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How reproductive hormonal changes affect relationship dynamics for women and men: A 15-day diary study

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ABSTRACT

Research suggests that women's sexual psychology and behavior change across the ovulatory cycle, but very little is known about how fluctuations in estradiol and progesterone – two hormones that systematically vary across the ovulatory cycle – affect romantic relationship dynamics. We present the first dyadic study to assess daily hormonal fluctuations and personal and relationship well-being from both partners' perspectives. Specifically, we recruited women who were not using hormonal contraception and their partners for a 15-day diary study. Participants collected daily urine samples to assess estradiol, progesterone, and testosterone, and they responded to daily questions about their relationship. Results revealed that increases in estradiol negatively affected women's relationship evaluations. Men perceived these changes, which in turn, affected men's well-being. The present findings highlight the importance of women's hormonal fluctuations in shaping relationship dynamics and provide, for the first time, information about how such fluctuations affect male partners.

1. Introduction

Hormonal fluctuations across the ovulatory cycle impact women's cognition, emotions, and behaviors (e.g., Durante, Griskevicius, Cantu, & Simpson, 2014; Eisenbruch, Simmons, & Roney, 2015; Motta-Mena & Puts, 2017; Roney & Simmons, 2013; Stenstrom, Saad, & Hingston, 2018). Surprisingly, despite the centrality of conceptive status and romantic relationships to human reproduction, little research has investigated how these hormonal changes affect women's long-term romantic relationships. The few studies on this topic (e.g., Larson, Haselton, Gildersleeve, & Pillsworth, 2013) have overwhelmingly relied upon reports from women only (cf. Gangestad, Garver-Apgar, Cousins, & Thornhill, 2014), and none have tracked women's estradiol, progesterone, and testosterone over time. Given romantic couples' intense interdependence (Kelley & Thibaut, 1978) – and given work suggesting that men detect and respond to cues of women's ovulation (e.g., Haselton & Gildersleeve, 2011) – a dyadic perspective can provide inroads into understanding how hormonal changes affect relationship and personal well-being for both members of a romantic couple. We report here the first dyad-level examination of how daily fluctuations in estradiol, progesterone, and testosterone are associated with relationship evaluations, personal well-being, and sexual dynamics of both women and men involved in a romantic relationship, where both partners were active participants.

1.1. Relationship changes during conceptive phases

How might relationship dynamics change as a function of hormonal changes that women experience during the ovulatory cycle? Evolutionary theories would make specific predictions on how the relationship with one's romantic partner may become more negative during the conceptive phase as compared to non-conceptive phase. At least two theoretical arguments derived from evolutionary and biological psychology support this idea.

1.1.1. Dual mating strategy

Offspring survival is aided by fathers' contribution of direct benefits (e.g., physical protection, mentorship, food provisioning) and indirect benefits (e.g., genes that promote robustness and attractiveness). Evolutionary perspectives have been used to predict that women prefer long-term partners possessing characteristics indicative of both good genes and an ability and willingness to invest in the family (and such predictions have received substantial empirical support; e.g., Buss, 1989; Fletcher & Simpson, 2000; Lu, Zhu, & Chang, 2015). However,

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men who have both good investment characteristics and good genes are in limited supply. Thus, according to the dual mating hypothesis, shifting mate preferences across the cycle motivate women to reproduce with a man of high genetic quality while preserving a long-term romantic relationship with an investing partner (e.g., Pillsworth, Haselton, & Buss, 2004). Some data support this idea by showing that women's preferences for symmetrical and masculine men increase prior to ovulation (e.g., Gangestad, Simpson, Cousins, Garver-Apgar, & Christensen, 2004; Gangestad & Thornhill, 2008; Gildersleeve, Haselton, & Fales, 2014; Penton-Voak et al., 1999; Puts, 2005), although these ovulatory shifts have not been always replicated (see, e.g., Jones, Hahn, Fisher, Wang, Kandrik, Han et al., 2018; Jünger, Kordsmeyer, Gerlach, & Penke, 2018; Jünger, Motta-Mena et al., 2018; Marcinkowska, Galbarczyk, & Jasienska, 2018; Wood, Kressel, Joshi, & Louie, 2014).

