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Human Kinetics
ORIGINAL INVESTIGATION

Influence of Menstrual-Cycle Phase on Sleep and Recovery Following High- and Low-Intensity Training in Eumenorrheic Endurance-Trained Women: The Female Endurance Athlete Project

Madison Y. Taylor,[1] Maria Hrozanova,[2,3] Liv Nordengen,[3] Øyvind Sandbakk,[1,3] John O. Osborne,[1] and Dionne A. Noordhof[3]

[1]School of Sport Sciences, UiT The Arctic University of Norway, Tromsø, Norway; [2]Department of Public Health and Nursing, Norwegian University of Science and Technology, Trondheim, Norway; [3]Department of Neuromedicine and Movement Science, Center for Elite Sports Research, Norwegian University of Science and Technology, Trondheim, Norway

Purpose: To investigate the influence of menstrual-cycle (MC) phase on objective sleep and perceived recovery following high- (HIT) and low-intensity training (LIT) in endurance-trained women. ***Methods:*** Fifteen naturally menstruating, endurance-trained women completed standardized HIT and LIT sessions during the early follicular phase (EFP), ovulatory phase (OP), and midluteal phase (MLP) of 2 MCs. Overnight sleep was monitored using a Somnofy sleep monitor after each training session, and perceived recovery was assessed after 24 hours using self-report scales. MC phases were determined using the 3-step method, and noneumenorrheic MCs were retrospectively excluded from analysis. ***Results:*** MC phase had a main effect on wake after sleep onset ($P \le .001$), with higher values in MLP (33 [22] min) than EFP (22 [19] min, $P = .043$) and OP (14 [9] min, $P = .001$), sleep efficiency ($P = .033$), with lower values in MLP (87% [6%]) than OP (90% [8%], $P = .047$), and light sleep ($P = .023$) with higher values in MLP (59% [6%]) than EFP (54% [7%], $P = .037$). Session type had a main effect on perceived recovery ($P < .018$) and perceived muscle soreness ($P = .007$), indicating lower perceived recovery and higher perceived muscle soreness following HIT compared to LIT ($P < .001$, $P = .018$, respectively). No interactions were found between MC phase and session type for any of the measured variables. ***Conclusions:*** Objective sleep quality, but not perceived recovery, was influenced by MC phase, as indicated by small impairments to multiple indices of objective sleep during MLP. There were no interactions between MC phase and session type, indicating that the effect of MC on sleep and recovery is consistent regardless of session type.

Keywords: sex hormones, estrogen, progesterone, fatigue, training load, endurance training

The increased participation of women in sport necessitates systematic training strategies that consider the nuances of female physiology.[1,2] Well-designed training programs seek to balance training-induced stimuli with adequate recovery in order to maximize adaptations while avoiding states of excessive fatigue (ie, nonfunctional overreaching), and injury.[3] Recovery refers to the physiological and psychological processes necessary for cognitive, muscular, and metabolic restoration.[3] An athlete's recovery status can be monitored and assessed through subjective self-report questionnaires and/or objectively, for instance, by monitoring sleep.[3,4] Together, these markers provide an indication of an athlete's biopsychosocial balance and may be used to make adjustments to training load as necessary.[4] However, most of the literature on sleep and recovery is based on male-centric study designs, which leaves a clear knowledge gap regarding female-specific factors, such as the effect of the menstrual cycle (MC).[5,6]

Naturally menstruating women experience cyclical hormonal fluctuations across the MC. The MC can be divided into several phases, characterized by the concentration of estrogen and progesterone, that is, the early follicular phase (EFP), ovulatory phase (OP), and midluteal phase (MLP; Figure 1). Studies in trained[7,8] and untrained[9–11] women have suggested that sleep may vary across the MC, with more sleep disturbances generally reported around menstruation or in the luteal phase.[12,13] Sleep plays an essential role in the rejuvenation of many recovery-enabling functions (ie, cognition, immune, metabolic, musculoskeletal repair, etc), making it particularly relevant for athletic development and recovery.[3,14,15] In addition to sleep, subjective markers of mood, motivation, and fatigue are frequently used to provide an indication of an athlete's perceived recovery status.[3] While limited research is available, lower mood, motivation, and readiness to train have also been reported in the luteal phase in athletic women.[16–18] In contrast to the aforementioned studies, no effect of MC phase on sleep[11,19] as well as indications of impaired sleep and recovery in the follicular phase[7,20] has also been reported. The scarcity of female-athlete specific data, together with lack of consensus in the available literature, has prompted repeated calls for more high-quality research initiatives in this area.[6,21,22]

The current literature is limited by multiple factors. First, biological confirmation of MC phases (ie, detection of ovulation and/or serum hormone analysis) has been underutilized in favor of calendar-based counting methods.[23] This approach leads to inconsistencies in the identification of MC phases and the unintentional inclusion of participants with abnormal hormonal profiles.[21] Second, most studies examining the effect of the MC on sleep compared healthy controls to a unique group of interest (eg, severe menstrual pain, perimenopausal or postmenopausal).[12] Sleep in athletes is influenced by various athlete-specific factors, such as

