, and assumptions were met. Effect sizes were calculated based on Nakagawa and Schielzeth[23] as marginal R^2 (variance explained by fixed effect only) and conditional R^2 (variance explained by fixed and random effects) and interpreted according to Cohen et al.[24]. Descriptive data are presented as mean (standard deviation). All statistical analyses were performed using R[25] with the packages “lme4” (version 1.1-29) and “multilevelTools” (version 0.1.1); the figures were generated using the package “ggplot2” (version 3.3.6).

RESULTS

Weekly training volume (hh:mm) in each tier during the study period was as follows: 07:24 (02:47) hours/week in Tier 2, 09:24 (03:05) hours/week in Tier 3, whereas athletes in Tier 4 trained 11:27 (02:35) hours/week.

Figure 3 illustrates the change in recovery measures between MC phases (estimates based on the adjusted models). Results of the association model for each recovery variable are reported in Table 2. Resting HR was significantly higher in MLP compared to EFP (P = 0.006), without significant differences between the other MC phases. The average perceived sleep quality was 7.1 in EFP. Perceived sleep quality differed significantly between LFP and MLP, with it being lower in MLP (P = 0.035). Physical readiness to train was significantly lower in both OP (P = 0.015) and MLP (P = 0.026) compared to EFP. Mental readiness to train did not show a significant difference between MC phases, but a significant interaction was found between MC phase and MC-related symptoms (P = 0.010). The influence of MC phase on mental readiness to train was weaker with increasing values of MC-related symptoms. For resting HR, the variance explained by fixed effects was 1.3% (negligible effect size) while 82.4% (large effect size) was explained by both fixed and random effects. Fixed effects explained 2.0, 4.6 and 6.6% (small effect sizes) of the variance in perceived sleep quality, physical readiness, and mental readiness to train respectively while fixed and random effects taken together accounted for 54.9, 56.5 and 54.0% (large effect sizes) of the variance.

Insert Table 2 about here.

Insert Figure 3 about here.

DISCUSSION

This study investigated the influence of MC phase on objective and subjective measures of recovery status among endurance trained female athletes. The main finding was that resting HR, perceived sleep quality and physical readiness to train were all significantly influenced by MC phase, with the following differences between phases: resting HR was significantly higher in MLP compared to EFP; perceived sleep quality was significantly decreased in MLP compared to LFP; physical readiness to train was significantly lower in OP and MLP compared to EFP. In contrast, mental readiness to train did not show a significant difference between MC phases.

Resting HR. Resting HR was higher in MLP compared to EFP. This increase in resting HR in MLP may be explained by several physiological changes, such as increased cardiovascular strain, altered fluid regulation, reduced vagal activity, or alternatively by a shift in thermoregulatory control, which results in an increased basal body temperature[26]. The pattern found in resting HR throughout the MC identified in competitive women in this study was comparable to the pattern found in non-athletic participants[7,9], as well as in exercising women[8,27]. However, the absolute increase in resting HR in MLP found in our study was smaller compared to previous findings. The discrepancies in absolute increases in HR between studies are most likely due to methodological differences (e.g., MC phase determination and statistical analyses) as well as differences in the training status of the participants (e.g., lower resting HR in endurance trained participants). However, when considering the percentage change (3.4%), the current study is in line with previous findings that employed a similar methodological approach for determining MC phases[7,9]. An increase of approximately 2 beats per minute might not constitute a meaningful change for well-trained women and athletes, as the day-to-day variation in submaximal HR may be up to 6.5%[28]. Thus, an increase of 3.4% due to MC phase could be easily masked by the influence of other stressors. Moreover, the low effect size (marginal R^2) highlights a limited practical relevance of this finding on a group level.

