Interaction of Sleep and Emotion Across the Menstrual Cycle

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Abstract

Menstruating individuals experience increased risk for sleep and affective disorders, attributed in part to monthly oscillations in sex hormones. Emotional functioning and sleep continuity worsens during the perimenstrual phase of the menstrual cycle. This study examined the interactive effects of sleep, menstrual phase, and emotion in healthy women. Participants (N=51, 43% Caucasian) aged 18-35 (*m*=24 years) completed actigraphy and daily sleep/emotion diaries over two menstrual cycles (*m* days=51.29). Diary and actigraphic total wake time at night (TWT) and daily ratings of positive and negative affect were compared across four phases of the menstrual cycle: perimenstrual, mid-follicular, periovulatory, and mid-luteal. Relationships between phase, sleep, and emotion were estimated using multistep hierarchical linear modeling. Mean menstrual cycle length was 28.61±2.69 days. Perimenstrual phase positively predicted anger (p<.001) but no other emotions. Additionally, perimenstrual phase predicted higher rates of TWT, such that diary TWT was 8-16 minutes longer during the perimenstrual (*m*=67.54, *SE*=3.37) compared to other phases (p<.001). Actigraphic TWT was also increased by 4-7 minutes (*m*=61.54, *SE*=3.37) in the perimenstrual phase (p<.001). Positive emotions were .05-.10 points lower (*p's*=.006-.02) when TWT was greater in the perimenstrual phase. Greater rates of anger and sleep disruption are seen during the perimenstrual phase compared to other phases. When poor sleep occurred during the perimenstrual phase individuals reported reduced positive emotions. Reducing perimenstrual sleep disruptions may be an important intervention target for those at risk for affective disorders.

Keywords: menstrual cycle, sleep, emotion, luteal phase, actigraphy

Introduction

Sex differences in affective disorders emerge after pubertal onset, attributed in part to the complex interactions of neuroendocrine changes associated with sexual maturation (Conley et al. 2012). Affective risk can be defined (in part) by disruptions across several domains of emotional processing. Disruptions in these systems, such as increased negative emotions, decreased positive emotions, and maladaptive emotion regulation (e.g., reactivity, rumination) may provide transdiagnostic mechanisms that contribute to and maintain affective disorders. Yet, sex-based study of these mechanisms is lacking, and the contribution of menstrual phase to these processes is not well understood.

In healthy females, puberty initiates monthly cyclic changes in the production of various hormones, including estrogen and progesterone. During the first half of the cycle (roughly the first two weeks), the follicular phase, estrogen predominates and initiates the rise in other hormones (follicle stimulating hormone (FSH) and luteinizing hormone (LH)), which induce ovulation and the transition into the luteal phase. During the luteal phase (the final two weeks of the cycle), progesterone predominates and combined with estrogen, thickens the uterine lining to support implantation of the egg, should fertilization occur. If it does not, hormone levels decline, and the uterus sheds its lining through menses (Knudtson and McLaughlin 2017).

The late luteal and early follicular phases, collectively termed the perimenstrual period, and encapsulating the final 3 days of one cycle and the first 3 days of the next, are associated with the greatest changes in emotion. Roughly 1 in 5 women report at least mild mood changes during this phase (Wittchen et al. 2002) which are observable at a neural level, as estrogen and progesterone receptors are distributed in great numbers in the emotion-based structures of the amygdala, hippocampus, and hypothalamus (Osterlund et al. 2000; Guerra-Araiza et al. 2003). As such, neuroimaging studies indicate menstrual-related changes in areas of the brain known to affect response to emotional stimuli and reward, as well as cognitive control of emotion (Sacher et al. 2013). Although these complex relationships are poorly understood, evidence suggests estrogen has positive effects on mood and cognition (Comasco et al. 2014). Conversely, progesterone is associated with more negative mood, e.g., irritability and depression (Lundin et al. 2017a).

The emotional changes during the perimenstrual phase follow the sharp increase and decline of progesterone at the end of the luteal phase, typically carrying over into the early follicular phase (menses) (Romans et al. 2012a; Nevatte et al. 2013).

Disruptions in emotional reactivity are common across all affective disorders and are often reported in the perimenstrual phase. Those with depression exhibit altered affective reactivity in response to daily stressors. In fact, negative emotional reactivity is predictive of depressive symptomatology (Cohen et al. 2005). Women have greater difficulty regulating their emotional responses during the perimenstrual phase (Lusk et al. 2017a) and exhibit increased physiological reactivity to stress (Liu et al. 2017a). Increased negative affect during this phase is therefore common. Although changes in positive affect have received little empirical attention (Romans et al. 2012b) the lowest levels are typically observed in the perimenstrual phase (Liu et al. 2017a).

In addition to changes in emotional outcomes, sleep changes are also common in the perimenstrual phase and may provide another mechanism for increased female risk of affective disorders. At least one third of women report sleep disruptions specifically related to their menstrual cycle (NSF 2007). Sleep quality decreases and sleep disturbances increase during the perimenstrual phase (Kravitz et al. 2005; Baker and Driver 2007; Romans et al. 2015; Baker and Lee 2018). These subjective sleep complaints mirror objective findings showing decreased sleep efficiency and total sleep time just prior to menses (Sharkey et al. 2014; Zheng et al. 2015). Sleep disruptions may be hormonally driven, as sleep efficiency is positively associated with estrogen and negatively associated with progesterone (Li et al. 2015). Increased progesterone is thought to initiate a rise in core body temperature, disrupting sleep (Sharkey et al. 2014). However, research examining these complex relationships has primarily focused on mid- to late-reproductive aged women (i.e., menopausal) and/or those with severe premenstrual symptoms (e.g., premenstrual dysphoric disorder). The relationship between sleep and menstrual phase in healthy, reproductive-aged adults is less understood, particularly within the context of emotional changes and affective risk. Impaired or misaligned circadian dynamics also represent a robust risk factor for depression. An ‘eveningness chronotype,’ or preference for later bed and wake times that are misaligned with natural

light-dark cycles significantly increases lifetime affective risk (Merikanto et al. 2016). More women than men endorse an eveningness chronotype (Duarte et al. 2014) which is associated with greater mood fluctuations and depressive symptoms (Jeong et al. 2015). There is also consistent evidence for alteration in the functioning of circadian rhythmicity during the perimenstrual phase, suggesting an interaction between the circadian system, sleep disruption, and the menstrual cycle.

