ASSOCIATIONS BETWEEN OVARIAN HORMONES AND EMOTIONAL EATING ACROSS THE MENSTRUAL CYCLE: DO OVULATORY SHIFTS IN HORMONES MATTER?

By

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ABSTRACT

ASSOCIATIONS BETWEEN OVARIAN HORMONES AND EMOTIONAL EATING ACROSS THE MENSTRUAL CYCLE: DO OVULATORY SHIFTS IN HORMONES MATTER?

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Prior research suggests a substantial role for ovarian hormones in increased risk for binge eating and emotional eating during the mid-luteal phase of the menstrual cycle. However, past studies have not examined how and if pronounced hormonal changes that precede the mid-luteal phase (i.e., the dramatic decrease in estradiol and increase in progesterone during/after ovulation) also contribute to mid-luteal increases in binge-related symptoms. Past theories and studies of phenotypes strongly related to binge eating (e.g., depression) suggest that these pronounced hormonal changes may also play a role. This study examined this hypothesis in 390 female twins (aged 15-25 years) from the Michigan State University Twin Registry. Daily ratings of emotional eating (assessed with the Dutch Eating Behavior Questionnaire) and daily saliva samples of hormones were measured over 45 consecutive days. Results revealed no significant associations between pronounced changes in estradiol or progesterone across ovulation and emotional eating scores in the mid-luteal phase, even after controlling for BMI and negative affect and examining participants with clinical binge eating episodes. Taken together, data suggest that pronounced hormonal change across ovulation may play less of a role in emotional eating than changes in estradiol and progesterone that occur during the mid-luteal phase.

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KEY TO ABBREVIATIONS

BMI= body mass index

EST= estradiol

Follic= follicular phase

Max= maximum

Mid-lut= mid-luteal phase

Min= minimum

Ovul= ovulatory phase

Premen= premenstrual phase

PRO= progesterone

SE= standard error

T= transition days that are in between phases

INTRODUCTION

Prior research implicates ovarian hormones (i.e., estrogen and progesterone) in the risk for binge eating (Edler, Lipson, & Keel, 2007; Klump, Keel et al., 2013; Klump et al., 2014) and emotional eating (i.e., overeating for comfort, to relieve stress, or to cope with emotional difficulties; Klump, Keel et al., 2013; Klump et al., 2015; Klump et al., 2016) across the menstrual cycle. The highest levels of binge eating and emotional eating have been found to occur following ovulation, during the mid-luteal phase, whereas the lowest levels of binge eating and emotional eating have been shown to occur prior to ovulation, during the follicular phase (Blaustein & Wade, 1976; Edler, Lipson, & Keel, 2007; Gray & Wade, 1981; Kemnitz, Gibber, Lindsey, & Eisele, 1989; Klump et al., 2012; Klump, Keel et al., 2013; Klump et al., 2014; Varma et al., 1999). Changes in ovarian hormones across the cycle seem to account for these effects, with high levels of both estrogen and progesterone (i.e., mid-luteal phase) predicting increased levels of binge eating and emotional eating across the cycle (Edler, Lipson, & Keel, 2007; Klump et al., 2012; Klump, Keel et al., 2013; Klump et al., 2015; Klump et al., 2016). These associations between hormones and binge eating/emotional eating have been shown to be present in community (Klump, et al., 2008; Klump et al., 2012; Klump, Keel et al., 2013; Klump et al., 2015; Klump et al., 2016) and clinical samples (Edler, Lipson, & Keel, 2007; Klump et al., 2014) of women, although effects seem to be strongest in clinical samples (Edler, Lipson, & Keel, 2007; Klump et al., 2014).

The majority of studies that have examined the relationship between ovarian hormones and binge eating and emotional eating have relied solely on same-day morning levels of ovarian hormones. In other words, they have examined whether a woman's hormone levels in the morning predicted her emotional eating scores later that same day. Because these studies used

within-person, standardized hormone levels, they indexed the extent to which women with high or low levels of hormones, relative to their own baseline hormone levels, predicted later emotional eating that day. These analyses have been informative for increasing our understanding of daily changes in hormones/emotional eating and underscoring the importance of overall hormone changes in emotional eating risk.

However, some have argued that the degree of change in ovarian hormone levels (i.e., the difference between high versus low levels) may also predict binge eating phenotypes (Edler, Lipson, & Keel, 2007) across the menstrual cycle. If this is the case, then perhaps women who experience the most pronounced changes in estrogen and progesterone levels around ovulation may be at the greatest risk of binge eating and emotional eating. Importantly, ovulation is the time of greatest hormonal change during the menstrual cycle. As diagrammed in Figure 1, estrogen levels are at their peak during ovulation and fall sharply following ovulation. Conversely, progesterone is at its valley levels prior to ovulation and rises sharply to reach its peak following ovulation. Given that the greatest increases in binge eating and emotional eating occur right after this time of maximum hormonal change, increased change in hormone levels during/after ovulation may also contribute to increases in binge eating and emotional eating post-ovulation.

This is particularly true given that hormone effects often are time-lagged. Hormones function over a large spatial and temporal period, such that there may be a latency between a hormone's release and observable behavioral or phenotypic outcomes (Nelson 2011). In animal models, most estrogen-dependent responses have been shown to occur hours to days after estrogen's release (Asarian & Geary, 2013). For example, pharmacological doses of estradiol decrease food intake approximately 24-48 hours later in mice and rats (Geary, Asarian, 1999;

Gray, Greenwood, 1982; Santollo, Wiley, Eckel, 2007; Thammacharoen, Geary, Lutz, Ogawa, Asarian, 2009). These delayed or time-lagged effects may reflect dependence of behavior on transcriptional effects of estrogens on gene expression (Asarian, Geary, 2013), whose downstream consequences require hours or days to complete. While no known studies of hormonal time-lag effects on eating behavior exist in humans, it is possible that events that occur during the mid-luteal phase of the menstrual cycle (e.g., increased binge eating and emotional eating) may be partly due to changes in the hormones during earlier phases, including the ovulatory phase which is characterized by dramatic changes in both estrogen and progesterone and occurs approximately 3-8 days before the mid-luteal phase. Indeed, in the absence of progesterone, estrogen decreases food intake, binge eating and emotional eating (Asarian & Geary, 2013). Thus, when estradiol levels are high (e.g., during the late follicular/ovulatory phase), levels of binge eating and emotional eating are low (Edler, Lipson, & Keel, 2007; Gray & Wade, 1981; Kemnitz, Gibber, Lindsey, & Eisele, 1989; Klump et al., 2012; Klump, Keel et al., 2013; Klump et al., 2014; Varma et al., 1999). By contrast, progesterone antagonizes estrogen and inhibits estrogen's protective benefits against binge eating and emotional eating. Therefore, when progesterone levels are high (i.e., during the mid-luteal phase), the frequency of binge eating and emotional eating is also high (Klump, Keel, et al., 2013; Klump et al., 2014).

Given these patterns of hormonal changes and effects, it is possible that women with larger decreases in estrogen from ovulation to immediately post-ovulation would exhibit the highest levels of emotional eating in the mid-luteal phase. Additionally, women with the largest increases in progesterone in the time after ovulation to the mid-luteal phase would be expected to report higher levels of emotional eating. Following what has been found in previous studies in terms of an interaction between estrogen and progesterone (Klump, Keel et al., 2013; Klump et

al., 2014), it may also be that the combination of large decreases in estrogen and large increases in progesterone during/after ovulation contribute to the high frequency of binge eating and emotional eating in the mid-luteal phase.