Regardless of whether women's preferences for putative good-genes indicators increase during the fertile window, an array of findings suggest that women report greater sexual interest in extra-dyadic partners in the fertile window as compared to the luteal phase (e.g., Arslan, Schilling, Gerlach, & Penke, 2018; Gangestad, Thornhill, & Garver-Apgar, 2002; Gangestad, Thornhill, & Garver-Apgar, 2005; Haselton & Gangestad, 2006; Shimoda, Campbell, & Barton, 2017; Shirazi et al., 2019; but see a negative finding by Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018) and that women's general sexual desire and general attraction to men increases in the fertile window (e.g., Arslan et al., 2018; Bullivant et al., 2004; Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018; Jünger, Kordsmeyer et al., 2018; Jünger, Motta-Mena et al., 2018; Roney & Simmons, 2013). Consequently, changes in attraction toward extra-dyadic partners may also impact feelings toward one's long-term partner (e.g., Rusbult, Martz, & Agnew, 1998). Indeed, some evidence suggests that women feel less close and are less attracted to their partner during the peri-ovulatory phase (e.g., Grebe, Thompson, & Gangestad, 2016), especially if their partner is not very sexually attractive (Larson et al., 2013), though other work has found generalized increases in sexual attraction to primary partners as well as extra-dyadic men (e.g., Arslan et al., 2018).

Furthermore, ancestrally, men likely paid higher fitness costs when their partners engaged in extradyadic sexual interactions during the fertile period, as women's extradyadic sexual behaviors increased the probability that men would have invested in another man's offspring. Thus, selection may have favored greater male vigilance toward female partners at that time. In turn, women may be expected to resist these efforts. Indeed, several studies examining cycle shifts in relationship dynamics report greater male jealousy and vigilance (Gangestad et al., 2002, 2014; Haselton & Gangestad, 2006; Pillsworth & Haselton, 2006; but for a null finding, see Arslan et al., 2018) and increased female resistance to vigilance (Gangestad et al., 2014) during the conceptive phase.

1.1.2. Female extended sexuality

An alternative evolutionary perspective emphasizes the function and nature of women's non-conceptive sexual interests. Most mammalian females are sexually active only when conceptive. Primate females are often sexually active during some non-conceptive days, but rarely to the extent that women are. As sexual receptivity and proceptivity would have entailed opportunity costs ancestrally (e.g., in terms of investment in offspring and food acquisition), why did human females evolve sexual interests during non-conceptive phases? One possibility is that, ancestrally, these interests served to solidify pair-bonds and bolster commitment and intimacy between romantic partners (e.g., Grebe, Gangestad, Garver-Apgar, & Thornhill, 2013; Thornhill & Gangestad, 2008). Accordingly, the non-conceptive luteal phase may promote intradyadic, but not extradyadic, sexual interest (Grebe et al., 2016; cf. Roney & Simmons, 2016), especially for women strongly invested in their relationships (Grebe et al., 2013; Grøntvedt, Grebe, Kennair, & Gangestad, 2017; for an alternative perspective, see Eastwick & Finkel, 2012). Preliminary empirical evidence indeed suggests that women report higher commitment to their romantic partner during the luteal phase than in the follicular phase (Jones et al., 2005). In sum, there are multiple reasons to hypothesize that women will feel more negatively toward their romantic partner during the conceptive phase, and will feel more positively during the non-conceptive phases.

1.2. The male partner's perspective

Given the physical and psychological changes that women experience across the cycle, male partners might be able to detect such changes and react to them (e.g., Haselton & Gildersleeve, 2011). Besides changes in jealousy and mate guarding, little is known about how men's feelings toward their romantic partner vary as a function of their partner's hormonal changes across the cycle. Given that romantic partners are strongly interdependent and respond to each other's behavioral and emotional changes (Kelley & Thibaut, 1978), men might also be affected by their partner's hormonal fluctuations. Further, no studies have investigated how men's hormones respond to their partner's cycle shifts. This gap contrasts with a sizeable literature reporting that men's testosterone fluctuates as a function of investment in mating versus pair-bond activities. For example, research has found that married men have lower testosterone than non-married men, and that married men who invest more in their spouses have lower testosterone than married men who invest less in their spouses (Gray, Kahlenberg, Barrett, Lipson, & Ellison, 2002). Further, other studies have found that men increase attentiveness when their partners are in the fertile window (Gangestad et al., 2002; Pillsworth & Haselton, 2006; but for null findings see Arslan et al., 2018; Gangestad et al., 2014; Haselton & Gangestad, 2006). Thus, if men invest more in their partners during the fertile window, their testosterone might decrease during this period. Alternatively, if men become more intrasexually competitive during this period – either to signal to their partner or to deter intrasexual rivals – then their testosterone might increase. Existing work on single men's hormonal responses to the scent of fertile women is equivocal – one study reported that men's testosterone increases after smelling shirts worn by ovulating women (Miller & Maner, 2010), but another study failed to replicate this finding (Roney & Simmons, 2012).