Hrozanova https://orcid.org/0000-0002-1309-489X
Sandbakk https://orcid.org/0000-0002-9014-5152
Osborne https://orcid.org/0000-0001-8681-8521
Noordhof https://orcid.org/0000-0002-1630-4696
Taylor (madison.taylor@uit.no) is corresponding author, https://orcid.org/0009-0000-4241-3004

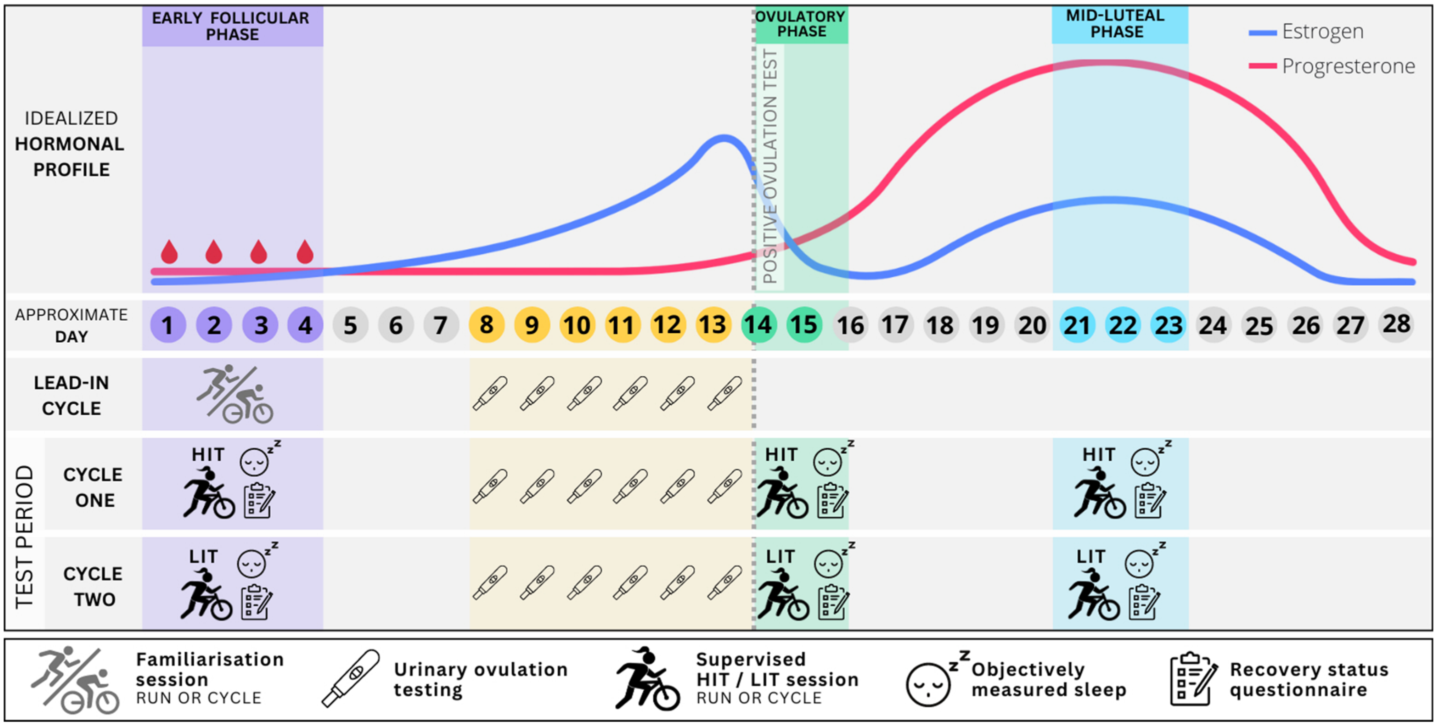

Figure 1 — Illustration of study design. HIT indicates high-intensity training; LIT, low-intensity training.

high training loads, early morning/late night training, and mental strain,[15,24,25] precluding the generalizability and comparability of sleep outcomes from the general population with athletic populations. Finally, higher daily training loads have been shown to negatively influence recovery status in athletes, indicated through changes in sleep quality, mood, muscle soreness, and fatigue.[4,24] However, it remains unclear whether this relationship is further moderated by exercise intensity and/or the MC.

To address the current gaps in the literature, the present study utilized a validated at-home sleep monitor and self-report questionnaires to assess sleep and perceived recovery status in 3 MC phases (EFP, OP, and MLP) following a standardized high-intensity training (HIT) or low-intensity training (LIT) session. The aim was to investigate the influence of MC phase on objectively measured sleep and perceived recovery status following HIT and LIT in eumenorrheic endurance-trained women.