To date, no studies have examined whether pronounced changes in estrogen and progesterone during ovulation predict increases in binge eating and emotional eating during later phases. However, studies of other phenotypes linked to binge eating and emotional eating (e.g., depression; see Munn-Chernoff et al., 2015) suggest that general variability in a women's hormones may be important, particularly during major hormonal transition periods (e.g., menopause; Freeman et al., 2007; Freeman, 2010; Moran-Santa Maria, Flanagan, & Brady, 2014; Schmidt & Rubinow, 2009). For example, in an 8-year longitudinal study, Freeman and colleagues (2006) examined associations between absolute and fluctuating levels of ovarian hormones with onset of depressed mood during menopause in women. Results revealed a fivefold increase in risk for depressive symptoms in women during the menopausal transition compared to the perimenopausal period, with implications for increased variability in estradiol levels around the woman's mean. Although this and other studies (Freeman et al., 2007; Freeman, 2010; Moran-Santa Maria, Flanagan, & Brady, 2014; Schmidt & Rubinow, 2009) have not examined the menstrual cycle per se, they do provide evidence for the role of general hormonal variability in risk for psychopathology during hormonal milieus marked by significant shifts in estradiol and progesterone levels.

The mechanisms underlying these effects, and potential effects for emotional eating, remain unclear. Animal studies have shown that female brains are programmed to display flexible neuronal responses to predictable fluctuations in ovarian hormone levels (Deecher et al., 2008; Gould et al., 1990; Woolley & McEwen, 1993), however the brain may lose this flexibility

if the hormonal milieus become more pronounced (Deecher et al., 2008). For example, in response to sharp decreases in estrogen and progesterone, hippocampal (Gould et al., 1990) and prefrontal cortex (Tang et al., 2004) dendritic spine density decreases. Although dendritic spine density fluctuates naturally across the estrous cycle (Wooley et al., 1990), pronounced changes in hormone levels may create abnormal decreases in dendritic spine density that impairs neuronal communication between these brain areas (see Deecher et al., 2008). These brain regions play a prominent role in many higher-order cognitive processes (e.g., planning, inhibition) that help regulate eating behavior. Thus impairments in neuronal signaling/communication via irregular decreases in dendritic spine density may inhibit the ability to resist the urge to binge eat. Thus, it may be that the women who experience the most pronounced changes in estrogen and progesterone across ovulation are most at risk for binge eating and emotional eating in the mid-luteal phase due to underlying neuronal changes. Clearly, these mechanistic hypotheses are speculative and non-specific, as no studies have directly examined these neuronal changes or the extent to which pronounced hormonal changes predict emotional eating.

Given the above, the aim of the current study was to examine whether pronounced hormonal change across ovulation predicted increased levels of emotional eating during the mid-luteal phase. The study aims were examined in an archival community-based sample of 445 women (Klump, Keel et al., 2013, Klump et al., 2014) who previously collected daily hormone and emotional eating data for 45 consecutive days. Due to the small number of twins (n=28 – see Klump et al., 2014) endorsing clinical binge eating, this study focused primarily on emotional eating. However, prior studies suggest that the phenotypic effects of ovarian hormones during the mid-luteal phase are similar across emotional eating versus binge eating and clinical versus community samples of women (Edler et al., 2007; Klump et al., 2008, 2013, 2014). As noted

above, it was expected that large decreases in estrogen and large increases in progesterone during/after ovulation would lead to the highest levels of emotional eating across the menstrual cycle in women.

METHODS

Participants

The initial sample included 445 female twins (aged 15-25 years old) who participated in the *Twin Study of Hormones and Behavior Across the Menstrual Cycle* (TSHMBC; Klump, Keel, et al., 2013) within the Michigan State University Twin Registry (MSUTR; Burt & Klump, 2013; Klump & Burt, 2006). Although the MSUTR began as a university-based twin registry assessing undergraduate men and women, we have been recruiting twins via birth records since 2004. The Michigan Department of Health and Human Services (MDHHS) identifies twin pairs residing in Michigan who meet our study age criteria (see criteria below) and whose addresses or parents' addresses (for twins who are minors) can be located using driver's license information obtained from the state of Michigan. Twins were identified either directly from birth records or via the Michigan Twins Project (Burt & Klump, 2013; Klump & Burt, 2006), a large-scale twin registry within the MSUTR that doubles as a recruitment resource for smaller, more intensive projects. Because birth records are confidential in Michigan, recruitment packets are mailed directly from the MDHHS to eligible twin pairs. Twins indicating interest in participation via pre-stamped postcards or e-mails/calls to the MSUTR project office were then contacted by study staff to determine study eligibility and to schedule their assessments. Four recruitment mailings were used to ensure optimal twin participation. Overall response rates across all MSUTR studies (56–85%) are on par with or better than those of other twin registries that use similar types of anonymous recruitment mailings (Burt & Klump, 2013; Klump & Burt, 2006).

For the TSHMBC study, all participants were required to meet the following inclusion criteria: (a) menstruation every 22 to 32 days for the past 6 months, (b) no hormonal contraceptive use within the past 3 months, (c) no psychotropic or steroid medications within the

past 4 weeks, (d) no pregnancy or lactation within the past 6 months, and (e) no history of genetic or medical conditions known to influence hormone functioning or appetite/weight.

Given the current study's focus on examining changes in hormone levels across ovulation, additional exclusion criteria were needed; specifically, participants were excluded from analyses if: 1) their cycles were found to be anovulatory; or 2) data during key hormone phases (e.g., transition to mid-luteal phase - see below) were missing and/or against expectations (e.g., a participant had lower (rather than higher) estradiol levels during the ovulatory versus mid-luteal phase). These exclusions resulted in a final sample size of 390 (88% of total; 390/445), 20 (5%, 5/390) of which engaged in objective binge episodes (OBEs). Even with these additional exclusion criteria, participants were found to be demographically representative of the recruitment region (see Table 1 and Klump, Keel et al., 2013). Participants were mostly of Non-Hispanic descent (91%), with the majority identifying as Caucasian (84%), followed by African-American (10%), Multiracial (5%), Native American (0.5%), and Asian or Pacific Islander (0.3%).

Procedures

All study measures and procedures were approved by the Institutional Review Board of Michigan State University. Participants provided daily behavioral and hormone data for 45 consecutive days. Salivary samples were used to assay ovarian hormones and were collected using previously established methods (Edler et al., 2007; Klump et al., 2008). Participants were instructed to collect 4 ml of saliva (indicated by a line on collection tubes) each morning for 35 days within 30 minutes of waking and before brushing teeth, eating, drinking, chewing or smoking. Questionnaires were completed each evening (after 5:00 p.m.) using an online data

system or preprinted scantrons. The timing of data collection ensured that a given day's hormone collection preceded that day's behavioral ratings (Edler et al. 2007; Klump et al., 2008).

In addition to daily data collection, all participants completed three in-person visits occurring at the start of the study, at the halfway point (approximately day 23), and at the end of the data collection (after day 45). During these in-person assessments, eligibility was reassessed, height and weight were measured, and completed materials were collected from participants. The diagnostic interview for OBEs was administered after the last study visit to ensure that all symptoms that were present during the 45-day study period were captured. Between visits, staff contacted participants once per week to answer questions and confirm continued protocol adherence. These procedures were effective at minimizing participant dropout (< 3%) and missing data (< 6%), as well as at identifying individuals who were no longer eligible to participate as a result of missed periods, medication use, or pregnancy (< 3%).

Measures

Emotional Eating

Emotional eating was assessed daily using the Emotional Eating scale of the Dutch Eating Behavior Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986). The Emotional Eating scale assesses eating in response to negative emotions (example item: “Did you have a desire to eat when you were depressed?”); responses were made using scales from 1 (not at all) to 5 (very often). Internal consistencies for the DEBQ Emotional Eating scale were excellent in previous research ($\alpha = .93$; Klump et al., 2008; Racine et al., 2012; van Strien et al., 1986) and in the current sample (45-day average $\alpha = .90$). It is important to note that eating in response to negative emotions is thought to be a core feature of binge eating, and the DEBQ Emotional Eating scale has demonstrated validity in differentiating among individuals with

clinical and subclinical OBEs, overweight individuals, and college students (Wardle, 1987). Furthermore, the DEBQ Emotional Eating scale is correlated with established measures of binge eating (*r*'s = .55–.69; Racine, Culbert, Larson, & Klump, 2009; van Strien, 2000) as well as with palatable food intake (i.e., ice cream) in a laboratory setting (van Strien, 2000). Similar to previous research (Klump et al., 2008), the instructions for the DEBQ emotional eating scale were modified with permission to ask about emotional eating over the current day.