Better understanding of the inter-relationships between sleep, emotion, and menstrual phase holds promise for improving prevention and treatment efforts of affective disorders because reciprocal links between poor sleep and mental health problems are also well-established. Sleep disruption is a core symptom of affective disorders and predicts treatment non-response (Harvey et al. 2013), and insomnia also represents one of the most robust predictors of future depression (Baglioni et al. 2011). These pervasive relationships are theorized to be rooted in the shared neurobiology of sleep and emotional processing (Yoo et al. 2007) as emotional reactivity to both positive and negative stimuli is amplified after sleep deprivation (Gujar et al. 2011) due to enhanced reactivity in the mesolimbic reward brain network, giving way to general instability in emotion regulation (Tempesta et al. 2018). There is therefore significant overlap in the neural mechanisms affecting both sleep regulation and emotional processing. Thus, delineating relationships between sleep and emotional responding across menstrual phases represents an important step towards better understanding the sex differences underpinning risk for affective disorders.

The aim of this study therefore was to evaluate the interaction of subjective (sleep diary) and objective (actigraphy) sleep continuity variables and a woman's subjective experience of positive and negative emotions across the menstrual cycle. We hypothesized that sleep parameters would be more disrupted during the perimenstrual phase and that greater levels of sleep disruption would coincide with higher levels of negative emotion and lower positive emotion during the perimenstrual phase.

Method

This prospective study evaluated how night-to-night sleep patterns influence aspects of emotion across the menstrual cycle. Utilizing ecological momentary assessment (EMA) methodology, reproductive-aged

women completed daily self-reports on their sleep and emotion measures and wore actigraphy to track sleep across two menstrual months. EMA, involving multiple assessments over multiple days, is well suited to explore these transitory variables by providing real-time data in the context of a participant's everyday life. Despite being considered the gold standard approach to menstrual cycle research, time series data collection methods have rarely been employed in the study of the menstrual cycle (Romans et al. 2012b; Schmalenberger et al. 2021) and therefore represent a particular strength of this study design. Importantly, as data collection occurred during the COVID-19 pandemic, we additionally controlled for pandemic-related stress within analyses.

Participants & Recruitment

Biological females aged 18-35 were recruited from web advertisements targeting the local community and a research participant pool of undergraduate psychology students. Inclusion criteria included: 1) regular menstruation, with cycle length of 24-35 days and self-reported month-to-month cycle variability of no more than 7 days within the last 6 months and during the study period (to increase the likelihood of identifying ovulatory cycles (Baker and Driver 2004; Sharkey et al. 2014); 2) body mass index (BMI) of 18-30; 3) no use of hormonal contraceptives within the last 3 months, including oral medications or devices (i.e., IUD, implant, ring, patch, etc.); and 3) smartphone user (to allow for EMA data collection). Exclusion criteria included: 1) DSM-5 criteria of Premenstrual Dysphoric Disorder (PMDD) met or provisionally met; 2) the presence of any reproductive health disorders (i.e., polycystic ovarian syndrome, uterine fibroids, or endometriosis); 3) current or recent suicidality; 4) substance use disorders; 5) pregnancy or trying to conceive; and 6) shift work. A total of 466 individuals responded to recruitment advertisements, of those, 98 met eligibility requirements based on initial screening measures, and a total of 64 participants were determined eligible to participate after a baseline assessment. Four participants dropped out before beginning data collection and data from nine participants who completed the study were removed from the analyses due to observed cycle duration greater than 35 days or cycle variability >7 days (eight participants) or invalid data (one participant) for a final sample of 51 participants.

Measures

Participant Characteristics and Covariates. Participants completed several questionnaires to establish eligibility and provide information on menstrual health, sleep, and emotion characteristics. Menstrual health measures included self-reported date of most recent menstrual bleeding, cycle length variability, somatic/cognitive symptoms, and history reproductive disorders. Baseline measures of sleep and emotional health were collected, but not used in analysis for the current study.

Data were collected between May 2020 and January 2021, beginning just as local mandatory stay-at-home orders were lifting. Quantitative measures were collected to examine the potential influence of the pandemic on outcomes of interest. First, the John's Hopkins report of total global and US COVID-19 case and deaths as well as a local measure of case reports were used (www.ReadyHarris.org) to account for the dynamic and time-varying nature of the pandemic's evolvement over time. Several items from the measures described by Jones and Salathé (2009), were used to provide self-reported risk perception, COVID-related anxiety levels and ability to avoid infection (Jones and Salathé 2009). Finally, individuals were asked at baseline and upon study end if they had been tested for, and/or received a positive test for COVID-19, as well as the number of their family and/or friends diagnosed with COVID-19. One individual tested positive for COVID-19 during her participation. She reported only mild symptoms and was not hospitalized. Nevertheless, data from the dates she reported symptoms were excluded from these analyses.

Menstrual Characteristics. Participants completed the Modified Moos Menstrual Distress Questionnaire (MDQ) (Ross et al. 2003) at baseline to characterize typical menstrual symptoms. Participants were asked to report on their experience of 34 symptoms during the perimenstrual phase of the most recent menstrual cycle. Each symptom was assessed on a 4-point Likert scale (*no experience of the symptom* to *present, severe*). Six symptom clusters were assessed: negative affect, cognitive symptoms, fluid retention, behavior change, somatic symptoms, and autonomic reactions. A total distress score was computed by summing subscales.

Data were collected across two menstrual months. The decision to collect data across two menstrual months was made to increase confidence in the reliability of cycle-dependent changes while also attempting to keep participant burden as low as possible. Menstrual phase was determined based on the start of menstrual bleeding and timing of a positive urine-based measures of the LH surge (indicative of ovulation). The first day of menses (start of the cycle) and date of a positive urinary ovulation test strip (mid-point of the cycle) were used as anchors in the determination of menstrual phase. A separate study calendar was created for each participant to estimate timing of next menstrual bleeding and ovulation testing window based on self-reported cycle frequency and duration. Menstrual cycles in healthy women can range from 24 to 35 days, with variability driven to a great extent by follicular phase length (LeRoux et al. 2014). Phase timing was estimated by calculating the projected start of the next menstrual cycle and subtracting 14 days to estimate ovulation. Women were provided with ovulation test strips which predict ovulation by measuring the rise in urinary luteinizing hormone (LH), signaling impending ovulation. Participants were instructed to perform the test once a day at any point after the first urination of the day (which could result in a false positive due to typical higher LH levels in the morning hours). Ovulation testing began two days prior to the estimated date of ovulation (calculated based on date of menses onset and typical cycle length) and continued once a day for five days or until a positive test. These dates were then updated upon participant report of menstrual bleeding and a positive ovulation test. Those with month-to-month cycle variability greater than 7 days were excluded from final analysis.