Methods

Participants

Naturally menstruating, endurance-trained women were recruited through sporting organizations, clubs, and social media. The inclusion criteria were (1) reported having a regular MC (cycle length between 21 and 35 d),[21] (2) had not used hormonal contraceptives for at least 3 months prior to enrollment,[21] (3) aged 17 to 40 years. In order to attract trained individuals with stable training loads, the following criteria were included, (4) trained in an endurance sport ≥ 5 hours per week, and (5) performed ≥ 1 HIT session per week, for the past 3 months. Participants were ineligible to participate if there was evidence of a menstrual disturbance, injury, illness, or had given birth within the past 12 months.[21]

Of the 23 participants that enrolled, 15 were included in the final analyses (Figure 2). Participants were classified as trained (tier 2, n = 11) and highly trained (tier 3, n = 4).[26] The mean (SD) age, body mass, and peak oxygen uptake (VO_2peak) of the participants were 32 (5) years, 62 (7) kg, and 54.8 (5.2) mL·kg^{-1}·min^{-1}, respectively.

Study Design

During the lead-in period, participants tracked menstrual function for up to 2 MCs and completed a familiarization session in the laboratory. The test-period was conducted across 2 MCs. Participants visited the laboratory during the EFP (days 1–4 of the MC), OP (within 36 h of a positive ovulation test,) and MLP (7–9 d following a positive ovulation test) to complete a supervised HIT or a LIT session. A counterbalanced, cross-over design was used, in which participants completed one MC of either HIT or LIT testing before moving on to the other session type in the second cycle (Figure 1). Exercise modality (running, n = 13, or cycling, n = 2) was self-selected upon enrollment and maintained throughout the test period. Following each session, overnight sleep was recorded with a Somnofy sleep monitor (Somnofy SM-100 Research Edition, Vitalthings AS) and perceived recovery status was reported via the Recovery Status Questionnaire 24-hour postsession (Figure 3).

The present study was part of the Female Endurance Athlete (FENDURA) project. The study was preapproved by the Norwegian Social Science Data Services (NSD, 955558) and performed according to institutional ethical requirements. All participants were given written information about the study and provided written informed consent before the start of the study.

MC-Phase Determination

MC phases were determined and verified using the 3-step method,[27] including calendar-based counting, detection of ovulation using a urinary ovulation kit (Clearblue Digital Ovulation Test,

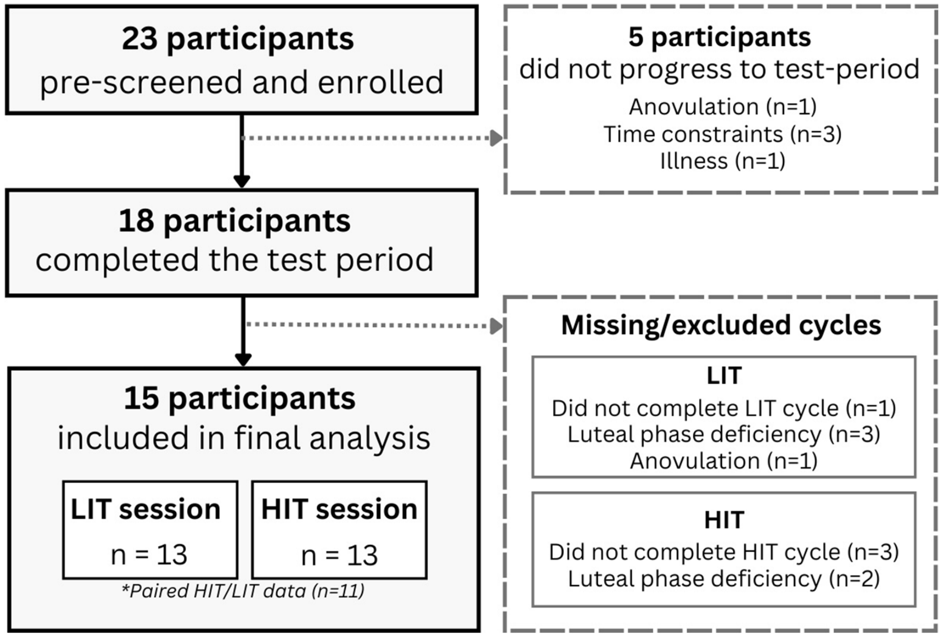

Figure 2 — Participant-inclusion flow chart. HIT indicates high-intensity training; LIT, low-intensity training.