Negative Affect

The Negative Affect scale from the Positive and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988) was used to assess daily negative affect. This scale consists of 10 items that assess the full range of daily negative emotions (e.g., distress, nervousness, irritability, fear). Participants rated the degree to which each emotion was experienced; responses were made using Likert scales from 1 (very slightly/not at all) to 5 (extremely). The Negative Affect scale has exhibited excellent internal consistency as well as good convergent and discriminant validity (Watson et al., 1988). Internal consistency in the current study was excellent (45-day average α = .85).

Ovarian Hormones

Saliva Samples

Participants provided daily saliva samples within 30 minutes of waking, using published methods (Klump et al., 2008; Klump et al., 2013). Saliva samples were processed for estrogen and progesterone by Salimetrics, LLC (State College, PA) using enzyme immunoassay kits designed specifically for analyzing saliva. Saliva samples are preferred over other methods (e.g., blood spots) because they represent a less invasive collection method, particularly if repeated samples are needed. Previous research has shown that saliva samples are associated with higher

compliance and more robust hormone-behavior associations than is blood-spot sampling (Edler et al., 2007). These assays show excellent intra- and inter-assay coefficients of variation (estradiol = 7.1% and 7.5%; progesterone = 6.2% and 7.6%), as well as assay sensitivity (measured by interpolating the mean optical density minus 2 SDs of 10–20 replicates at the 0-pg/ml level; estradiol = 0.10 pg/ml; progesterone = 5 pg/ml) and method accuracy (determined by spike recovery and linearity; estradiol = 104.2% and 99.4%; progesterone = 99.6% and 91.8%). To conserve resources, samples were assayed only every other day during menstrual bleeding and the early follicular phase when hormones are expected to be low and stable. This process ensured that periods of maximum hormonal change across the menstrual cycle (e.g., the mid-to-late follicular through premenstrual phase) were captured while also maximizing the number of participant samples assayed. Importantly for the current study, daily sampling was conducted around the days of ovulation, which ensures that the time of maximum hormonal change and variability was captured.

Menstrual Cycle Coding

Participants recorded days of menstrual bleeding in a daily log book (see Lester et al., 2003). Menstrual cycle phase was coded by trained raters (see training procedures below) after aggregating each twin's cycle and hormone data into a single graph. All raters underwent extensive training, including review of coding rules and practice coding sessions. Each rater had to achieve an inter-rater reliability of > 0.80 with senior raters. All graphs were coded by two raters, and the codes were compared for consistency. Discrepancies were resolved during weekly meetings. The first day of bleeding served as the graph anchor, and phase days were coded based on this anchor, hormone levels, and the overall length of each cycle. Raters began by examining hormone levels approximately 15 days prior to this anchor to find each twin's peal in estradiol

and ovulatory phase. The day with the highest estradiol peak, as well as the days prior to and after, were coded as the ovulatory phase (~3 days). The mid-luteal phase (~7 days) was coded after ovulation based on a secondary peak in estradiol and rising (and then falling) progesterone levels. The transition from ovulation to mid-luteal phase (~3 days) was coded after ovulation based on falling estradiol levels following ovulation and rising progesterone levels (still too low to be the mid-luteal peak). Even though this study focuses on the ovulatory, mid-luteal phase, and transition phase from ovulation to mid-luteal phase, the follicular and premenstrual phase were also coded. The premenstrual phase (~4 days) was coded based on falling levels of both progesterone and estradiol. The follicular phase (~10 days) was coded based on low progesterone levels and low (and then rising levels) of estradiol that occurred after menstruation but before ovulation.

BMI

Participant's height and weight were measured during the three in-person study visits using a wall-mounted ruler and a digital scale, respectively. BMI was calculated using the following formula: BMI= weight (in kilograms)/height (in meters)^2.

Statistical Analyses

Data Preparation

Data preparation followed methods used in previous studies examining relationships between ovarian hormones and binge eating and emotional eating across the menstrual cycle (Edler et al., 2007; Klump et al., 2008; Klump, Keel, et al., 2013). For the repeated measures (i.e., emotional eating, hormones, negative affect), 5-day rolling averages were calculated. Rolling averages have been used in previous research and are preferred because of their ability to minimize random variation that is present in behavioral data as a result of environmental

circumstances (Gladis & Walsh, 1987). Rolling average variables were then centered by subtracting each daily value from the person's overall mean value across the study period. They were then converted to within-person standardized scores based upon each individual participant's standard deviation across data collection. As noted briefly above, this standardization approach means that analyses indexed how variability in a woman's hormone levels, relative to her equilibrium, predicts changes away from her equilibrium in emotional eating. To accommodate the fact that BMI was assessed at only three time points across the study, the average BMI across all three study visits was calculated and included in analyses.

The average emotional eating score in the mid-luteal phase was calculated and used as the outcome variable in all analyses. Pronounced within-person changes in hormone levels were used as predictor variables and were assessed using each women's individual hormone difference scores (maximum – minimum hormone value). This difference score value was calculated differently for estrogen and progesterone. For estrogen, it was defined as the difference between maximum estradiol levels during ovulation and minimum levels during the transition to the mid-luteal phase (i.e., the phase right after ovulation). For progesterone, it was defined as the difference between maximum progesterone levels during the mid-luteal phase and minimum progesterone levels during the transition to mid-luteal phase (again, the phase right after ovulation). Negative affect difference scores (calculated in the same manner as described above) and BMI were included as covariates in all analyses to control for their effects. Because this study spanned 45 days, participants had, on average, 1.5 complete menstrual cycles across the study period. To ensure that all data were from the same cycle, hormone and emotional eating data from the one complete cycle were used in all analyses.

Statistical Models

Pearson correlations were conducted prior to any model-fitting in order to provide initial indications of associations between pronounced hormone changes and emotional eating scores. Then, using methods similar to those outlined in Klump, Keel, et al. (2013) and Klump et al. (2014), mixed linear models (MLMs) were used to examine how the hormone difference scores predicted average emotional eating scores in the mid-luteal phase. MLMs are ideal for these analyses, given that they examine predictive associations while controlling for covariates (i.e., negative affect and BMI) and the non-independence of the twin data.

Originally, all MLMs were going to include the difference scores and the maximum/minimum hormone values to ensure that any significant effects of the difference scores were above and beyond the effects of hormone maximums/minimums. However, high multicollinearity (i.e., tolerance= 1.00) was present between the maximum and minimum hormone values and the difference scores. Thus, separate models were run to examine the effects of: 1) maximum and minimum hormone levels together; and 2) hormone difference scores only. These models were conducted for estrogen only, progesterone only, and then a set of joint hormone models to examine potential estrogen x progesterone interactions.

RESULTS

Descriptive Statistics

Table 1 includes descriptive statistics for the raw scores and within-person z-score for emotional eating during the mid-luteal phase, ovarian hormone maximum values, minimum values, and differences scores, BMI, and negative affect. Although the z-scores were used in all analyses, the raw scores were included to give a sense of the overall levels of pathology/hormone variability in the sample to compare to past work. Average emotional eating scores in the mid-luteal phase showed a range of pathology in terms of both the raw scores (range = 0.00-4.01) from no emotional eating (score = 0.00) to clinically significant levels of emotional eating (score = 4.01) and within-person z scores (range = -1.39-1.71). These data reflect the fact that the sample includes women within clinical levels of emotional eating scores (i.e., scores ≥ 3) and that there were significant individual differences in the extent to which women were engaging in more or less emotional eating during the mid-luteal phase, as compared to their baseline levels. Ovarian hormone levels (both raw and z-scores) followed expected trends with higher estradiol levels occurring in the ovulatory phase and lower estradiol levels in the transition to mid-luteal phase. Similarly, higher progesterone levels were present in the mid-luteal phase as compared to the transition to mid-luteal phase. Hormone difference scores also showed ample variability (i.e., 0.03-4.46) across ovulation, transition to mid-luteal, and the mid-luteal phase for our primary analyses.