For the purpose of these analyses, each menstrual cycle was coded into four phases: perimenstrual (i.e., late luteal), mid-follicular, periovulatory, and mid-luteal (Schmalenberger et al. 2021). Table 1 provides a description for identifying each menstrual phase.

Sleep. The Morningness/Eveningness Questionnaire (Horne and Ostberg 1976) was administered at baseline and is a 19-item scale assessing preference for circadian preference for morning ("morningness") or evening hours ("eveningness"); lower scores indicate a more evening preference. Reliability in the current sample was good (Cronbach's $\alpha = .77$).

Objective sleep parameters were estimated via wrist actigraphy using the Actiwatch Spectrum Plus (Philips Respironics). Actigraphy is a well-validated objective measure of sleep (Sadeh et al. 1994). Participants were asked to wear the Actiwatch on their nondominant wrist only removing for brief breaks and when swimming. They were also instructed to press an event-marking button each night when they began trying to fall asleep. Data were downloaded and processed in 1-min epochs using the standard medium sensitivity threshold. A combination of sleep diary reports, event markers, and light data (collected from Spectrum Plus device) were used to identify sleep-wake patterns. Variables of interest included total sleep time (TST), total wake time (TWT, calculated as the number of minutes scored as wake between bedtime and rise time), and sleep efficiency (SE; calculated as (TST/[Wake Time–Bedtime])*100). Additionally, mid-sleep point (MSP) was calculated and person-mean centered for each participant as a measure of chronotype.

A Daily Sleep Diary was also collected at the first EMA assessment each day (see below). This included a subjective measure of the above actigraphy variables. To differentiate objective (actigraphy) and subjective (sleep diary) sleep variables, the above acronyms will be followed by the relevant subscript (e.g., TST_{obj} and TST_{sub}, respectively).

Ecological Momentary Assessment of Affect & Emotion Processing. Participants completed brief emotion assessments daily via smartphone app, PACO (Personal Analytics Companion; pacoapp.com). They were alerted to complete assessments via phone application 3 times per day: morning, evening, and once randomly between the morning and evening timepoints (to avoid potential bias in assessment based on time of day). For each alert they provided brief contextual information and current affect. Three Positive (Happy, Calm, Enthusiastic) and negative (Angry, Afraid, Sad) affect variables were rated on a 9-point Likert scale from 1 (*not at all*) to 9 (*very much*)Positive and negative emotions were chosen based on their established relevance to both sleep (Tomaso et al. 2021) and menstrual literature (Romans et al. 2012b; Beddig et al. 2020). The first daily EMA assessment included questions regarding the previous night's sleep and the last EMA assessment asked about menstrual timing (i.e., *Did you menstruate today?* (Yes/No).

Assessments took approximately 90 seconds to complete, and participants had 60 minutes after each alert to provide responses.

Procedure. Study procedures were approved by the university's institutional review board and written informed consent was obtained from all participants. All participants completed a brief online questionnaire assessing inclusion/exclusion criteria. Those meeting eligibility criteria then completed baseline measures via a telephone interview (45-60min) followed by an online survey. Participants then downloaded EMA software onto their cell phones and received a wrist actigraph, Participants completed daily EMA and wore actigraphy for two menstrual months. Data collection began at any point in the menstrual cycle and concluded at the same point in the cycle two cycles later.

Analytic Plan

To account for the time-nested structure of the data within persons and across two menstrual months, the MIXED procedure in SPSS 27.0 was used for multistep hierarchical modeling (HLM). All models were estimated using maximum likelihood estimation. Model fit was determined by change in -2 log likelihood (Δ-2LL) of progressive models against a baseline (null) model, with significant change tested using a chi-square likelihood ratio test. An autoregressive error structure controlled for correlation between errors in repeated measurements (Schwartz and Stone 2007).

To describe changes in and relationships between emotion and sleep (outcome variables) across the monthly menstrual cycle in women, models were built in a series of three steps. *Step one*: the null model (no predictors) allowed for the calculation of interclass correlation coefficient (ICC), which partitions the within-person variance from the between-person variance. *Step two*: this model included the addition of relevant covariates. First, the addition of a Time variable, representing the number of days of participation for each individual (i.e., the first day of data collection for each individual was labeled 1, the next day labeled 2, and so on). The addition of the Time variable controlled for any temporal trends in the data that could create potential confounding time-varying relationships between predictors and emotion (e.g., participant fatigue) beyond the inherent autocorrelation of time series data (Mccrae et al. 2008). Predictors

of pandemic stress were also entered at this step. Time varying covariates relating to COVID-19 stress and anxiety were added at Step Two of the models described above. The addition of these covariates examined the variability accounted for by pandemic-related stress, including daily case counts of COVID-19 (nationally and regionally), COVID-related anxiety and risk perception, and the number of people participants knew personally with a diagnosis of COVID-19, reported at study end. *Step three*, the random intercepts model, added a menstrual phase variable to those described above. Menstrual phase was entered as a categorical predictor (peri-menstrual, mid-follicular, periovulatory, mid-luteal) of emotion and sleep variables, estimating the mean effect across all participants (level 1) and between participants (level 2). *Step Four* then added an interaction term to the models described above. This allowed for the examination of the interactive effects of menstrual phase and sleep on emotion outcomes. This model therefore included menstrual phase, sleep variables (e.g., TWT), and an interaction term (e.g.,TWT*Phase) as predictors for emotion variables. *Step Five* added two time-invariant covariates (chronotype, average MSP) and an interaction term (e.g., Phase*MEQ) to the models as described above to explore individual-level factors that may modify emotion and sleep patterns during each phase of the menstrual cycle.

Results

Mean cycle length among participants was 28.61 days (SD = 2.69). A mean of 51.29 nights of actigraphy (range 22-78, median = 59 days, $n_{reports}$ = 2587, 19% missing) and 59.31 days of EMA data (range 19-87) was recorded. The median EMA response rate was 83%, with 6505 out of 9403 total EMA alerts across all participants completed. Models were fit with maximum likelihood estimation, which is robust to missing data, particularly when missing values relate to the response variables and not the predictor variables, as was the case in these analyses (Anderson et al. 2014). Demographic and menstrual characteristics for the sample are presented in Table 2.

Preliminary Analyses

Analyses were first conducted to identify potential sociodemographic and individual-level variables associated with emotion and sleep. Statistically significant associations were detected between sociodemographic and emotion variables, although effect sizes were small (*r's* ≤ 0.18, η^2s ≤ 0.05; see supplemental Table 1). Significant correlations between emotion variables were also found (see Supplemental Table 2). Correlations among the three positive emotions (happy, enthusiastic, calm) were much higher (*r's* > .50) than those among negative emotions (anger, afraid, sad; *r's* ≤ .41).