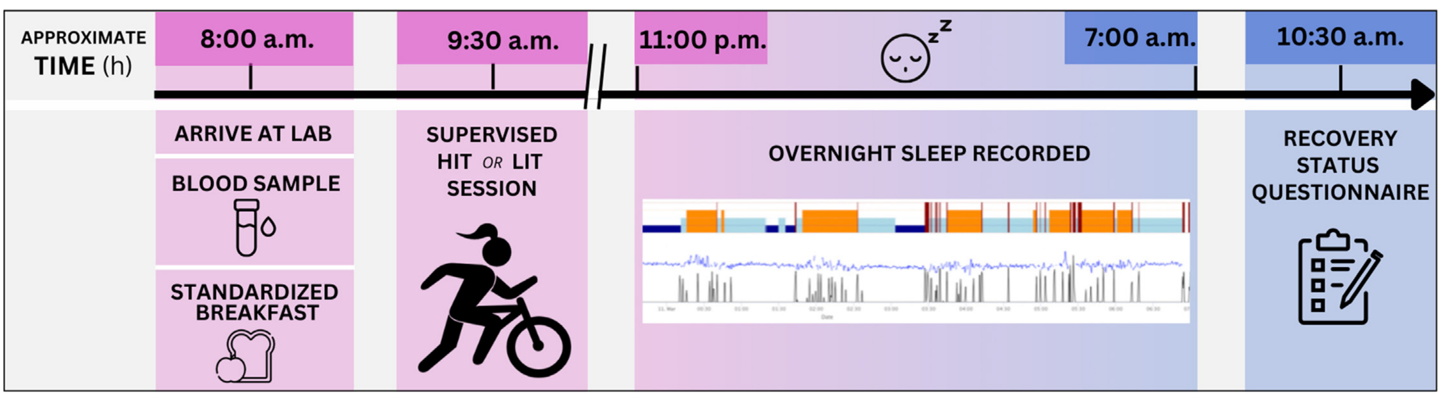

Figure 3 — Illustration of test-day protocols. HIT indicates high-intensity training; LIT, low-intensity training.

SPD Swiss Precision Diagnostics GmbH), and serum hormone sampling on each test day.

Menstrual disturbances were defined as: (1) oligomenorrhea, that is, MC length > 35 days and < 90 days; (2) anovulation, that is, no ovulation detected by the urinary ovulation test; and (3) luteal phase deficiency, that is, progesterone concentration below 16 nmol·L^{-1} in the MLP.[21] Participants presenting with repeated anovulatory cycles during the lead-in period did not progress to the test period. MCs identified with a menstrual disturbance during the test period were retrospectively excluded from the analysis.

Familiarization Session

During the EFP of the lead-in cycle, participants completed a maximal incremental test to exhaustion in the laboratory either while running on a treadmill (Woodway PPS Med 55) or cycling on a cycle ergometer (Lode Sport Excalibur). The running protocol started at 6.0 km·h^{-1} and an incline of 5%, with speed increments of 1 km·h^{-1} each minute until exhaustion. The cycling protocol started at 150 W and increased by 20 W each minute until exhaustion. The average intensity (velocity or power output) during the final minute of the incremental test (iVO$_2$peak) was used to calculate individualized exercise intensities for HIT and LIT. VO$_2$peak was defined as the highest average 30-second VO$_2$ measurement using a moving average filter.

Test Day

Participants were instructed to avoid HIT and consume an individualized high-carbohydrate diet consisting of 8 g of carbohydrate per kg body weight[28] during the 24 hours preceding each test. On each test day, participants arrived at the laboratory between 6:00 and 10:00 AM in a fasted state. A venous blood sample was drawn, and participants were provided with a standardized breakfast (2 g carbohydrate per kilogram body mass).

HIT started with a 15-minute incremental warm up (3 min at 35%, 5 min at 45%, 5 min at 60%, and 2 min at 40% of iVO$_2$peak) followed by 5 high-intensity interval blocks (4 min at 80% iVO$_2$peak and 2 min at 40% iVO$_2$peak) and concluded with a 10-minute cool down (5 min at 60% and 5 min at 35% of $i\text{VO}_2$peak). LIT started with a 13-minute incremental warm up (3 min at 35%, 5 min at 45%, and 5 min at 60% of $i\text{VO}_2$peak), followed by 3 low-intensity running blocks (3 min at 50% of $i\text{VO}_2$peak, 3 min at 45% $i\text{VO}_2$peak, and 7 min at 55% of $i\text{VO}_2$peak), or 5 low-intensity cycling blocks (3 min at 50% of $i\text{VO}_2$peak 3 min at 45% $i\text{VO}_2$peak, and 8 min at 55% of $i\text{VO}_2$peak) and concluded with an 8-minute cool down (5 min at 60% and 3 min at 35% of $i\text{VO}_2$peak). Sessions were modeled from typical LIT and HIT sessions used in sport practice.[29]

Following the training session, participants were instructed to avoid further training and/or specific recovery strategies (ie, stretching, massage, etc) for the subsequent 24 hours.

Sleep Monitoring

Overnight sleep was recorded with a Somnofy sleep monitor on the evening of each test day. Somnofy is a noncontact sleep monitor based on impulse radio ultra-wideband (IR-UWB) radar. It has previously been validated against polysomnography and showed substantial agreement (Cohen kappa coefficient of .63) in detecting sleep/wake and sleep stages in healthy adults.[30] Variables investigated in the current study are described in Table 1.

