Ovarian hormone fluctuations predict within-cycle shifts in women's food intake

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ABSTRACT

What role do ovarian hormones play in modulating day-to-day shifts in women's motivational priorities? In many nonhuman mammals, estradiol causes drops in feeding and foraging, progesterone reverses this effect, and the two hormones in combination produce cycle phase shifts characterized by lower food intake near ovulation when sexual receptivity is at its peak. Hormonal predictors of within-cycle shifts in women's total food intake have not been previously tested. Here, in a study with both daily hormone measures and self-reported food intake, we found that within-cycle fluctuations in estradiol negatively predicted shifts in food intake, progesterone fluctuations positively predicted them, and the two hormones together statistically mediated a significant peri-ovulatory drop in eating. These patterns are precisely opposite to those previously reported for sexual desire from this same sample (i.e. positive and negative effects of estradiol and progesterone, respectively, on desire). To more precisely test endocrine regulation of tradeoffs between sexual and eating motivation, a difference score for the daily standardized values of the sexual desire and food intake variables was created. Fluctuations in estradiol and progesterone were oppositely associated with shifts in this difference score, supporting hormone modulation of tradeoffs between alternative motivational priorities. These tradeoffs were especially pronounced during the fertile window of the menstrual cycle on days when conception was possible, consistent with the hormone effects functioning to shift motivational salience between feeding and mating depending on within-cycle changes in fecundity. The findings provide direct evidence that phylogenetically conserved endocrine signals regulate daily shifts in human motivational priorities.

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1. Introduction

Gonadal hormones have been proposed to regulate the ranking of immediate motivational and behavioral priorities (Fessler 2003; Schneider et al. 2013). Females of many species shift their behavioral priorities from feeding and foraging to sexual behaviors when in the fertile region of the estrous or menstrual cycle (Fessler 2003; Klingerman et al. 2010; Schneider et al. 2013). In nonhuman primates, in particular, estradiol administration decreases food intake in ovariectomized females, whereas progesterone injections are without effect in isolation but reverse the effects of estradiol on eating (e.g., Bielert and Busse 1983; Kemnitz et al. 1989; Michopoulos and Wilson 2011; for a review, see Asarian and Geary 2006). Sexual receptivity in nonhuman primates follows the opposite pattern, with positive effects of estradiol but negative effects of progesterone (e.g., Kendrick and Dixson 1985; Wallen et al. 1984; Zehr et al. 1998; for a review, see Emery Thompson 2009). Because estradiol peaks near ovulation but progesterone does so in the

non-fecund luteal phase, these hormone effects are the likely causes of estrous shifts in motivational priorities in naturally cycling animals.

Although a number of studies have reported cycle phase shifts in women's sexual motivation (reviewed in Roney 2015; Wallen 2001) and food intake (reviewed in Asarian and Geary 2006; Buffenstein et al. 1995; Fessler 2003), very little research has addressed the hormonal predictors of these variables in natural menstrual cycles. Two smaller studies supplied some evidence for associations between within-cycle shifts in estradiol and progesterone and measures of women's emotional or binge eating (Klump et al. 2008, 2013), but the current study is the first, to the best of our knowledge, that measures ovarian steroid hormones and reports of total food intake across full menstrual cycles. With respect to sexual motivation, published results from the current study demonstrated positive relationships between within-cycle fluctuations in estradiol and day-to-day changes in sexual desire, but negative relationships between progesterone and desire (Roney and Simmons 2013, 2016). Our goal here is to test whether these hormones have associations with food intake that are opposite to their associations with sexual motivation.

We hypothesized negative and positive effects of estradiol and progesterone, respectively, on women's daily reports of total food intake;

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tested for a positive interaction between the two hormones given that in nonhuman primates estradiol inhibits feeding only when progesterone is low; and tested for hormonal mediation of possible cycle phase shifts in eating. Because this study is unique in having data on both food intake and sexual desire from the same women on the same days, we also tested hormonal predictors of a difference score between standardized values of the two dependent variables as a means of assessing hormonal modulation of tradeoffs between the two motivational priorities.

2. Methods

2.1. Participants

Participants were part of a broader study that examined hormonal correlates of temporal shifts in women's psychology and behavior (Roney and Simmons 2013). Fifty-two women participated across 1–2 menstrual cycles, with 37 having participated in both cycles. Although hormone data were collected in both cycles, food intake measures were collected only in the second cycle, and thus the present manuscript analyzes data from cycle 2 only. Hormone data were available for 36 women in this cycle (saliva samples from one woman with many missing samples were not assayed), who had a mean age of 18.7 years. We estimated that 24 of these 36 cycles were ovulatory (see below), and the analyses in the main text focus on these women (mean age = 18.9 years). All women were naturally cycling and provided written informed consent for their participation; the research was approved by the UCSB Institutional Review Board. Further details regarding this sample appear in Roney and Simmons (2013).