With regard to sleep, participant age was significantly associated with TWT_{obj} (r = -.32, p <.001) and SE_{obj} (r =.34, p <.001), such that older participants had shorter objectively measured TWT and higher SE (see Supplemental Table 3). Further, age significantly negatively correlated with MSP (r = -.42, p <.001). Age was therefore included as a covariate in final models.

Distributions were approximately normal for all outcome variables except for negative emotions. Data for negative emotions (angry, afraid, sad) were somewhat positively skewed, indicating a floor effect for these emotions (skewness = 1.39 – 2.65, *SE* = 0.32). Hierarchical linear modeling is generally robust to violations of normality, particularly in the case of predicting fixed effects in large numbers of data points such as ours, therefore, the standard linear mixed model command was used (Bartlett 2014; Schielzeth et al. 2020).

We examined and controlled for relationships between COVID-19 stress and daily measures of emotion and sleep. These variables included two population-level daily case counts: US and region (Harris County and the City of Houston). Individual-level (Level 2) COVID variables included the number of people diagnosed with COVID-19 known personally to the participant, a rating of perceived risk, and COVID-19-related anxiety (all measured at study end). Bivariate correlations are presented in Supplemental Tables 2 and 3. Most COVID-19-related predictors were significantly correlated with emotion and sleep variables; however, these correlations were generally small (*r's* ≤ .18). Nevertheless, each were included in all models as covariates.

Cycle Dependent Variation of Emotion

Positive Emotion. First, the intercept-only (null) model examined the degree to which the variance in positive emotion variables (happy, calm, enthusiastic) differed between women. For each predictor, the intraclass correlation coefficient (ICC), an index of between- and within-person variability, was calculated. The ICCs for positive emotions ranged from .44-.53 (see supplemental Table 4). Thus, 44-53% of the variance in positive emotions was attributable to differences between individuals, indicating HLM is appropriate for these analyses (Shek and Ma 2011).

The random intercepts model added menstrual phase as a predictor of positive emotion variables by allowing the intercept to be random. This allowed for examination of the overall effect of menstrual phase, averaged across all subjects. Menstrual phase was dummy coded with the perimenstrual phase as the reference variable, to which each of the other three phases (mid-follicular, periovulatory, and mid-luteal) was compared. In terms of model fit statistics (change in -2LL), goodness of fit was significantly improved for all models after including menstrual phase, however *F* tests examining menstrual phase as a predictor did not reach statistical significance for any of the positive emotion variables. Results were similar when phase was allowed to vary within participants (random coefficients). Positive emotion therefore did not differ meaningfully across different menstrual phases, nor did it vary significantly within subjects across the menstrual cycle. Supplemental Table 4 shows the model fit results for each progressive model.

Negative Emotion. For negative emotions (angry, afraid, sad), 22-35% of the variance was attributable to differences between individuals. The addition of menstrual phase as a predictor again showed model fit to be significantly improved for all predictors (see Supplemental Table 4), however menstrual phase predicting anger was the only model to reach statistical significance ($F(3,1743.35) = 3.71$, $p = .01$). The regression coefficients relating menstrual phase to anger were negative and statistically significant for the periovulatory phases ($b = -.17$, $p = .006$) and approached significance for the mid-follicular phase ($b = -.10$, $p = .053$), indicating that during these phases, women endorsed anger scores .10 and .17 points lower on average compared to the perimenstrual phase. Table 3 shows the fixed effects of menstrual phase. When phase was allowed to vary within participants (random coefficients), results did not reach statistical significance, indicating these relationships did not vary significantly between participants.

Cycle Dependent Variation of Sleep

To describe changes in objective and subjective sleep across the menstrual cycle, separate models were calculated with menstrual phase as a predictor of sleep variables. Supplemental Table 5 shows the model fit results for each progressive model predicting objective and subjective sleep variables. The ICCs ranged from .15-.38.

Objective Sleep. The addition of menstrual phase significantly improved model fit for all objective sleep models, but only reached statistical significance for Total Wake Time (TWT_{obj}; $F(3,1697.06^{1} = 7.46)$, p <.001) and Sleep Efficiency ($SE_{obj;}$ $F(3,1551.11) = 4.21$), p =.006). For TWT_{obj}, regression coefficients were again negative and statistically significant with significantly greater wake time in the perimenstrual phase than the mid-follicular and mid-luteal phases when measured objectively. During the mid-follicular (b = -6.51, p <.001) and mid-luteal phases (b = -4.43, p = .01), women spent roughly 4-7 fewer minutes in bed awake compared to the perimenstrual phase. Similarly, compared to the perimenstrual phase, sleep efficiency was significantly higher in the mid-luteal phase (b = 1.79, p <.001). Table 4 shows the fixed effects for each subjective and objective sleep outcome variable. The random coefficients model was again nonsignificant indicating these relationships did not vary significantly between participants.

Subjective Sleep. For subjectively-reported sleep variables, menstrual phase significantly predicted TWT_{sub} ($F(3,1831.65) = 5.73$, p <.001), SE_{sub} ($F(3,2077.16 = 5.47$, p <.001), and subjective sleepiness ($F(3,653.67) = 3.15$, p = .02). The regression coefficients were again negative and statistically significant for all phases, indicating that during the perimenstrual phase, women endorsed spending more time awake in the middle of the night (by 8-16 minutes, p's = <.001-.02), a greater proportion of time spent in bed awake (1.3 - 3.2 percentage points, p's = <.001-.04), and feeling sleepier in the morning compared to the periovulatory phase (b = -.43, p =.01). The random coefficients model remained nonsignificant indicating these relationships did not vary significantly between participants.

[1] SPSS computes degrees of freedom (*df*) via Satterthwaite method, therefore *df* are approximate and may not be reported as integers.

Interaction of Sleep and Emotion across the Menstrual Cycle

To examine the combined effects of menstrual phase and sleep on daily emotions, one additional step was added to the models described above. *Step Four* included the addition of sleep variables and their interactions with menstrual phase (random intercept, fixed slope). Predictors were person-mean centered. As seen in Table 5, the interaction between TWT_{obj} and menstrual phase was found to predict levels of happiness ($F(3,2893.04) = 4.14$, $p = .006$), calm ($F(3,2645.40) = 3.42$, $p = .02$), and enthusiasm ($F(3,2658.53) = 3.54$, $p = .01$). In general, these positive emotions were lower when wake time was greater in the perimenstrual phase compared to the mid-follicular and periovulatory phases. No other sleep variables (subjective or objective) interacted with menstrual phase.