Recovery Status Questionnaire

Twenty-four hours after each training session, participants completed a recovery status questionnaire composed of the Perceived Recovery Status Scale,[31] and the Hooper Scale,[32] in the participants' native language (English or Norwegian). The former is a single-item questionnaire recording perceived recovery status on a scale of 0 (very poorly recovered/extremely tired) to 10 (very well recovered/highly energetic), validated for assessment of perceived next-day recovery following exercise.[31] The latter consisted of 4 items (sleep quality, fatigue, stress, and muscle soreness) ranked on a scale of 0 (very poor) to 7 (very good), which has been shown to be a stable and reliable tool to monitor fatigue and training load in athletes.[33,34]

Table 1 Description of Sleep Variables Collected With the Somnofy Sleep Monitor

Sleep variable	Unit	Description
Sleep/wake variables		
Sleep onset latency	h	Time from lights off to sleep onset in any sleep stage
Total sleep time	h	Total sleep time achieved during the night
Wake after sleep onset	h	Time spent awake during the night
Sleep stages		
Light sleep	%	Percentage of total sleep time in light stages of sleep
Deep sleep	%	Percentage of total sleep time in deep stages of sleep
REM sleep	%	Percentage of total sleep time in REM sleep
Sleep quality		
Sleep efficiency	%	The percentage of time from sleep onset to wake-up that was spent asleep

Abbreviation: REM, rapid eye movement. Note: Sleep stages are analyzed as percentages in order to account for the influence of total sleep time on the time spent in the different stages of sleep.

Blood-Sampling Procedures and Analysis

A venous blood sample was drawn from an antecubital venipuncture on the morning of each test day. The sample was left to clot for 30 minutes, centrifuged, and the serum was separated, and stored at −80°C until analysis. The samples were analyzed for estradiol, progesterone, follicle-stimulating hormone and luteinizing hormone using liquid chromatography-tandem mass spectrometry at the University Hospital of Northern Norway, Tromsø, Norway (ISO/IEC 15189).

Data Compliance

Each of the 15 participants attended up to 6 test days, one in each of the 3 MC phases following a LIT and a HIT training session, respectively. From the 90 possible test days, 27 days (30%) were retrospectively excluded (see Figure 2 for details), resulting in a total of 63 days included in the final analysis. Overall compliance for nights of recorded sleep and response to individual items on the recovery status questionnaire was 81% and 89%, respectively. Missing data were assumed to occur at random.

Equity, Diversity, and Inclusion Statement

Only biological females were included in this study. Women from diverse cultural and socioeconomic backgrounds were welcome to participate. Authors from a variety of career stages were included, of which the first and last authors are women.

Statistical Analysis

Data were analyzed using linear mixed effects regression models. The association between the dependent (sleep/recovery) and independent variables (MC phase/session type) was modeled with a random intercept for participant and MC phase nested within participant. Models included MC phase (levels: EFP; OP; MLP), session type (levels: LIT; HIT), and their interaction (MC phase by session type) as fixed factors. The alpha level was set at .05. Significant main effects were investigated using pairwise comparisons with a Tukey correction. Unless otherwise stated, results are presented as estimated marginal means with 95% confidence intervals (CIs), followed by *P* values. Effect sizes were estimated using marginal R^2 (ie, effects explained by fixed factors; mR^2) and Cohen *d*.[35] The sigma used for calculating Cohen *d* was the square root of pooled random variance. Cohen *d* values were interpreted as; small ($d = 0.20$–0.49), medium ($d = 0.50$–0.79), and large ($d \geq 0.80$).[36] For analyses with singular fit (light sleep and sleep efficiency), Cohen *d* was not reported.

All statistical analyses were performed using R in RStudio,[37] with the packages "lme4" (version 1.1-29), "emmeans" (version 1.8.4-1) and "ggplot2" (version 3.3.6), and "JWileymisc" (version 1.4.1).

Results

MC Characteristics

Menstrual disturbances were observed in 26% of the recorded MCs (Figure 2). Thus, 26 eumenorrheic MCs with 63 phase-specific test days were included in the analysis (EFP = 21, OP = 19, MLP = 23). MC length ranged from 25 to 33 days (mean [SD]: 28 [2]) and the day of ovulation ranged from day 9 to 21 (mean [SD]: 14 [3]). Serum hormone concentrations were reflective of eumenorrheic MCs and are presented in Table 2.

Table 2 Serum Concentrations of Ovarian Hormones in 3 Phases of the Menstrual Cycle

Hormone	Early follicular phase	Ovulatory phase	Midluteal phase
Estradiol, pmol·L^{-1}	127 (92–176)	365 (251–510)	544 (610–677)
Progesterone, nmol·L^{-1}	0.4 (0.3–0.7)	3.6 (2.5–9.6)	41.8 (28.8–51.5)
Luteinizing hormone, IU·L^{-1}	5.9 (5.2–7.1)	15.4 (8.9–17.6)	7.1 (3.6–10.0)
Follicle-stimulating hormone, IU·L^{-1}	5.7 (4.2–6.8)	6.2 (5.6–7.9)	3.4 (2.3–4.2)

Note: Values are presented as median and interquartile ranges.