2.2. Procedure

Participants were asked to complete a survey each morning via a secure website beginning on the day of menses onset and continuing until the end of their cycle as marked by the onset of next menses. The measures analyzed here were contained in this survey (see below). Women also collected saliva samples on days corresponding to the survey response days. These were collected by passive drool into polypropylene vials each morning. Further details regarding sample collection and storage appear in Roney and Simmons (2013).

2.3. Measures

We previously constructed a composite measure of daily food intake from specific items in the online survey for use as a control variable in a paper that examined relationships between daily stress and estradiol (Roney and Simmons 2015). For consistency, we have used the same measure of food intake in this paper. The composite was constructed from a global measure of amount eaten, "How much did you eat yesterday?" (1–5 scale from much less to much more than usual), as well as from ratings of individual meal sizes (for each meal, participants rated from 1 to 5 the size of meal from much smaller to much larger than usual; zero was assigned if the meal was skipped). The three meal size ratings were averaged and this mean was then further averaged with the global rating ($r = 0.57$ across all data points) to compute the composite measure of food intake.

Participants also indicated how "hungry" they were each day (1–5 scale from much less to much more than usual). This item was analyzed separately from the food intake variable for two reasons. First, findings in nonhuman species suggest that ovarian hormones affect eating by reducing thresholds for satiety and thus decreasing meal sizes, but without affecting latency to eating or number of meals (Asarian and Geary 2006; Butera 2010); subjective ratings of hunger might index initial desire for eating more than thresholds for satiety, and thus exhibit different relationships with hormone fluctuations than measures of amount eaten. Second, hunger ratings exhibited only modest correlations with

meal size ratings ($r = 0.39$ across all samples). Because the nonhuman literature from which our hypotheses were constructed has assessed hormonal predictors of total food intake, our food intake measure is treated as the primary dependent variable in the main text. For completeness, however, we present in Supplementary Online Materials (SOM) parallel data analyses for both the hunger variable in isolation and a composite measure that adds the hunger variable to the food intake variable.

Participants indicated any intentional food restriction each day via the item: "Did you try to restrict your eating (diet) yesterday?" (yes/no binary response). Amount of exercise was reported each day by selecting among choices for minutes of exercise (0, 0–15, 15–30, 30–60, and >60). Subjective sexual desire was assessed daily via the survey item: "How much did you desire sexual contact yesterday?" (1–7 scale). Hormonal predictors of this item across both cycles were reported in Roney and Simmons (2013); here, we analyzed responses to this item in cycle 2 only as part of a difference score (see Statistical models) in order to test tradeoffs between eating and sexual motivation. Because survey items referred to "yesterday," responses for all items were aligned with hormone concentrations from the previous day. For the ovulatory cycles with food intake data, average cycle length was 26.4 days, resulting in 634 possible survey response days. Valid data for the food intake measure were available for 564 days, for a compliance rate of 89%.

2.4. Hormone assays

Saliva samples were shipped on dry ice for hormone assay at the California Regional Primate Research Center, Davis, CA. Prior to shipping, we estimated the day of ovulation as 15 days prior to the end of each cycle and then sent for assay each of the available samples in a nine day window centered on this day, as well as samples from alternating days outside of this window. Samples were assayed for estradiol, testosterone, and progesterone; because our hypotheses pertained to estradiol and progesterone, models containing only these hormones appear in the main text, but exploratory analyses including testosterone appear in Supplementary Online Materials (SOM). Full details of the assay procedure were reported in Roney and Simmons (2013); intra- and interassay CVs were below 10% for each of the hormones. Five-hundred and sixty-five samples from cycle 2 were sent for assay, but insufficient saliva in some samples led to receipt of 549 and 534 assay values for progesterone and estradiol, respectively (progesterone was assayed first, thus explaining the discrepancy). Hormone concentrations >3 SD from phase-specific means were removed as described previously (Roney and Simmons 2013). After such exclusions, 542 and 525 hormone values were available for progesterone and estradiol, respectively, for the total set of 36 cycles; these figures were 356 and 345 values for progesterone and estradiol, respectively, among the 24 ovulatory cycles.

2.5. Cycle phase estimation

Hormone data were used to estimate the day of ovulation within ovulatory cycles. First, following Ellison et al. (1987), we designated as ovulatory cycles with maximum progesterone values of at least 300 pmol/l (24 of 36 cycles). For these cycles, we used a previously published algorithm (Lipson and Ellison 1996) to estimate the day of ovulation: we identified the day of peak estradiol (conditional on this day preceding the luteal phase rise in progesterone) and then designated the day of ovulation as the day after this peak with the largest drop in estradiol from the previous day. For example, if estradiol was measured at 6 pg/ml on the peak day, 5.8 the next day, and 3.2 two days after the peak, then two days after the peak would be designated the day of ovulation. For cases in which there were missing hormone data for the day after peak estradiol ($n = 5$), the peak day was designated day minus one and the following day was designated the day of ovulation (day zero);