Individual-Level Predictors of Emotion and Sleep

To examine individual-level factors as potential moderators of relationships of interest, one final step was added to the models above (*Step Five*). This step added MEQ score as well as the person-level mean MSP to the models and included an interaction term to examine combined effects with menstrual phase. None of these predictors, nor their interaction terms, were found to account for a significant amount of variance above and beyond the findings described above.

Chronotype. The addition of MEQ into the model significantly improved model fit for all sleep variables except TST_{obj} (see fit statistics listed in Supplemental Table 5, step four). MEQ negatively predicted TWT_{obj} ($F(1,36.39) = 9.70$, $p = .004$), however the interaction term was nonsignificant. Therefore, as morningness chronotype increased, objectively measured wake time decreased, and this effect was similar across menstrual phases. A similar effect for SE_{obj} was also found. MEQ scores were positively predicted sleep efficiency ($F(1,37.89) = 10.38$, $p = .003$), but the interaction term for MEQ and menstrual phase was nonsignificant. An interaction was found, however, between menstrual phase and MEQ scores in predicting TST_{sub} ($F(3,1765.92) = 4.09$, $p = .007$). As morningness chronotype increased, self-reported total sleep time was significantly higher in the periovulatory ($b = 1.81$, $p = .01$ and mid-luteal phases ($b = 2.03$, $p < .001$) compared to the perimenstrual phase.

Circadian Timing. The addition of MSP statically improved model fit for all models except TST_{obj} and SE_{obj} (Δ-2LL ranged from 1243 - 13398). The interaction of MSP and menstrual phase reached statistical significance for predicting TST_{sub} only ($F(3,1354.38) = 3.53$, $p = .01$) such that TST_{sub} was statistically shorter for the periovulatory phase compared to the perimenstrual phase ($b = -.005$, $p = .002$).

Discussion

This longitudinal study examined daily reports of sleep and emotion in healthy young women across two consecutive menstrual cycles. Our findings align with previous reports indicating cycle-dependent changes in emotion and sleep as well as their interaction. These findings were robust in the full sample and largely observable independent of individual-level characteristics or the effects of COVID-19-related stress.

Variations in Emotion across the Menstrual Cycle

First, we examined positive and negative emotions by menstrual phase. Anger was the only specific emotion that varied significantly in relation to menstrual phase. Compared to the perimenstrual phase, reports of anger were significantly lower at the cycle midpoint (periovulatory phase). This finding is consistent with a number of studies identifying anger and irritability to be of the most commonly reported symptoms of premenstrual syndrome (Hartlage 2002; Nisar et al. 2008). For example, compared to other menstrual phases, perimenstrual women appear to respond more quickly to negative or stressful situations, have decreased ability to suppress processing of negative stimuli, recognize emotion in others with poorer accuracy, and have enhanced emotional memory; thereby increasing sensitivity to stress (Sundström Poromaa and Gingnell 2014; Lusk et al. 2017b; Liu et al. 2017b; Sundström-Poromaa 2018). Fluctuations in progesterone, such as those seen in the latter half of the menstrual cycle, have been associated with negative mood states such as irritability (Lundin et al. 2017b). Imaging studies also suggest increased reactivity in areas of the brain tied to emotion, i.e., the amygdala, during the perimenstrual phase (Sundström Poromaa and Gingnell 2014) Therefore, during this phase, women experience enhanced

sensitivity to perceptions of threat or biological harm (perhaps as a means by which to protect pregnancy, should fertilization occur) (Conway et al. 2007).

By comparison, higher levels of estrogen (i.e., during the follicular phase) have been found to be protective against the effects of stress on the limbic system. Women may therefore be most vulnerable to the effects of stress when estrogen is lowest, such as during the perimenstrual phase, in turn increasing risk for affective disorders (Albert et al. 2015). This may also be one explanation for the lack of an association between positive emotion and menstrual phase in the current study. Women may be simply more attuned or sensitive to negative rather than positive stimuli/events during this menstrual phase. Indeed, far fewer studies have reported significant changes in positive emotion compared to negative between menstrual phases, though this may be attributable in part to fewer studies focused on positive emotion and/or a publication bias towards significant findings.

This literature, however, is not without inconsistencies. One review of prospective studies determined no clear pattern of results for specific mood states in relation to menstrual phase (Romans et al. 2012a). Similarly, two longitudinal studies examining self-reported emotion across the menstrual cycle found no cycle-dependent change in positive or negative emotion in healthy women (Hengartner et al. 2017; Beddig et al. 2020). One explanation for these discrepancies could lie in how emotion itself is measured. Most studies have used an aggregate measure of either negative or positive emotion. Aggregating emotions by valence only (positive or negative) may obscure understanding of specific emotions most influenced by menstrual phase. Our findings suggest that two out of three of negative emotion variables did not vary significantly across menstrual phase. Therefore, it may be that more precise measures of different emotions may be required to elucidate affective risk, as certain emotions, such as anger or irritability, may be more subject to fluctuations in the hormonal milieu than others. This theory appears supported by the fact that we found lower correlations among negative emotion variables than positive emotions. Therefore, the negative emotions measured in this study were more distinct (i.e., orthogonal) from each other than positive emotions.

Additionally, the categorization/measurement of menstrual phase itself could underlie some of the variability seen within the literature. The vast majority of studies that have examined cycle-dependent attributes of mood and ovarian hormones have examined only steady state levels of hormones. More recent findings, however, have determined that it is likely not the steady state hormone level that drive symptom variation, but the change, or withdrawal, of these hormones (Schmidt et al. 2017). This is important because examining only the points at which hormones are highest (e.g., mid-to late-luteal) may be obscuring much of the true phase-related variations by failing to measure outcome variables as these hormones are shifting (i.e., the entire perimenstrual period, including late-luteal through early follicular phases). Therefore, methodological discrepancies in operationalizing the specific menstrual phases can limit interpretation and comparison of findings. Overall, there is need to better standardize measurement and classification in menstrual phase research (Schmalenberger et al. 2021).