Correlations and Mixed Linear Models

As shown in Table 2, there were no significant associations between emotional eating scores in the mid-luteal phase and any of the maximum hormone values, minimum hormone values, or difference scores. All correlations were non-significant and small in magnitude (*r*'s < .06), suggesting minimal associations between the magnitude of changes in hormones across

ovulation/mid-luteal phase and average emotional eating scores in the mid-luteal phase. Results from the MLM analyses corroborated these impressions (see Table 3). There were no significant main effects of maximum or minimum hormone levels, or significant interactions (i.e., minimum x maximum interactions), for either estrogen or progesterone alone or in the joint hormone models (all *p*'s > .05). Likewise, MLMs for the difference scores yielded all non-significant effects (all *p*'s > .05).

Because of the large number of null effects, a series of post hoc analyses were conducted to ensure that results were not unduly influenced by study design decisions or missing data. Thirty-five participants (8% of the original total sample of 445 women) were excluded from the primary analyses because the transition to mid-luteal phase was missing in their data (i.e., days immediately after ovulation seemed more consistent with the mid-luteal phase than a transition phase). To ensure that results were not due to the exclusion of these subjects, MLMs for estrogen (and the joint hormone models) were re-run using maximum scores, minimum scores, and difference scores from ovulation to the mid-luteal phase (rather than the transition to mid-luteal phase). Again, no significant main effects or interactions were observed for any of the models (all *p*'s > .05; see Supplemental Table S1).

Cycle phase length varies quite a bit across the menstrual cycle, ranging, on average from 1 day (i.e., ovulation) to 7 days (e.g., mid-luteal phase). Therefore, calculating minimum, maximum, and difference scores using 5-day rolling averages during ovulation might have been over- or underestimated the mean hormone levels in women across the ovulatory hormonal milieu, thereby masking potential effects of pronounced hormonal change on emotional eating in women in the mid-luteal phase. To address this concern, all models were re-run using single day maximum and minimum values, as well as 2- and 3-day rolling averages. Consistent with all

results thus far, no significant associations were found for maximum hormone levels, minimum hormone levels, or difference scores on emotional eating scores using single day maximum/minimum or 2- or 3-day rolling averages (all *p*'s > .05; see Supplemental Tables S2).

Finally, although past work shows nearly identical hormone/emotional eating associations in the mid-luteal phase of the menstrual cycle in clinical versus non-clinical samples (Edler et al., 2007; Klump et al., 2008, 2013, 2014), it is possible that the effects of pronounced hormonal change on emotional eating are only present in women with more severe levels of emotional eating. To examine this possibility, exploratory analyses were conducted within the small sample of women ($n = 20$) who endorsed a lifetime history of objective binge eating episodes (i.e., episodes defined by a large amount of food and a loss of control over food intake – assessed via semi-structured interviews – see Klump et al., 2014 for methods) and who met the current study's inclusion/exclusion criteria (see above). Results continued to show no significant associations between emotional eating scores and maximum hormone values, minimum hormone values, or differences scores in this clinical sample (all *p*'s > .05; see Supplemental Table S3).

DISCUSSION

This is the first study to examine the effect of pronounced hormonal changes across ovulation on emotional eating in women across the menstrual cycle. Others have posited the importance of pronounced hormonal change on binge-eating phenotypes (Edler, Lipson, & Keel, 2007), and studies have shown the importance of the degree of hormonal change in phenotypes strongly related to binge eating (e.g., depression; Freeman et al., 2006). Despite this, we found no significant associations between emotional eating scores and pronounced hormonal change in either estradiol or progesterone across ovulation.

Post-hoc analyses were conducted to rule-out the potential influence of missing data, study design decisions, and/or clinical status of participants on the current results. Results from analyses examining pronounced hormonal change across ovulation and the mid-luteal phase (i.e., rather than the transition to mid-luteal phase) revealed no significant effect of missing data in the primary analyses (see Supplementary Table S1). Similarly, no significant effects were found for models examining single day maximum/minimum or 2- and 3-day rolling averages for the hormone data (see Supplementary Table S2), and results were unaffected by the clinical status of participants (see Supplementary Table S3). These findings suggest that, contrary to our hypotheses, pronounced changes in ovarian hormones across ovulation do not significantly influence emotional eating scores in the mid-luteal phase of the menstrual cycle.

Because ovarian hormones exhibit constant fluctuations across the menstrual cycle, non-significant effects of pronounced hormonal change across ovulation does not necessarily negate the possible role of pronounced hormonal change on binge-related phenotypes. Instead, it may suggest that pronounced hormonal change during ovulation may occur too late in the menstrual cycle to elicit significant effects on eating behavior in the mid-luteal phase. To date, latency

effects of ovarian hormones have only been examined in animal models, and results suggest a delay of 24-48 hours from the hormone's release before phenotypic effects can be observed (Geary, Asarian, 1999; Gray, Greenwood, 1982; Santollo, Wiley, Eckel, 2007; Thammacharoen, Geary, Lutz, Ogawa, & Asarian, 2009). Given differences in length between the estrous cycle (~4 days) in rodents and the menstrual cycle in humans (average of 28 days), this latency effect may be more prolonged in women. Although the duration of this latency in humans remains unknown, we tested whether pronounced hormone changes in phases that occurred before ovulation (i.e., the follicular phase to ovulatory phase) influenced mid-luteal emotional eating scores. Consistent with all results thus far, there were no significant effects of maximum estradiol values, minimum estradiol values, or difference scores on emotional eating in the mid-luteal phase (all *p*'s >0.05; see Supplemental Table 4; progesterone was not examined, as it is stable and low prior to ovulation).

Overall, results of the current study suggest that, contrary to our hypotheses, pronounced changes in ovarian hormones across ovulation (or the follicular phase) do not significantly influence emotional eating scores in the mid-luteal phase of the menstrual cycle. Rather, same day deviations from a woman's mean that have been examined in previous studies (Blaustein & Wade, 1976; Edler, Lipson, & Keel, 2007; Gray & Wade, 1981; Kemnitz, Gibber, Lindsey, & Eisele, 1989; Klump et al., 2012; Klump, Keel et al., 2013; Klump et al., 2014; Varma et al., 1999) may be the driving force behind the increase in emotional eating during the mid-luteal phase. This may be because natural hormonal changes, such as pronounced changes in estradiol and progesterone across ovulation, are an expected component to the menstrual cycle. As a result, they may create an expected rhythm in the body representing an acceptable range for hormonal change, such that when pronounced increases or decreases in either hormone occurs,

the body knows how to respond and risk for emotional eating does not increase. In contrast, large deviations from a women's mean hormone levels in the mid-luteal phase (such as those examined in previous studies) may reflect a more risky hormonal milieu for women because they are outside of the expected range for hormonal change. Interestingly, it may be that women who engage in emotional eating experience regularly occurring deviations from their expected hormone levels that repeatedly places them at increased risk for emotional eating each month. Although the current data did not explore this hypothesis, studies of other phenotypes strongly related to emotional eating (e.g., depression) support the importance of unexpected deviations on increased risk of psychopathology (Avis et al., Freeman et al., 2006). Future studies are needed to test whether the effects of unexpected deviations extend to women with binge-related phenotypes.

Before ending, key study limitations should be noted. First, a subsample of participants (8%) were eliminated from the primary analyses due to missing data during key hormone phases (e.g., transition to mid-luteal phase) and/or data that were against expectations (e.g., a participant had lower rather than higher estradiol levels during the ovulatory versus mid-luteal phase). While this may have affected results, post-hoc analyses that examined effects of pronounced hormonal change across ovulation and the mid-luteal phase (i.e., not including the transition to mid-luteal phase) yielded similar results. Because these analyses included a larger sample of women compared to the primary analyses, exclusion is unlikely to have unduly influenced the current results.

Second, this study relied on a community rather than clinical population of women. Although past findings suggest no differences in effects across clinical and community samples, post-hoc analyses suggest similar findings between women with and without OBEs.