MC Phase

A main effect of MC phase on wake after sleep onset ($P < .001$, $mR^2 = 19\%$) was observed. In MLP, wake after sleep onset was 34 minutes (95% CI, 26–43 min), representing a 12 min (95% CI, 24–0.3 min) increase from EFP ($P = .043$, $d = 0.3$) and a 19 min (95% CI, 31–7 min) increase from OP ($P = .001$, $d = 0.5$). There was a main effect of MC phase on light sleep ($P = .023$, $mR^2 = 13\%$). Light sleep was 54.1% (95% CI, 51.2%–57.0%) in EFP and increased by 5.1% (95% CI, 10.0%–0.3%) in MLP ($P = .037$).

There was a main effect of MC phase on deep sleep ($P = .045$, $mR^2 = 8\%$), although no significant differences were found in pairwise comparisons. Lastly, there was a main effect of MC phase on sleep efficiency ($P = .033$, $mR^2 = 7\%$). Sleep efficiency was 90.1% (95% CI, 86.8%–93.3%) in OP and decreased by 3.5% (95% CI, 0.04%–7.02%) in MLP ($P = .047$). Total sleep time remained stable across MC phases ($P = .966$), with an average of 7.6 hours (95% CI, 7.4–7.8 h). MC phase had no significant effect on any of the recovery status questionnaire variables.

Session Type

A main effect of session type (HIT/LIT) on perceived recovery ($P < .001$, $mR^2 = 34\%$) and perceived muscle soreness ($P = .007$, $mR^2 = 15.0\%$) was observed. Perceived recovery was 7.8 points (95% CI, 7.2–8.3 points) following LIT and 1.3 points (95% CI, 0.6–1.9 points) lower following HIT ($P < .001$, $d = -1.0$). Perceived muscle soreness was 5.8 points (95% CI, 5.3–6.2 points) following LIT and 0.8 points (95% CI, 0.1–1.4 points) higher following HIT ($P = .018$, $d = 0.6$). There were no significant effects of session type on any of the objective sleep variables, perceived sleep quality, fatigue, or stress.

No interactions between MC phase and session type were observed for any of the reported variables. Individual data points and group means are presented by main effect in Figure 4. Figures of the interaction models can be found in the Supplementary Material (available online).

Discussion

This study investigated the influence of MC phase on objectively measured sleep and perceived recovery status following 2 commonly practiced session types (HIT and LIT) in endurance-trained women. The main findings were (1) sleep was impaired following exercise in MLP, indicated by more time awake after sleep onset in MLP compared with EFP and OP, lower sleep efficiency in MLP compared with EFP and a greater proportion of light sleep in MLP compared with OP; (2) none of the perceived recovery status items were influenced by MC phase, but perceived recovery was impaired following HIT compared with LIT along with more perceived muscle soreness; and (3) the effects of MC phase on sleep and recovery were not modulated by session type.

The findings that MC phase affected the objective characteristics of sleep are consistent with previous studies in nonathletic groups which have shown similar patterns of more time awake after sleep onset, lower sleep efficiency, and more light sleep in the luteal phase compared with the follicular phase.[10,12,13,38,39] During the luteal phase, the rise in progesterone triggers an increase in core body temperature which has direct and indirect effects on the regulation of sleep.[40] For instance, elevated core body temperature in the luteal phase has been linked to increased sleep fragmentation,[40] which may be further exaggerated by steeper increases in progesterone from the follicular to the luteal phase.[41] Additionally, estrogen and progesterone receptors are localized in many sleep-regulatory centers in the brain which directly influence multiple aspects of the sleep/wake cycle.[13,42] In the current study, the most pronounced phase-based sleep disruption was attributed to increases in wake after sleep onset from EFP (22 min) and OP (15 min) to MLP (34 min). The variation between EFP and MLP is consistent with what has been found in untrained populations (~+40%).[10,43] While midsleep awakenings are a normal part of the sleep cycle, >20 minutes awake after sleep onset is indicative of impaired sleep quality.[44] Beyond this finding, the other objective sleep variables (ie, total sleep time, sleep efficiency, and sleep stages) remained within the recommendations for "good sleep quality"[44] across the recorded phases. Particularly when compared with patients with sleep/wake disorders[45] or even in athletes as a result of early-morning training sessions,[46] the magnitude of the sleep alterations between MC phases was quite modest. Thus, it remains unclear whether these sleep alterations would affect performance and/or long-term athletic development.