Variations in Sleep across the Menstrual Cycle

Actigraphy data indicated that during the perimenstrual phase, time spent awake during the sleep period was significantly greater than during the two adjacent phases (mid-follicular and mid-luteal) and sleep efficiency was significantly lower as compared to the mid-luteal phase. These findings lend further support to studies demonstrating sleep to be more fragmented and less efficient during the perimenstrual phase (Sharkey et al. 2014; Zheng et al. 2015). Further, participants' subjective reports of their sleep mirrored objective findings, with women reporting greater wake time and lower sleep efficiency during the perimenstrual phase. Women's reports of subjective sleepiness were also higher during this phase. National survey data have shown as many as one third of reproductive-aged women report disturbed sleep related to their menstrual cycle (Francini and Tumminello 2007). Longitudinal, sleep diary-based studies also show a perimenstrual decline in perceived sleep quality (Baker and Driver 2004). Again, ovarian hormones are implicated. Li and colleagues found objectively measured sleep efficiency to be positively associated with levels of estrogen and negatively associated with progesterone (Li et al. 2015). Progesterone is associated,

with a nearly one degree Fahrenheit increase in core body temperature, which may contribute to sleep fragmentation (Baker and Driver 2007).

It is important to note, however, that studies examining phase-related differences in objectively measured sleep in healthy women are equivocal, with several studies reporting no to only minimal sleep disruption (Baker et al. 2012). For instance, a study examining the sleep of nine healthy women throughout the menstrual cycle via polysomnography and subjective assessments of sleep quality found no differences in sleep continuity across menstrual phases (Driver et al. 1996). In fact, while our findings are statistically significant, clinical significance is less clear, as objectively measured sleep differences between phases were between 4-7 minutes only. Although perceived sleep disruption was greater (8-16 minutes), individual differences in sleep patterns and need preclude understanding of the amount of sleep disruption that is clinically meaningful (Li et al. 2015). Still, it may be that even mild changes in sleep quality across the menstrual cycle underlie the gender disparity that exists in sleep disorders. Insomnia occurs in women at nearly two times the rates of men, suggesting a sex-specific mechanism underlying the condition (Soares 2005). Additionally, menstrual-related hypersomnia, although rare, is further indication of sleep disturbances unique to women that require further study (Villar-Martínez et al. 2022). Indeed, it may be that the variability in the occurrence of menstrual related sleep problems may represent inter-individual differences in hormonal sensitivity, akin to those identified in reproductive mood disorders (Standeven et al. 2020).

Interactive Effects of Sleep and Menstrual Phase on Emotion Outcomes

We also observed partial support for the interactive role of menstrual phase and sleep on emotion. Effects emerged for all three positive emotions examined but were not detected for any of the negative emotions. A number of studies suggest that poor sleep impairs positive emotions to the same or greater extent than negative (Palmer and Alfano 2017). A recent meta-analysis including 64 studies of sleep and emotion confirms this finding and reported no difference in the effects of partial sleep restriction versus total sleep deprivation on positive emotions; suggesting that even a few hours of lost sleep in a night can

have the same impact as no sleep at all (Tomaso et al. 2021). In fact, this relationship between sleep and positive emotion appears to be related to the development of anhedonia, a core feature of depression. Failure to sustain activity in the neural circuits underlying reward learning and positive emotion may explain the development of anhedonic features such as loss of pleasure (Heller et al. 2009). An intensive longitudinal study that examined daily reports of sleep and emotion in women (not examining menstrual phase) also found sleep variables to be more strongly associated with positive emotion, and that over time, these associations were predictive of depressive risk (De Wild-Hartmann et al. 2013). Thus, diminished ability to experience or maintain positive emotions after sleep loss may be one mechanism by which insomnia is linked to depression (Finan et al. 2019). Our study builds on and expands these findings by examining these relationships in the context of menstrual phase. On its own, menstrual phase was not predictive of positive emotion. When poor sleep coincided with the perimenstrual phase, however, ratings of positive emotions declined significantly. It is also notable that in our sample, only the interaction was statistically significant, meaning that increased total wake time alone was not predictive of positive emotions during the perimenstrual phase. Thus, sleep disruption, which is a natural occurrence in the perimenstrual phase, directly enhances affective risk through its impact on positive emotion.

It is important to note again, however, that although statistically significant, these interactive effects were small in this non-treatment-seeking sample of healthy women. However, these findings may be suggestive of heightened vulnerability for women at higher risk for affective disorders. For instance, those with perimenstrual syndrome have been shown to exhibit a greater tendency towards trait-based measures of stress, anxiety, and ruminative thinking (Kappen et al. 2022). This risk can then be compounded by the effects of poor sleep (Meers et al. 2019) to increase vulnerability to mood disorders.

Interestingly, although anger was found to be the only emotion impacted my menstrual phase alone, we did not find anger to be enhanced by the effects of poor sleep in the perimenstrual phase. This suggests that menstrual phase may have a more direct impact negative emotions like anger, but only impacts positive emotions through the biological influence on sleep disruption. Changes in progesterone may be contributing to emotional vulnerability in various ways. Enhanced reactivity to negative stimuli (due to progesterone's

influence on emotion centers of the brain) co-occurring with reductions in positive emotion resulting from poorer quality sleep (caused by progesterone's influence on thermodynamics) may set the stage for enhanced susceptibility to anxiety and depressed mood in women. This again points towards greater need to explore both positive and negative affective variables longitudinally across the menstrual cycle and in relation to sleep.

Individual-Level Predictors

We found an effect of age on some sleep variables. As participant age increased, women demonstrated reduced objective total wake time and better sleep efficiency. This finding could relate to the youth of our sample in general (range 18 to 34 years; mean age = 24), who tended towards later bedtimes (12:31 AM) than national averages (11:22 PM). Reports from the 2007 *National Sleep in America Poll*, commissioned by the National Sleep Foundation, indicated that bedtimes for young adult women between the ages of 18 to 24 were nearly 57-87 minutes later than their 25 to 34-year-old counterparts (NSF 2007). This can be attributed to normal changes in chronotype across the adult lifespan, with a preference for later bedtimes during adolescence/early adulthood and advancing towards an earlier hour as age progresses (Wittmann et al. 2006). This, too, was reflected in our findings, as there was a strong relationship between age and MSP, with older participants showing earlier sleep timing.

An eveningness chronotype is generally associated with reduced sleep continuity and quality, as well as "social jetlag;" a term for the discrepancy between an individual's preferred sleep-wake timing, and the schedule imposed on them by social activities like work and school (Wittmann et al. 2006). We found eveningness predicted greater objective total wake time and lower objective sleep efficiency, regardless of menstrual phase. For subjectively reported sleep duration, however, the opposite relationship was found; an effect for TST_{sub} only emerged when menstrual phase was also considered. Women reporting a stronger preference for eveningness reported their total sleep time during the perimenstrual phase to be shorter. By and large, evidence for menstrual phase effects on circadian timing is mixed (Baker and Driver 2007). Instead, it is likely that women with a greater eveningness preference likely have more variable sleep

patterns and may be at greater risk for disruptions to sleep during the perimenstrual phase. We also did not find an effect for chronotype or circadian timing on any of the emotion variables. This may indicate that that the relationship between mood and circadian misalignment likely stems from the effects of poor sleep rather than a direct relationship with emotion.