Nevertheless, the sample size in the group with clinical binge eating was small (*n*=20), suggesting a need for future studies with a larger percentage of individuals with clinical binge eating episodes to verify our results. Finally, we focused on changes during discrete cycle phases (e.g., ovulation, follicular phase) rather than across multiple phases of the cycle. As shown in Figure 1, ovarian hormones display multiple logarithmic and non-linear changes across the cycle that may contribute to emotional eating fluctuations. Future studies should use more comprehensive models (e.g., latent growth curve models, fast Fourier transform models) and approaches to study hormonal changes and variability across the cycle, as well as their contribution to risk for emotional eating and other binge-related phenotypes.

APPENDICES

APPENDIX A

Primary Analyses

Table 1. *Descriptive data for demographic variables, primary study variables, and covariates.*

Variables	Full sample (*n*=390)
Demographic Variables	
Age, mean (*SD*)	17.66 (1.75)
Zygosity, *n* (%)	
Monozygotic	229 (58.1%)
Dizygotic	165 (41.9%)
Race/ethnicity, *n* (%)	
White	331 (84.0%)
African American	39 (9.9%)
Asian/Pacific Islander	1 (0.3%)
Native American	2 (0.5%)
Multiracial	20 (5.1%)
Non-Hispanic	360 (91.4%)
Hispanic	30 (7.9%)
Primary Study Variables	
Average Emotional Eating in Mid-Luteal Phase	
Raw Mean (SD)	0.32 (0.43)
Raw Score Range	0.00-4.01
Within-Person, Z Score Mean (*SD*)	0.01 (0.56)
Within-Person, Z Score Range	-1.39-1.71
Estradiol (pg/mL) per phase	
Maximum EST during Ovulation	
Raw Mean (SD)	3.40 (1.52)
Raw Score Range	0.29-11.89
Within-Person, Z Score Mean (*SD*)	1.32 (0.66)
Within-Person, Z Score Range	-0.53-2.66
Minimum EST during the Transition to Mid-Luteal	
Raw Mean (SD)	2.90 (1.47)
Raw Score Range	0.41-11.67
Within-Person, Z Score Mean (*SD*)	-0.54 (0.96)
Within-Person, Z Score Range	-3.19-2.64
Difference score for EST	
Raw Mean (SD)	0.52 (0.62)
Raw Score Range	-1.63-3.51
Within-Person, Z Score Mean (*SD*)	1.16 (0.80)
Within-Person, Z Score Range	0.03-4.46
Progesterone (pg/mL) per phase	
Minimum PRO during the Transition to Mid-Luteal	
Raw Mean (SD)	111.91 (69.48)
Raw Score Range	15.93-368.57
Within-Person, Z Score Mean (*SD*)	-0.27 (0.64)
Within-Person, Z Score Range	-2.33-1.44

Table 1. *(cont'd)*

Variables	Full sample (*n*=390)
Maximum PRO during Mid-Luteal	
Raw Mean (SD)	213.91 (115.39)
Raw Score Range	21.29-640.62
Within-Person, Z Score Mean (*SD*)	1.85 (0.55)
Within-Person, Z Score Range	0.30-3.21
Difference score PRO	
Raw Mean (SD)	104.61 (71.52)
Raw Score Range	2.49-421.34
Within-Person, Z Score Mean (*SD*)	2.11 (0.74)
Within-Person, Z Score Range	0.15-4.09
Covariates	
Body mass index (raw BMI)	
Mean (*SD*)	23.54 (5.41)
Range	15.31-47.51
Negative affect (within-person z score)	
Maximum Negative Affect during Ovulation	
Raw Mean (SD)	15.68 (4.73)
Raw Score Range	10.00-41.41
Within-Person, Z Score Mean (*SD*)	0.85 (0.84)
Within-Person, Z Score Range	-1.21-3.37
Minimum Negative Affect during the Transition to Mid-Luteal	
Raw Mean (SD)	15.58 (4.23)
Raw Score Range	10.00-36.18
Within-Person, Z Score Mean (*SD*)	-0.69 (0.56)
Within-Person, Z Score Range	-2.08-2.22
Maximum Negative Affect during Mid-Luteal	
Raw Mean (SD)	16.41 (4.78)
Raw Score Range	10.00-37.40
Within-Person, Z Score Mean (*SD*)	-0.46 (0.74)
Within-Person, Z Score Range	-2.06-2.64
Difference score from Ovulation to the Transition to Mid-Luteal	
Raw Mean (SD)	1.09 (2.03)
Raw Score Range	-4.75-12.00
Within-Person, Z Score Mean (*SD*)	0.58 (0.93)
Within-Person, Z Score Range	-1.86-3.39
Difference score from the Transition to Mid-Luteal to Mid-Luteal	
Raw Mean (SD)	1.83 (2.43)
Raw Score Range	-3.33-15.60
Within-Person, Z Score Mean (*SD*)	1.01 (1.10)
Within-Person, Z Score Range	-2.18-4.94
Difference score from Ovulation to Mid-Luteal	
Raw Mean (SD)	-0.78 (2.78)

Table 1. *(cont'd)*

Variables	Full sample (*n*=390)
Raw Score Range	-10.20-11.59
Within-Person, Z Score Mean (*SD*)	-0.43 (1.30)
Within-Person, Z Score Range	-3.94-3.05

Note: EST= estradiol, PRO=progesterone, Difference score= maximum – minimum values. These values are unstandardized (i.e., raw scores) and standardized (i.e., z-scored) means and standard deviations across the 45-day collection period that index the average level of study variables on any given day in relation to the women's mean levels.

Table 2. *Pearson Correlations between the Emotional Eating Scores during the Mid-Luteal Phase and each of the Hormone Values and Covariates.*

Hormone variables and covariates		**r**	***p***
Estrogen	Maximum during Ovulation	0.10	.12
	Minimum during Transition to Mid-Luteal	0.07	.25
	Difference Score	< 0.01	.97
Progesterone	Maximum during Mid-Luteal	-0.05	.39
	Minimum during Transition to Mid-Luteal	-0.02	.72
	Difference Score	-0.03	.63
Negative Affect	Maximum during Ovulation	0.01	.88
	Maximum during Mid-Luteal	0.08	.18
	Minimum during Transition to Mid-Luteal	0.06	.30
	Difference Score Ovulation to Mid-Luteal	-0.07	.17
Body Mass Index	Mean BMI	-0.05	.38

Note: Difference score= maximum – minimum hormone or negative value; Mean BMI= average BMI across all three study visits

Table 3. *Mixed linear models (MLMs) examining associations between emotional eating scores and minimum, maximum, and difference scores for estradiol and progesterone levels in the ovulatory, transition to mid-luteal, and mid-luteal phase.*

Model	*b(SE)*	*t*	*df*	*p*
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=336)				
Intercept	0.08 (0.16)	0.51	315	.61
Min EST during Transition to Mid-Luteal	0.04 (0.04)	0.91	318	.34
Max EST during Ovulation	0.07 (0.06)	1.24	319	.22
Min Negative Affect during Transition to Mid-Luteal	-0.01 (0.06)	-0.23	312	.82
Max Negative Affect during Ovulation	-0.02 (0.04)	-0.54	319	.56
BMI	-0.01 (0.01)	-1.06	317	.29
Difference Score Models (n=336)				
Intercept	0.18 (0.15)	1.16	317	.25
Difference Score EST	-0.01 (0.04)	-0.18	320	.86
Difference Score Negative Affect	-0.01 (0.03)	-0.37	318	.71
BMI	-0.01 (0.01)	-0.96	317	.34
Progesterone Levels				
Maximum/Minimum Model (n=390)				
Intercept	0.16 (0.18)	0.89	343	.38
Min PRO during Transition to Mid-Luteal	0.02 (0.06)	0.37	343	.71
Max PRO during Mid-Luteal	-0.05 (0.06)	-0.86	343	.39
Min Negative Affect during Transition to Mid-Luteal	-0.03 (0.06)	-0.47	335	.64
Max Negative Affect during Mid-Luteal	<0.01 (<0.01)	1.02	342	.31
BMI	<0.01 (0.01)	-0.57	341	.57
Difference Score Models (n=390)				
Intercept	0.13 (0.16)	0.80	342	.42
Difference Score PRO	-0.03 (0.04)	-0.61	342	.55
Difference Score Negative Affect	<0.01 (<0.01)	0.98	342	.33
BMI	<0.01 (0.01)	-0.52	341	.61
Joint Hormone Models				
Maximum/Minimum Models (n=336)				
Intercept	0.08 (0.21)	0.36	290	.72
Min EST during Transition to Mid-Luteal	0.03 (0.05)	0.59	290	.55
Max EST during Ovulation	0.10 (0.06)	1.68	290	.09
Min PRO during Transition to Mid-Luteal	-0.01 (0.07)	-0.11	290	.92
Max PRO during Mid-Luteal	-0.02 (0.06	-0.32	290	.75
Max Negative Affect during Ovulation	-0.02 (0.04)	-0.51	290	.61