Perceived sleep quality. Perceived sleep quality was significantly decreased in MLP compared to LFP, with no differences between other MC phases. In agreement with the present study, a recent review showed changes in sleep characteristics during the MC and an increased incidence of sleep disturbances in the luteal phase compared to the follicular phase[29]. The higher concentration of progesterone in the luteal phase compared to the follicular phase is associated with elevated core body temperature, which could interfere with sleep[29]. Self-reported sleep quality has previously been found to be poorer in the 3 days prior to the bleeding phase (i.e, late luteal phase)and during the bleeding phase (i.e., EFP) compared to the mid-follicular and early/MLP in young healthy non-athletic women[15] , which might be due to the higher incidence of MC-related symptoms during these days[30]. Since it is conceivable that MC-related symptoms occurring before and during the bleeding phase can disrupt sleep, the variable was controlled for in our analysis (i.e., MC-related symptoms were added to the model as confounder). Moreover, our participants did not report severe symptoms (see Figure 4 in the supplementary material), which might explain why this study did not show a poorer sleep quality during the bleeding phase (i.e., EFP). Baker and Driver[15] did, unlike our study, not find a lower perceived sleep quality in MLP compared to the follicular phase. This discrepancy between studies could also be due to sample characteristics. The participants in our study were trained individuals with likely good sleep hygiene (reasonable to assume based on the sleep quality scores) and thus, different characteristics and sleeping routines compared to the previous studies[15,16]. A recent study showed altered sleep patterns across the MC among young endurance athletes[31], in which sleep efficiency measured objectively with an at-home sleep monitor was impaired in the follicular phase compared to the luteal phase[31]. This contrasts the finding of the present study; however, objectively measured sleep characteristics have previously been shown to poorly reflect perceived sleep quality[32], and it has been shown that subjective measures trump objective ones as markers of training response[13]. Moreover, the study of Hrozanova et al.[31] only employed the calendar-based counting method for determination of MC phases. In addition to the risk of overlooking possible menstrual disturbances, and thus abnormal hormonal concentrations, it is challenging to compare our findings to the ones of Hrozanova et al. [31] since the identification of MC phases was performed using different methodologies.

Readiness to train. Our study addressed the influence of MC phase on readiness to train, a widely used marker of recovery in sports practice. Physical readiness to train was significantly reduced in OP and MLP compared to EFP. Higher muscle damage, inflammatory response as well as delayed recovery of muscle soreness have been associated with lower sex hormones concentrations[4,33]. Thus, a slower recovery process and, in turn, a decreased physical readiness to train could be expected when estrogen concentration is low. This would confirm the lower physical readiness to train found in OP in our study. However, EFP is also marked by a low concentration of female sex hormones, which makes this finding difficult to interpret. MLP is normally characterized by high concentrations of both estrogen and progesterone, and the protective effect of estrogen might be blunted by the increased concentration of progesterone. The antagonistic effect of progesterone promotes protein catabolism during exercise[5] and it might explain the lower physical readiness to train found in MLP in the present study.

Mental readiness to train was not influenced by MC phase in our study, although mental readiness to train is expected to reflect the psychological recovery status as well as psychological changes induced by MC phase. A rise in serum progesterone during the luteal phase has previously been linked to negative mood symptoms[34]; increased negative mood pre-exercise has been found in MLP[35] and motivation to train was decreased on day 21 of the MC (i.e., supposedly MLP)[14]. Moreover, a higher incidence of mood swings and irritability was found 1-4 days before and during the bleeding phase (i.e., late luteal phase and EFP) [36]. We corrected for the possible confounding effect of MC-related symptoms in our analysis, and this might explain the lack of influence of MC phase on mental readiness to train found in the present study. Alternatively, this can be due to our sample characterized by no severe MC-related symptoms and/or differences in MC phase determination. The discrepancies between studies suggest that MC phase do not consistently influence readiness to train on a group level, but we cannot exclude meaningful individual effects.

Methodological considerations. This study has several limitations that should be considered when interpreting the findings. First, isolating the effect of a single stressor (e.g., MC phase) on recovery measures outside of a controlled laboratory environment is clearly challenging. We tried to mitigate this limitation by including several MCs for most of the participants to capture the acute response to the stressor over time. Second, most of the data is self-reported with measures such as perceived sleep quality, readiness to train, as well as sRPE that were all scored using the same scale. This could potentially result in participants answering in a default fashion (i.e., common method bias). However, participants received a booklet containing an explanation and an anchor question for each recovery variable to make them aware of what a specific variable and scale meant. Third, serum hormone verification of MC phases would have improved the validity of the results, as we might have included MCs not showing appropriate hormonal concentrations. Indeed, the study might have failed to detect MCs presenting with subtle menstrual disturbances, such as luteal phase deficiency [10], which should have been excluded from the analysis. However, the serum hormone verification of MC phases would probably have limited the generalizability of the findings since employing such methodology would have resulted in a dramatic reduction of sample size, both because the participants were located all over the country and because of the lower compliance with the busy and ever-changing schedule of athletes. Moreover, using two different measurement methods for resting HR may entail larger variability, because one being dependent on the subject's accuracy in performing it. Lastly, the inclusion of participants with a high prevalence of MCs presenting menstrual disturbances during the study period may have yielded biased results. However, we performed additional analyses excluding participants presenting ≥ 50% or > 50% of disturbed MCs and showed that this did not substantially change the results (Tables 9 - 12 in Supplementary material). On the other hand, the exclusion of many MCs because of subtle menstrual disturbances, as well as the a priori exclusion of athletes with severe menstrual disturbances, limits the generalizability of the findings to all non-HC user female athletes of reproductive age. Since it has been shown that the prevalence of menstrual disturbances in exercising women and athletes is significantly higher than in the general population [10], it is quite unrealistic to draw a sample from the female athletic population presenting with no menstrual disturbances. In this regard, a thorough tracking of the MC history prior to the initiation of the study would have helped identifying possible menstrual disturbances and making the inclusion/exclusion of participants more precise.