The results of the current study contradict Hrozanova et al[7] who reported reduced sleep efficiency during the follicular phase compared to the luteal phase, along with more time in bed and less light sleep during the bleeding compared with nonbleeding days in a group of junior endurance athletes. They proposed that the sleep impairments could be related to a higher prevalence of MC symptoms during the bleeding days of the cycle. Indeed, MC symptoms, such as abdominal cramping, headaches, and stress have been shown to negatively affect perceived sleep quality[47]; however, associations with objective sleep variables have not been established.[10] It is likely that the relationship between MC symptoms and sleep is independent of MC phase, since various symptom patterns are possible within a group of individuals.[47] That is to say, experiencing abdominal cramping would reduce perceived sleep quality regardless of when during the MC these symptoms occur. Thus, further research is certainly required in this area. Finally, the aforementioned study[7] used calendar-based counting to establish MC phases, which introduces some uncertainty into the phase-based comparisons since neither ovulation nor hormonal concentrations were confirmed.[21] Since exercising women have a high prevalence of subtle menstrual disturbances (ie, anovulation),[48] and thus abnormal hormonal profiles, it is difficult to compare findings across studies.

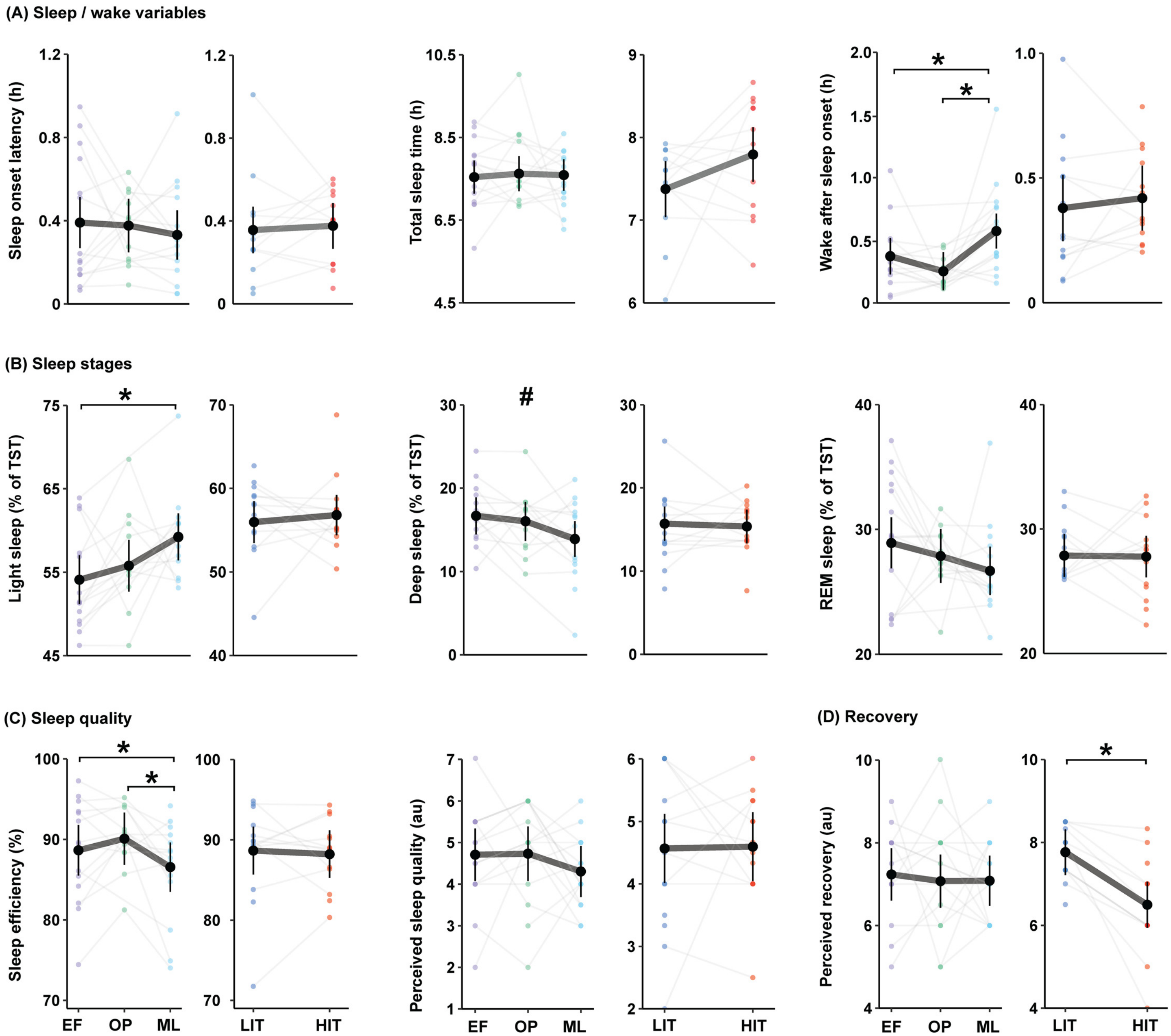

Figure 4 — The effect of MC phase and exercise intensity on (A) sleep/wake variables, (B) sleep stages, (C) sleep quality, and (D) perceived recovery. Data represent objective sleep and perceived recovery data of 15 endurance-trained females in EF, OP and ML, and following standardized LIT and HIT sessions. Black dots connected by gray thick lines represent the estimated marginal means, and error bars indicate 95% CIs. Individual data points are connected by thin lines. *Significant difference between given pairs; significant main effect of MC phase. EF indicates early follicular phase; HIT, high-intensity training; LIT, low-intensity training; MC, menstrual cycle; ML, midluteal phase; OP, ovulatory phase; TST, total sleep time.