Table 3 *(cont'd)*

Model	***b(SE)***	***t***	***df***	***p***
Min Negative Affect during Transition to Mid-Luteal	-0.02 (0.07)	-0.25	290	.80
Max Negative Affect during Mid-Luteal	<0.01 (<0.01)	0.69	290	.49
BMI	-0.01 (0.01)	-1.05	290	.30
Difference Score Models (n=368)				
Intercept	0.13 (0.22)	0.58	284	.56
Difference Score EST	0.08 (0.14)	0.62	290	.54
Difference Score PRO	<0.01 (0.08)	0.05	291	.96
Difference Negative Affect Ovulation to Mid-Luteal	<0.01 (<0.01)	-0.37	291	.71
Difference Score EST x Difference Score PRO	-0.03 (0.06)	-0.56	291	.58
BMI	-0.01 (0.01)	-0.94	280	.35

Note: Abbreviations include: SE= standard error; EST= estradiol, PRO= progesterone, BMI= body mass index, Max= maximum, Min= minimum.

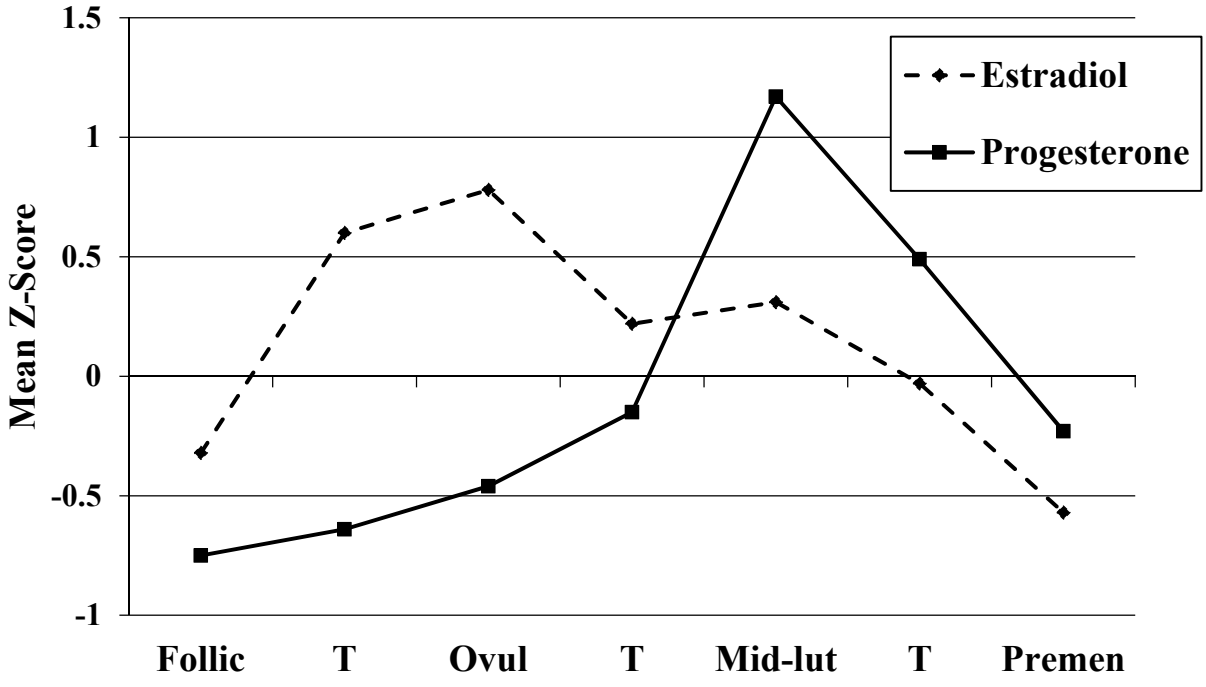

Figure 1. *Changes in ovarian hormone levels across the menstrual cycle in the current sample.* Mean *z*-score= the mean of the 5-day rolling averages calculated within-subjects and then averaged across participants; Follic= follicular phase; Ovul= ovulatory phase; Mid-lut= mid-luteal phase; Premen= premenstrual phase; T= transition days that are in between phases. The number of days included in each phase varied by participant based on their cycle length, but the days roughly corresponded to the following (1st day of menstrual bleeding= +1; previous day= -1); Follicular= +3 to +12; Ovulatory= -15 to -12; Midluteal= -9 to -5; Premenstrual= -3 to +1.

APPENDIX B

Post-hoc Analyses

Table S1. *Mixed linear models (MLMs) examining associations between emotional eating scores and minimum, maximum, and difference scores for estradiol and progesterone levels in ovulation and the mid-luteal phase.*

Model	*b(SE)*	*t*	*df*	*p*
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=361)				
Intercept	0.19 (0.16)	1.20	343	.23
Max EST during Ovulation	0.04 (0.05)	0.89	345	.38
Min EST during Mid-Luteal	-0.02 (0.05)	-0.35	344	.73
Max Negative Affect during Ovulation	-0.02 (0.03)	-0.55	338	.58
Min Negative Affect during Mid-Luteal	0.10 (0.05)	2.08	345	.04
BMI	-0.01 (0.01)	-0.91	345	.36
Difference Score Models (n=361)				
Intercept	0.18 (0.15)	1.19	341	.23
Difference Score EST	0.03 (0.04)	0.82	345	.42
Difference Score Negative Affect	-0.04 (0.03)	-1.55	340	.12
BMI	-0.01 (0.01)	-1.03	345	.31
Progesterone Levels				
Maximum/Minimum Model (n=427)				
Intercept	0.28 (0.19)	1.47	342	.14
Min PRO during Ovulation	0.08 (0.06)	1.41	339	.16
Max PRO during Mid-Luteal	-0.05 (0.06)	-0.92	343	.36
Min Negative Affect during Ovulation	-0.02 (0.03)	-0.44	338	.66
Max Negative Affect during Mid-Luteal	0.05 (0.03)	1.67	341	.10
BMI	-0.01 (0.01)	-0.92	343	.36
Difference Score Models (n=427)				
Intercept	0.32 (0.18)	1.78	343	.08
Difference Score PRO	-0.07 (0.04)	-1.59	342	.11
Difference Score Negative Affect	0.04 (0.02)	1.49	337	.14
BMI	-0.01 (0.01)	-1.01	343	.31
Joint Hormone Models				
Maximum/Minimum Models (n=361)				
Intercept	0.29 (0.20)	1.44	343	.15
Max EST during Ovulation	0.04 (0.05)	0.84	341	.40
Min EST during Mid-Luteal	-0.02 (0.05)	-0.33	340	.74
Min PRO during Ovulation	0.07 (0.06)	1.19	341	.23
Max PRO during Mid-Luteal	-0.05 (0.06)	-0.87	343	.38
Max Negative Affect during Ovulation	-0.01 (0.05)	-0.12	342	.90
Min Negative Affect during Ovulation	-0.01 (0.06)	-0.22	341	.82
Max Negative Affect during Mid-Luteal	0.03 (0.04)	0.81	342	.42
Min Negative Affect during Mid-Luteal	0.08 (0.05)	1.52	343	.13

Table S1 *(cont'd)*

Model	***b(SE)***	***t***	***df***	***p***
BMI	-0.01 (0.01)	-0.93	343	.36
Difference Score Models (n=361)				
Intercept	0.13 (0.31)	0.43	343	.66
Difference Score EST	0.12 (0.13)	0.91	343	.36
Difference Score PRO	<0.01 (0.10)	0.02	342	.98
Difference Negative Affect Ovulation to Mid- Luteal (Max Ov, Min ML)	-0.03 (0.03)	-0.84	343	.40
Difference Negative Affect Ovulation to Mid-Luteal (Max ML, Min Ov)	0.02 (0.03)	0.76	343	.45
Difference Score EST x Difference Score PRO	-0.04 (0.05)	-0.72	343	.47
BMI	-0.01 (0.01)	-1.03	343	.31

Note: Abbreviations include: SE= standard error; EST= estradiol, PRO= progesterone, BMI= body mass index, Max= maximum, Min= minimum.