Future research should overcome the above-mentioned limitations by employing distinct item context and characteristics for each variable to minimize common method bias and by including serum hormone measurements for the verification of MC phases. Further, it would be useful to investigate the association between objective and subjective measures of recovery status in relation to the MC.

Practical applications.

Although significant, the findings had negligible to small effect sizes and thus limited practical relevance on a group-level. Thus, MC phase is likely not the main determinant of changes in resting HR, perceived sleep quality and physical readiness to train and it should rather be regarded as one of the many possible stressors. It is advisable to consider the influence of MC phase when anomalies in the measures of recovery status are found that cannot be explained by other stressors. Taking into account the MC could represent one of the elements for the optimization of training at an individual level.

The findings might indicate a slower recovery capacity in the luteal phase. Athletes and their support staff should consider optimizing the recovery strategies in this phase to prevent non-functional states.

The design of the current study makes the findings highly relevant for athletes and coaches, as the variables used are commonly reported by athletes. The inclusion of at-home ovulation testing is also an efficient and feasible tool for athletes.

CONCLUSIONS

This study showed that MC phase significantly influenced several commonly used measures of recovery status, although the effects were all small. Since mental readiness to train did not significantly vary between MC phases, changes in mental readiness to train throughout the MC are most likely influenced by other factors than MC phase. The generalizability of these findings is limited to ovulatory MCs with a duration between 21 and 35 days and a luteal phase longer than 10 days.

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CAPTIONS

TABLE 1 | Participants characteristics.

TABLE 2 | Association between menstrual cycle (MC) phase and recovery measures.

FIGURE 1 | Flowchart showing the inclusion procedure and the classification of menstrual cycles.

FIGURE 2 | Graphical visualization of the determination of menstrual cycle phases over an idealized 28-day menstrual cycle. *EFP = early follicular phase, LFP = late follicular phase, OP = ovulatory phase, MLP = mid-luteal phase, LH = luteinizing hormone.*

FIGURE 3| Change in recovery measures across menstrual cycle phases. A) Resting heart rate (HR), B) Perceived sleep quality, C) Physical readiness to train, D) Mental readiness to train. *Dotted grey lines = individual data, colored bold line = estimates and 95% CI. EFP = early follicular phase, LFP = late follicular phase, OP = ovulatory phase, MLP = mid-luteal phase, bpm = beats per minute, VAS = visual analogue scale, "*" shows differences between MC phases where P < 0.05 and "**" shows P < 0.01.*

CAPTIONS - SUPPLEMENTARY MATERIAL

TABLE 3| Association between menstrual cycle (MC) phase and resting heart rate.

TABLE 4 | Association between menstrual cycle (MC) phase and perceived sleep quality.

TABLE 5 | Association between menstrual cycle (MC) phase and physical readiness to train.

TABLE 6 | Association between menstrual cycle (MC) phase and mental readiness to train.

TABLE 7 | Multi comparisons between menstrual cycle (MC) phases.

TABLE 8 | Prevalence and type of menstrual disturbance within each participant.

TABLE 9 | Association between menstrual cycle (MC) phase and resting heart rate – additional analysis based on prevalence of menstrual disturbances.

TABLE 10 | Association between menstrual cycle (MC) phase and perceived sleep quality – additional analysis based on prevalence of menstrual disturbances.

TABLE 11 | Association between menstrual cycle (MC) phase and physical readiness to train – additional analysis based on prevalence of menstrual disturbances.

TABLE 12 | Association between menstrual cycle (MC) phase and mental readiness to train– additional analysis based on prevalence of menstrual disturbances.

FIGURE 4 | Change in confounding measures across menstrual cycle phases. A) Menstrual cycle (MC)-related symptoms, B) training load (session RPE), C) Monotony, D) Strain. *Dotted grey lines = individual data, colored bold line = estimates and 95% CI. EFP = early follicular phase, LFP = late follicular phase, OP = ovulatory phase, MLP = mid-luteal phase, VAS = visual analogue scale, A.U. = arbitrary unit.*