Limitations & Future Directions

Although this study has unique strengths, such as the use of both objective and subjective prospective data across two menstrual cycles, we do note that findings must be interpreted within the context of several limitations. As noted, precisely how the COVID-19 pandemic impacted outcomes cannot be fully known. Although we did not find strong effects for pandemic stress on outcome variables, we cannot discount the fact that the pandemic likely impacted participants' emotional experiences and sleep-wake behaviors.

Other limitations include methodological constraints related to measurement of self-reported emotion and menstrual phase. First, our emotional measure was relatively brief as the benefit of assessing a wider range of emotions had to be balanced against participant burden. Even so, the frequent administration of EMA emotion measures (i.e., three times a day for two months) may have exerted some effect on negative emotions such as anger/irritability due to their frequency. The physical symptoms of the perimenstrual phase may have exerted similar effects such that greater menstrual-related pain, headaches, cramping, and/or other similar symptoms may have impacted emotional outcomes. Similarly, although careful attention was paid towards accurately identifying menstrual phase, future studies using more intensive methodological approaches could further support these findings. For instance, the use of hormonal measures (e.g., blood, urine, or saliva) to confirm menstrual phase could provide enhanced reliability of menstrual data. A measure of core body temperature or dim light melatonin onset (DLMO) would advance understanding of the mechanisms underlying the relationship between sleep disruption and menstrual phase. Neuroimaging studies that explore the neurochemical underpinnings of the complex relationships between emotion and cognition (i.e., neuroplasticity in emotion processing, reactivity, and reward processing (Sacher et al. 2013)), as well as sleep are also warranted. Finally, while modeling the menstrual cycle as a

nonlinear function of time (versus the categorical approach used) could have provided a more nuanced visualization of the gradual changes in sleep and emotion occurring across the menstrual cycle, its complexity precluded its use in the current study (Schmalenberger et al. 2021). These represent important future directions in this domain.

Finally, although every effort was made to recruit women from the full age range of our inclusion criteria, younger women were oversampled, and therefore our mean age fell on the younger side. This likely impacted sleep variables given normal circadian phase delays seen in younger adults. Other variables may have been impacted as well. For instance, we know that affective stability and experience of positive emotions tend to increase across the lifespan (Brose et al. 2013). Therefore, future studies with broader age ranges may show different results and studies specifically investigating age-related interactions in emotion, sleep, and menstrual phase are warranted. Additionally, while more than 50% of our sample was made up of non-Caucasian individuals, we acknowledge that not every race/ethnicity was represented equally. We therefore cannot confidently know that there are not group differences in these outcomes based on race/ethnicity.

Conclusions

This novel study was one of the first to examine relationships between sleep and emotion in healthy women across two menstrual cycles, yielding several important results. Specifically, we found that daily reports of anger and disturbed sleep were highest in the perimenstrual phase (+/- 3 days of the start of menstrual bleeding). When poor sleep occurred during this menstrual phase, positive emotions decreased to a greater extent than when these variables were considered independently. These findings highlight the importance of considering the role of sleep health in understanding affective risk across the monthly menstrual cycle in reproductive-aged women. Equally important to improved understanding in this area is the need to identify prevention and intervention targets and to improve approaches that could serve to reduce vulnerability for mood disorders by way of reducing sleep disturbance and protecting the integrity of the sleep-wake diurnal processes in women.

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Table 1. *Timing of menstrual cycle phases.*

Phase	Cycle Day Ranges (Assuming an idealized 28-day menstrual cycle)
Perimenstrual	**3 days prior to menstrual bleeding and the first 3 days of bleeding** Cycle day -3 through +3 (days 26-28 of previous cycle + days 1-3)
Mid-follicular	**Cycle day 4 through the day prior to positive ovulation test** Cycle days 4-13
Periovulatory	**The day of positive ovulation test and the following day** Cycle day 14+15
Mid-Luteal	**The day after the periovulatory phase until 3 days prior to bleeding onset** Cycle day 16-25

809 **Table 2.** *Demographic and Clinical Characteristics of the Full Sample, N=51*

	M(SD)/ N(%)
Demographic Variables	
Age	23.67(4.68)
Race	
Caucasian	22(43.1%)
African American	5(9.8%)
American Indian/Alaska Native	1(2.0%)
Asian	15(29.4%)
Mixed Race	7(13.7%)
Not Reported	1(2.0%)
Ethnicity	
Hispanic	20(39.2%)
Non-Hispanic	29(56.49%)
Education	
High School Diploma	5(9.8%)
Some College	21(41.2%)
Bachelor's Degree	17(33.3%)
Advanced Degree	5(9.8%)
Not Reported	3(5.9%)
Menstrual Cycle Variables	
Menstrual Cycle Length (days)	28.61(2.69)
Menstrual Distress Questionnaire	
Negative Affect	6.5(5.62)
Cognitive Symptoms	2.46(2.50)
Fluid Retention	1.49(1.36)
Behavior Change	4.73(3.33)
Somatic Symptoms	7.54(3.37)
Autonomic Reactions	1.21(1.89)
Emotion Variables	
Happy	5.63(1.92)
Calm	5.46(2.05)
Enthusiastic	3.87(2.35)
Angry	1.62(1.25)
Afraid	2.47(1.89)
Sad	2.07(1.63)
Sleep Variables	
Circadian Phase Preference (MEQ)	46.94(8.02)
Actigraphy Variables	
Bedtime	12:31 AM (90 min.)
Wake Time	8:46 AM (98 min.)
Total Sleep Time min. (TST_{obj})	460.68(46.87)
Total Wake Time min. (TWT_{obj})	64.62(19.26)
% Sleep Efficiency (SE_{obj})	81.62(9.14)
Sleep Diary Variables	
Total Sleep Time min. (TST_{sub})	442.17(87.95)
Total Wake Time min. (TWT_{sub})	43.75(28.60)

% Sleep Efficiency (SE_{sub})	90.48(8.37)
Sleepiness (1-9 scale)	4.55(1.21)
COVID-19 Variables (Baseline / End of Study)	
COVID-Anxiety	5.27(1.99) / 5.73(2.06)
COVID-Risk Perception	3.89(2.50) / 3.79(2.39)
# COVID-Positive People You Know	1.63(2.17) / 4.71(2.18)