Table S2. *Mixed linear models (MLMs) examining associations between emotional eating scores and minimum, maximum, and difference scores for estradiol and progesterone levels across ovulation using single day maximum/minimum and 2- and 3-day rolling average variables.*

Model	*b(SE)*	*t*	*df*	*p*
Single Day Maximum/Minimum Variables				
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=395)				
Intercept	0.09 (0.14)	0.63	376	.53
Min EST during Transition to Mid-Luteal	0.01 (0.04)	0.24	378	.81
Max EST during Ovulation	0.03 (0.04)	0.83	373	.41
Min Negative Affect during Transition to Mid-Luteal	0.04 (0.04)	1.23	378	.22
Max Negative Affect during Ovulation	-0.01 (0.03)	-0.44	370	.66
BMI	<0.01 (0.01)	-0.56	374	.57
Difference Score Models (n=395)				
Intercept	0.12 (0.14)	0.85	377	.40
Difference Score EST	0.01 (0.03)	0.33	370	.74
Difference Score Negative Affect	-0.03 (0.02)	-1.05	376	.30
BMI	<0.01 (0.01)	-0.56	374	.57
Progesterone Levels				
Maximum/Minimum Model (n=402)				
Intercept	0.13 (0.19)	0.72	384	.48
Min PRO during Transition to Mid-Luteal	0.01 (0.05)	0.29	377	.77
Max PRO during Mid-Luteal	-0.03 (0.06)	-0.62	385	.54
Min Negative Affect during Transition to Mid-Luteal	0.04 (0.04	1.07	384	.29
Max Negative Affect during Mid-Luteal	0.06 (0.03)	2.09	276	.04
BMI	<0.01 (0.01)	-0.60	381	.55
Difference Score Models (n=402)				
Intercept	0.17 (0.17)	1.00	384	.32
Difference Score PRO	-0.03 (0.04)	-0.83	385	.41
Difference Score Negative Affect	0.02 (0.02)	1.03	383	.30
BMI	<0.01 (0.01)	-0.68	382	.50
Joint Hormone Models				
Maximum/Minimum Models (n=395)				
Intercept	0.13 (0.20)	0.66	378	.51
Min EST during Transition to Mid-Luteal	0.01 (0.05)	0.25	373	.80
Max EST during Ovulation	0.03 (0.04)	0.75	371	.45
Min PRO during Transition to Mid-Luteal	<0.01 (0.06)	0.06	350	.95
Max PRO during Mid-Luteal	-0.04 (0.06)	-0.79	378	.43

Table S2 *(cont'd)*

Model	***b(SE)***	***t***	***df***	***p***
Max Negative Affect during Ovulation	-0.01 (0.03)	-0.37	370	.71
Min Negative Affect during Transition to Mid-Luteal	0.03 (0.04)	0.97	378	.33
Max Negative Affect during Mid-Luteal	0.06 (0.03)	2.14	371	.03
BMI	<0.01 (0.01)	-0.68	374	.50
Difference Score Models (n=395)				
Intercept	0.27 (0.24)	1.15	377	.25
Difference Score EST	-0.02 (0.11)	-0.19	376	.85
Difference Score PRO	-0.06 (0.07)	-0.82	377	.42
Difference Negative Affect Ovulation to Mid-Luteal	-0.02 (0.03)	-0.66	373	.51
Difference Score EST x Difference Score PRO	0.01 (0.04)	0.34	378	.73
BMI	<0.01 (0.01)	-0.58	374	.56
2-day Rolling Average Variables				
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=391)				
Intercept	0.13 (0.15)	0.91	370	.36
Min EST during Transition to Mid-Luteal	0.02 (0.04)	0.43	371	.67
Max EST during Ovulation	0.01 (0.04)	0.24	368	.81
Min Negative Affect during Transition to Mid-Luteal	0.03 (0.04)	0.76	368	.45
Max Negative Affect during Ovulation	-0.02 (0.03)	-0.53	366	.60
BMI	<0.01 (0.01)	-0.62	367	.54
Difference Score Models (n=391)				
Intercept	0.15 (0.14)	1.06	370	.29
Difference Score EST	<0.01 (0.03)	-0.15	367	.88
Difference Score Negative Affect	-0.02 (0.03)	-0.85	367	.40
BMI	<0.01 (0.01)	-0.62	366	.54
Progesterone Levels				
Maximum/Minimum Model (n=402)				
Intercept	0.18 (0.19)	0.91	381	.37
Min PRO during Transition to Mid-Luteal	<0.01 (0.05)	0.03	374	.98
Max PRO during Mid-Luteal	-0.06 (0.06)	-1.03	381	.30
Min Negative Affect during Transition to Mid-Luteal	0.02 (0.04)	0.68	378	.51
Max Negative Affect during Mid-Luteal	0.07 (0.03)	2.40	372	.02
BMI	<0.01 (0.01)	-0.65	378	.52

Table S2 *(cont'd)*

Model	*b(SE)*	*t*	*df*	*p*
Difference Score Models (n=402)				
Intercept	0.15 (0.17)	0.86	382	.39
Difference Score PRO	-0.04 (0.04)	-0.92	382	.36
Difference Score Negative Affect	0.03 (0.02)	1.41	378	.16
BMI	<0.01 (0.01)	-0.58	379	.56
Joint Hormone Models				
Maximum/Minimum Models (n=391)				
Intercept	0.21 (0.21)	1.01	371	.31
Min EST during Transition to Mid-Luteal	0.03 (0.05)	0.60	365	.55
Max EST during Ovulation	<0.01 (0.04)	0.12	366	.90
Min PRO during Transition to Mid-Luteal	-0.02 (0.06)	-0.31	340	.76
Max PRO during Mid-Luteal	-0.07 (0.06)	-1.06	370	.29
Max Negative Affect during Ovulation	-0.02 (0.03)	-0.53	366	.60
Min Negative Affect during Transition to Mid-Luteal	0.02 (0.04)	0.54	368	.59
Max Negative Affect during Mid-Luteal	0.07 (0.03)	2.45	363	.02
BMI	<0.01 (0.01)	-0.76	366	.45
Difference Score Models (n=391)				
Intercept	0.31 (0.24)	1.28	374	.20
Difference Score EST	-0.03 (0.11)	-0.32	371	.75
Difference Score PRO	-0.05 (0.08)	-0.64	369	.52
Difference Negative Affect Ovulation to Mid-Luteal	-0.03 (0.03)	-1.23	371	.22
Difference Score EST x Difference Score PRO	0.01 (0.04)	0.34	373	.74
BMI	<0.01 (0.01)	-0.64	369	.52
3-Day Rolling Average Variables				
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=360)				
Intercept	0.06 (0.16)	0.40	310	.69
Min EST during Transition to Mid-Luteal	<0.01 (0.04)	-0.06	313	.95
Max EST during Ovulation	-0.01 (0.04)	-0.15	289	.86
Min Negative Affect during Transition to Mid-Luteal	0.06 (0.04)	1.44	307	.15
Max Negative Affect during Ovulation	-0.04 (0.03)	-1.29	291	.20
BMI	<0.01 (0.01)	0.41	302	.70
Difference Score Models (n=360)				
Intercept	0.06 (0.16)	0.38	311	.71
Difference Score EST	<0.01 (0.03)	-0.07	294	.94