Despite the observed changes in the objective sleep variables, perceived sleep quality and the other perceived recovery parameters did not differ between MC phases in the current study. The mismatch between objective and perceived sleep quality outcomes is well documented in the literature,[11,43,49] and may be attributed to the way perceived sleep is conceptualized. As such, an individual's perceived sleep quality rating is likely to reflect elements related to sleep and nonsleep phenomena (ie, stress, mood, or pain). Likewise, individuals reporting on perceived sleep quality ratings may disproportionately emphasize specific aspects of their sleep (ie, inability to fall asleep vs time spent awake).[49] To date, there is little consistency in the literature regarding the effect of the MC on perceived sleep quality. Studies in untrained women have reported lower subjective sleep quality preceding menstruation, during menstruation and midcycle,[9,47] or no effect,[11] while a study in trained women showed a small reduction in perceived sleep quality during the MLP compared to other phases.[16] The discrepancy across studies could be a result of different methodological approaches, such as the timepoints when data was collected, verification of MC phase, and participant group characteristics. Nevertheless, perceived sleep quality has been associated with changes in stress, fatigue, perceived recovery, and mood in athletic groups,[50,51] and remains a distinct and valuable indicator of sleep and recovery for athletic monitoring.

No changes in perceived sleep quality, fatigue, or stress following either session type (HIT/LIT) were observed in the current study; however, participants reported feeling less recovered, and having more perceived muscle soreness following HIT sessions compared with LIT sessions. The influence of HIT on recovery status could be mediated by the effect of HIT on exercise-induced muscle damage.[52] Session type did not influence any of the objectively measured sleep parameters or perceived sleep quality. While physical activity is generally considered to be beneficial to sleep, the relationship is moderated by factors such as sex, fitness level, and the characteristics and timing of exercise.[24] The participants in the current group were regularly performing HIT sessions prior to the study period, and the training sessions were always performed in the morning, so possibly the stimulus was not strong enough to induce changes in sleep quality. Interestingly, no interaction effects were found for MC phase and session type. Thus, it appears that session type does not specifically influence the potential for recovery following exercise in the different phases of the MC, rather both exert independent effects on the assessed variables.

Strengths and Limitations

This study utilized gold standard methodology to determine and verify MC phases.[27] This led to the identification and exclusion of multiple abnormal MCs (~25%) which would otherwise be included if simpler MC phase verification methods were used. Women presenting with menstrual disorders are more likely to suffer from sleep disturbances,[12] so the use of high-quality methodology is especially important when undertaking such studies. Additionally, the participant group was well trained, and HIT and LIT sessions are widely used for training purposes in a variety of endurance sports, making the outcomes of this study practically relevant.

We acknowledge that the study also has some limitations. The current study design focused only on 3 predefined phases of the MC. This design does not account for the broader changes that may occur throughout the MC. Furthermore, we defined perceived sleep quality based on a single-item response, which cannot discretely reflect the nuances of sleep quality, such as difficulty falling asleep versus difficulty staying asleep. However, this is a commonly used metric in sleep and training diaries, and has been shown to correlate well with multiple indices of objective sleep[49] and recovery status.[50] Lastly, the sample size was low and may not have sufficient statistical power to identify small between-phase differences, such as the effect of MC phase on deep sleep.

Practical Applications

Short-term consequences of reduced sleep quality include increased stress, mood disturbances, and daytime exhaustion.[53,54] Thus, while minor, the observed impairments to sleep in the MLP may warrant additional considerations around sleep hygiene and behaviors during the latter half of the MC. For instance, avoiding caffeine intake within 9 hours of scheduled bedtime, reducing evening screen time, and keeping the bedroom cool have all been shown to positively influence sleep quality.[55] Concurrently, recovery times following HIT sessions may be adjusted to accommodate deviations in perceived recovery and muscle soreness, possibly preventing accumulation of fatigue.[3] In a research setting, researchers should consider whether and how MC-related changes in sleep may influence their study design and outcomes. Future studies should consider including measurements in the late luteal phase, as well as objective and subjective sleep measurements over several days within each phase to further uncover the nuances of how the MC influences sleep quality in exercising women.

Conclusions

The current study revealed an effect of menstrual-cycle (MC) phase on objectively measured sleep, with indications of impaired sleep in the midluteal phase. However, the magnitude of the sleep alterations was modest, so it remains unclear whether these changes would practically influence training adaptations and/or performance. Perceived recovery was influenced by session type but not MC phase, suggesting that athletes and coaches can schedule training sessions without concern for MC-phase-related variations in perceived recovery and, rather, plan according to logistical convenience. Additional research should investigate whether sleep and perceived recovery measures also follow similar patterns in athletes with abnormal MCs or in those using hormonal contraceptives.

Acknowledgments

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