Table 3. *Menstrual Phase Predicting Positive and Negative Emotion*

	Positive						Negative					
	Happy		Calm		Enthusiastic		Angry		Afraid		Sad	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Fixed Effects:												
Intercept	5.61***	.21	5.49***	.22	3.96***	.27	1.70***	.10	2.48***	.19	2.22***	.15
Mid-Follicular	.05	.07	-.01	.07	-.07	.07	-.10	.05	.01	.08	-.08	.07
Periovulatory	.08	.09	.01	.08	.07	.09	-.17**	.06	.12	.10	-.16	.09
Mid-Luteal	-.01	.07	-.06	.07	-.02	.07	-.01	.05	.04	.08	-.03	.07
Random Effects:												
Within												
Variance	2.07***		2.26***		2.59***		1.24***		2.39***		2.05***	
r adjacent errors	.33***		.24***		.24***		.23***		.38***		.36***	
Between												
Variance	1.73***		1.9***		3.03***		.35***		1.35***		.82***	

Note. *p<0.05; **p<0.01. ***p<0.001. Perimenstrual phase serves as the reference variable, to which all other phases are compared.

Table 4. *Menstrual Phase Predicting Sleep*

	Objective (Actigraphy)						Subjective (Sleep Diary)							
	TST_{obj}		TWT_{obj}		SE_{obj}		TST_{sub}		TWT_{sub}		SE_{sub}		Sleepy	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Fixed Effects:														
Intercept	456.17**	8.74	67.54**	3.37	80.71**	.82	432.38**	8.06	52.23**	5.00	89.72**	.99	4.77**	.22
Mid-Follicular	-2.07	6.34	-6.51**	1.80	.93	.52	6.74	5.04	-7.54*	3.19	1.34*	.67	-.06	.12
Periovulatory	5.72	7.63	-.07	2.16	.83	.63	3.28	6.05	-15.72**	3.81	3.21**	.80	-.43**	.15
Mid-Luteal	7.19	6.23	-4.43*	1.77	1.79**	.51	3.31	5.02	-8.41**	3.17	1.19	.67	-.11	.13
Random Effects:														
Within														
Variance	9609.04**		676.62**		65.41**		6487.36**		2573.51**		114.40**		2.49**	
r adjacent errors	.67**		.70**		.67**		.72**		.74**		.75**		.13**	
Between														
Variance of Intercept	1782.72**		332.32**		17.78**		2006.35**		751.20**		28.03**		1.58**	

Note. *p<0.05; **p<0.01. Perimenstrual phase serves as the reference variable, to which all other phases are compared.

Table 5. *Interactions for Menstrual Phase and Sleep Predicting Positive and Negative Emotion*

	Positive Emotion						Negative Emotion					
	Happy		Calm		Enthusiastic		Angry		Afraid		Sad	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Fixed Effects:												
Intercept	5.67**	.24	5.53**	.25	4.01**	.29	1.62**	.09	2.45**	.18	2.24**	.17
Mid-Follicular	.004	.08	-.03	.08	-.18*	.08	-.09	.06	-.03	.09	-.08	.08
Periovulatory	-.01	.10	-.11	.09	-.11	.10	-.14*	.07	.14	.11	-.10	.10
Mid-Luteal	-.06	.08	-.15	.08	-.08	.08	-.03	.06	-.002	.09	.01	.08
TWT_{obj}	.001	.002	-.002	.002	.002	.002	-.002	.001	-.0002	.002	-.0005	.002
Mid-Follicular*TWT_{obj}	-.005*	.003	-.001	.003	-.006*	.003	.004	.002	.002	.003	.004	.003
Periovulatory* TWT_{obj}	-.006*	.003	-.0003	.003	-.003	.003	.005*	.002	-.0002	.003	.002	.003
Mid-Luteal* TWT_{obj}	-.002	.003	.006*	.003	.002	.003	.001	.002	-.0005	.003	-.001	.003
Random Effects:												
Within												
Variance	2.07**		2.21**		2.57**		1.16**		2.35**		2.14**	
r adjacent errors	.33**		.23**		.24**		.22**		.38**		.35**	
Between												
Variance	2.01**		2.20**		3.23**		.24**		1.05**		.91**	

Note. *p<0.05; **p<0.01. Perimenstrual phase serves as the reference variable, to which all other phases are compared.

Table 6. *MEQ as an Individual Level Predictor of Sleep*

	Objective (Actigraphy)						Subjective (Sleep Diary)							
	TST_{obj}		TWT_{obj}		SE_{obj}		TST_{sub}		TWT_{sub}		SE_{sub}		Sleepy	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Fixed Effects:														
Intercept	487.79**	51.84	123.55**	17.69	66.71**	4.26	512.94**	47.08	43.45**	28.77	93.10**	5.67	6.07**	1.26
Mid-Follicular	-52.12	37.03	-6.62	10.45	.73	3.04	-34.19	27.84	-39.10*	16.66	8.31	3.60	-.85	.68
Periovulatory	-31.77	46.79	-14.17	13.10	9.23*	3.84	-80.86*	34.03	-25.34**	20.31	3.98	4.37	-1.18	.85
Mid-Luteal	-66.01	37.34	-17.06	10.48	2.59**	3.07	-89.14**	28.37	-35.26**	16.94	5.54	3.65	-.15	.72
MEQ	-.67	1.11	-1.23**	.38	.31**	.09	-1.74	1.00	.18	.61	-.07	.12	-.03	.03
Mid-Follicular*MEQ	1.11	.80	.002	.22	.01	.07	.88	.60	.68	.36	-.15	.08	.02	.01
Periovulatory* MEQ	.80	1.00	.32	.28	-.19*	.08	1.81*	.73	.21	.43	-.01	.09	.02	.02
Mid-Luteal* MEQ	1.56	.80	.29	.22	-.02	.07	2.03**	.60	.57	.36	-.09	.08	.002	.02
Random Effects:														
Within														
Variance	9665.80**		757.99**		65.11**		6407.90**		2283.89**		107.05**		2.44**	
r adjacent errors	.67**		.70**		.67**		.71**		.73**		.74**		.15**	
Between														
Variance of Intercept	1831.70**		249.14**		12.43**		2048.01**		769.31**		27.69**		1.59**	

Note. *p<0.05; **p<0.01. Perimenstrual phase serves as the reference variable, to which all other phases are compared