Table S2 *(cont'd)*

Model	*b(SE)*	*t*	*df*	*p*
Difference Score Negative Affect	-0.05 (0.03)	-1.74	305	.08
BMI	<0.01 (0.01)	.411	303	.68
Progesterone Levels				
Maximum/Minimum Model (n=377)				
Intercept	0.15 (0.19)	0.77	341	.44
Min PRO during Transition to Mid-Luteal	-0.02 (0.05)	-0.31	336	.78
Max PRO during Mid-Luteal	-0.09 (0.07)	-1.34	338	.19
Min Negative Affect during Transition to Mid-Luteal	0.05 (0.04)	1.44	338	.15
Max Negative Affect during Mid-Luteal	0.07 (0.03)	2.38	334	.02
BMI	<0.01 (0.01)	0.08	342	.93
Difference Score Models (n=377)				
Intercept	0.07 (0.17)	0.40	344	.69
Difference Score PRO	-0.03 (0.04)	-0.68	343	.50
Difference Score Negative Affect	0.02 (0.02)	0.96	343	.34
BMI	< 0.01 (0.01)	0.08	343	.94
Joint Hormone Models				
Maximum/Minimum Models (n=360)				
Intercept	0.19 (0.21)	0.91	312	.37
Min EST during Transition to Mid-Luteal	<0.01 (0.04)	-0.07	308	.95
Max EST during Ovulation	-0.01 (0.04)	-0.31	290	.76
Min PRO during Transition to Mid-Luteal	<0.01 (0.07)	0.02	291	.98
Max PRO during Mid-Luteal	-0.09 (0.07)	-1.25	308	.21
Max Negative Affect during Ovulation	-0.04 (0.03)	-1.11	290	.27
Min Negative Affect during Transition to Mid-Luteal	0.05 (0.04)	1.31	305	.19
Max Negative Affect during Mid-Luteal	0.07 (0.03)	2.13	293	.03
BMI	<0.01 (0.01)	0.26	301	.79
Difference Score Models (n=360)				
Intercept	0.17 (0.25)	0.69	327	.49
Difference Score EST	0.01 (0.11)	0.11	328	.92
Difference Score PRO	-0.02 (0.08)	-0.28	324	.78
Difference Negative Affect Ovulation to Mid-Luteal	-0.05 (0.03)	-1.76	321	.08
Difference Score EST x Difference Score PRO	<0.01 (0.04)	-0.09	328	.93
BMI	<0.01 (0.01)	0.09	320	.93

Note: Abbreviations include: SE= standard error; EST= estradiol, PRO= progesterone, BMI= body mass index, Max= maximum, Min= minimum.

Table S3. *Regression models examining associations between emotional eating scores and minimum, maximum, and difference scores for estradiol and progesterone levels across the ovulatory, transition to mid-luteal, and mid-luteal phase in women with objective binge episodes.*

Model	*b*	*t*	*B(SE)*	*p*
Single Hormone Models				
Estradiol Levels				
Maximum/Minimum Model (n=17)				
Intercept		0.13	0.08 (0.61)	.90
Max EST during the Ovulation	0.15	0.50	0.08 (0.16)	.63
Min EST during the Transition to Mid-Luteal	0.05	0.13	0.02 (0.15)	.90
Max Negative Affect during Ovulation	-0.28	-0.88	-0.12 (0.13)	.40
Min Negative Affect during the Transition to Mid-Luteal	0.04	0.13	0.03 (0.25)	.90
BMI	0.02	0.06	<0.01 (0.02)	.95
Difference Score Models (n=17)				
Intercept		0.22	0.11 (0.51)	.83
Difference Score EST	0.07	0.29	0.04 (0.12)	.78
Difference Score Negative Affect	-0.19	-0.78	-0.08 (0.11)	.45
BMI	0.02	0.07	<0.01 (0.02)	.94
Progesterone Levels				
Maximum/Minimum Model (n=20)				
Intercept		-0.14	-0.10 (0.68)	.89
Max PRO during Mid-Luteal	0.11	0.41	0.10 (0.24)	.69
Min PRO during the Transition to Mid-Luteal	0.37	1.22	0.26 (0.21)	.24
Max Negative Affect during Mid-Luteal	0.18	0.45	0.13 (0.28)	.66
Min Negative Affect during the Transition to Mid-Luteal	-0.30	-0.65	-0.28 (0.43)	.52
BMI	-0.04	-0.15	<0.01 (0.02)	.89
Difference Score Models (n=20)				
Intercept		0.46	0.28 (0.61)	.66
Difference Score PRO	-0.17	-0.66	-0.12 (0.17)	.52
Difference Score Negative Affect	0.04	0.17	0.05 (0.27)	.87
BMI	<0.01	0.01	<0.01 (0.02)	.99
Joint Hormone Models				
Maximum/Minimum Models (n=16)				
Intercept		-0.31	-0.28 (0.92)	.77
Max EST during Ovulation	0.23	0.72	0.12 (0.16)	.50
Min EST during the Transition to Mid-Luteal	0.16	0.29	0.08 (0.26)	.78
Max PRO during Mid-Luteal	0.39	1.22	0.29 (0.24)	.26
Min PRO during the Transition to Mid-Luteal	0.16	0.30	0.10 (0.32)	.77
Max Negative Affect during Ovulation	-0.57	-1.59	-0.23 (0.15)	.16

Table S3. *(cont'd)*

Model	***b***	***t***	***B(SE)***	***p***
Min Negative Affect during the Transition to Mid-Luteal	-0.41	-0.55	-0.31 (0.56)	.60
Max Negative Affect during Mid-Luteal	0.21	0.30	0.13 (0.42)	.77
BMI	-0.12	-0.26	-0.01 (0.03)	.80
Difference Score Models (n=16)				
Intercept		1.81	1.74 (0.96)	.94
Difference Score EST	-1.94	-1.68	-0.92 (0.55)	.19
Difference Score PRO	-0.64	-1.72	-0.42 (0.25)	.11
Difference Negative Affect across Ovulation to Mid-Luteal	-0.44	-1.61	-0.20 (0.12)	.13
Difference Score EST x Difference Score PRO	2.12	1.74	0.40 (0.28)	.11
BMI	-0.21	-0.78	-0.02 (0.02)	.45

Note: Abbreviations include: SE= standard error; EST= estradiol, PRO= progesterone, BMI= body mass index, Max= maximum, Min= minimum.
Due to a small number of complete twin pairs in this sample (*n*=3), all analyses in the binge eating group of women were conducted using linear regression models.

Table S4. *Mixed linear models (MLMs) examining associations between emotional eating scores and minimum, maximum, and difference scores for estradiol levels across the follicular and ovulatory phases (n=224).*

Model	*b(SE)*	*t*	*df*	*p*
Estradiol Levels				
Maximum/Minimum Model				
Intercept	0.06 (0.22)	0.26	181	.79
Max EST during Ovulation	0.05 (0.07)	0.71	181	.48
Min EST during Follicular	0.12 (0.08)	1.49	173	.14
Max Negative Affect Ovulation	<0.01 (0.05)	-0.09	182	.93
Min Negative Affect during Follicular	-0.02 (0.04)	-0.39	181	.70
BMI	<0.01 (0.01)	-0.23	182	.82
Difference Score Models				
Intercept	0.07 (0.22)	0.34	181	.74
Difference Score EST	-0.02 (0.06)	-0.30	177	.76
Difference Score Negative Affect	<0.01 (0.04)	0.04	176	.97
BMI	<0.01 (0.01)	-0.24	183	.81

Note: Abbreviations include: SE= standard error; EST= estradiol, BMI= body mass index, Max= maximum, Min= minimum.

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