1.2.1. The roles of hormones

The fertile window is characterized by an increase in estradiol and low progesterone. After ovulation, estradiol levels fall rapidly and progesterone rises; although estradiol levels exhibit a secondary increase, they do not reach the peak levels of the periovulatory phase. These hormonal shifts underlie the surge in luteinizing hormone that induces ovulation and the thickening of the endometrial lining in preparation for blastocyst implantation. They also likely serve as the hormonal mechanisms that underlie behavioral changes across the cycle (e.g., Garver-Apgar et al., 2008). As estradiol peaks during the conceptive phase, whereas progesterone peaks during the non-conceptive luteal phase, one might expect estradiol and progesterone to have opposing influences on relationship dynamics – estradiol giving rise to processes that, on average, degrade relationship satisfaction, and progesterone giving rise to processes that, on average, promote relationship evaluations.

Research examining the role of hormones on changes in romantic dynamics has found that estradiol is associated with increases – and progesterone is associated with decreases – in general sexual desire (Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018; Roney & Simmons, 2013). However, when making a distinction between in-pair vs. extra-pair sexual attraction, Grebe et al. (2016) found that estradiol reduced – and progesterone increased – in-pair sexual attraction, whereas estradiol increased extra-pair sexual attraction. In contrast, a recent analysis of Roney and Simmons' previous work found that progesterone related negatively to both in-pair and extra-pair sexual desire, whereas estradiol related positively to extra-pair sexual attraction (albeit with a sample of only 15 partnered women) (Roney & Simmons, 2016).

Regarding relationship satisfaction, previous research has shown that women who, in general, have higher levels of estradiol tend to report lower levels of relationship satisfaction and commitment toward their current romantic partners (Durante & Li, 2009). This research though did not assess how changes in hormonal levels may affect relationship evaluation within the same person (i.e., in a within-person approach).

1.3. The current research

Evolutionary theories suggest that evaluations of one's own romantic partner may shift across the ovulatory cycle, but very little research has investigated this research question. Furthermore, in some respects, inconsistent findings have emerged. This work aims at contributing to this literature by investigating how hormonal fluctuations across the cycle affect romantic relationships evaluations and well-being, gathering data, for the first time, from both female and male partners.

Much work on ovulatory cycle effects has been criticized for reliance on self-reports to estimate women's conceptive status, a method with modest validity (e.g., Gangestad et al., 2016). Furthermore, many studies have used between-participants designs or within-participant designs in which data are collected on just two occasions (during the conceptive phase or not); both approaches limit statistical power. Only a handful of studies have systematically assessed hormonal changes for an extended period of time and examined the correlated psychological effects of such hormonal changes (Jones, Hahn, Fisher, Wang, Kandrik, Han et al., 2018; Roney & Simmons, 2013). In the current study, we used this approach and measured, in urine, three steroid hormones daily through a 15-day period, which was intended to include the peri-ovulatory phase, of natural ovarian cycles of romantically involved women: estradiol, progesterone, and testosterone. We also assessed daily levels of men's testosterone. Using multilevel modeling, we assessed how these hormonal fluctuations were associated, across the cycle, with psychological outcomes of both partners.

In this study, we specifically address the following theoretically driven questions:

First, do women and their male partners evaluate their relationships more negatively on days in which women have high estradiol levels and/or low progesterone levels? Do women and men perceive that their partners evaluate their relationships more negatively on those days?

Second, do women experience lower sexual attraction to partners on days in which they have high estradiol levels and/or low progesterone levels? Do men perceive that their partners experience lower attraction to them on those days?

Third, do women experience greater attraction to individuals other than partners on days in which women have high estradiol levels and/or low progesterone levels? Do men experience greater jealousy with regard to partners on days in which women have high estradiol levels and/or low progesterone levels?

Fourth, do women and their male partners experience lesser personal well-being on days in which women have high estradiol levels and/or low progesterone levels? If so, are these changes mediated by changes in relationship evaluations?

We also examined the following questions of interest: do women's and men's general sexual desire change as a function of hormonal changes? Do men's testosterone levels rise and fall as a function of women's hormonal changes across the cycle?

We conducted two sets of analyses. In the first, we examined the unique role played by each hormone by simultaneously regressing estradiol, progesterone and testosterone (each log-transformed) onto the dependent variables. In the second, we examined the log ratio of estradiol and progesterone (while controlling for log testosterone), which peaks just prior to ovulation and hence detects the fertile window of the cycle better than either hormone does in isolation (Baird, Weinberg, Wilcox, McConnaughey, & Musey, 1991; see Sollberger & Ehlert, 2016, on the advantages of log hormone ratios over raw ratios).

2. Method

2.1. Participants

Participants were 33 Dutch-speaking heterosexual couples. The majority of the couples lived in the Randstad, the megalopolis including Amsterdam, Rotterdam, Den Haag, Utrecht, and surrounding communities. Participants' mean age was 26.30 years (SD = 3.97), and 33.3% were university students. On average, couples reported being involved for 46.27 months (SD = 26.56 months). Participants were recruited via advertisements on social media (e.g., Facebook), internet forums, a professional recruiting agency, and around the University campus. Couples could participate in the study only if: (a) the woman was not taking any hormonal contraceptive and was younger than 40 years old, (b) the woman was not pregnant or breastfeeding, (c) the woman was having a regular menstrual cycle, (d) partners had been together for longer than 4 months, (e) they were cohabiting or spending at least 5 nights together a week, (f) they were not consciously attempting to conceive (to avoid that changes in sexual behaviors may be driven by conscious effort to conceive during ovulation). Two couples withdrew from the study after intake, and data from one couple were excluded due to abnormalities in all their hormone results. Thus, the main analyses are conducted on the remaining 30 couples. Though our sample size may appear, at first blush, modest given all the exclusions criteria that couples had to meet – 30 couples (hence, 60 individuals) – the current research compensated with extensive sampling per couple/individual (15 consecutive days per month); hence, empirical associations were based on 450 cycle days (30 × 15), 450 outcome-days per gender (450 × 2), and thus 900 outcome-days (2 × 30 × 15) total. The dense within-person nature of the design offers power to detect hormonal main effects comparable to a sample of many hundreds of individuals in a between-subjects design (Gangestad et al., 2016). Participants were paid up to 50 Euro (100 Euro per couple) for participating in this study.[1]

2.2. Procedure

After a screening correspondence via email, eligible couples completed an intake session either at their home or at the research lab. During this session, they received an explanation of the study procedures, signed an informed consent form, and were separated and asked to privately reply to some questions about themselves and their relationship. After that, the experimenter provided instructions about the diary procedure and gave the participants a booklet containing those instructions. Participants were instructed to reply to some questions about themselves and their relationship every day in the evening (as close to bed time as possible) for 15 days. They also received a nightly automatic reminder email to complete these measures. Each day, at the same time of the diary completion, they were also asked to collect a sample of their urine in tubes that had been pre-labeled with collection dates and to store it in their home freezer. During scheduling, the

[1] We also met with the participants on other two occasions in which we forecasted the woman to be in the fertile window versus the luteal phase. On these two occasions, participants replied to some questions and were videotaped while discussing a topic regarding their relationship. Our aim was to have a sufficient sample size to be able to compare the responses across these two sessions. However, given the sample size of women who were in the fertile window when the second session was scheduled (estimated based on daily hormone measures), we did not reach a sufficient sample size to draw inferences based on these comparisons.

woman of each couple reported her last date of menstruation, and she was asked to contact the researchers at the onset of her next menses. We estimated the date of ovulation based on this information, and we scheduled couples to begin their diary study seven days before this date and continue seven days after (for a total of 15 days) to increase the likelihood that we should capture the hormonal fluctuations around ovulation and, consequently, sample days with variable progesterone and estradiol. At the end of the study, couples returned their urine samples.

2.3. Material

2.3.1. Diary assessments

Participants completed the following on a 7-point scale (1 = *strongly disagree*, 7 = *strongly agree*). Note that items were given in Dutch – the English versions of the items are described below. Each day, we assessed *partner evaluation*[2] (6 items; "I felt satisfied with my relationship with my partner, "I felt positive feelings toward my partner", "I felt negative feelings toward my partner" – reversed scored, "I felt close to my partner", "I felt very grateful to my partner", "I felt my partner was very trustworthy"; $\alpha = .87$) and *perceived partner evaluation* (1 item; ""I think that my partner felt satisfied with our relationship"). We further assessed participant's *extradyadic attention* (3 items; "I felt physically attracted to or had a fantasy about someone other than my partner", "I flirted with someone other than my partner", "It would have been difficult for me to resist temptation if someone very attractive (other than my partner) approached me in a physical manner"; $\alpha = .64$), and *jealousy* (6 items; e.g., "I felt romantically jealous because of my partner's attention or action to others today; "I felt romantically jealous because of my partner's behavior today", "I closely monitored my partner's things and behavior", "I felt the urge to look at my partner's email or phone", ""I think that my partner may have experienced physical attraction to someone other than me", "I think that my partner may have flirted with someone other than me"; $\alpha = .77$). We also measured variables related to sexual desire and behavior, such as *general sexual desire* (1 item; "I desired sexual stimulation or activity"), *physical attraction toward partner* (1 item; "I felt physically attracted to my partner"), *perceived partner sexual desire* (1 item; "My partner desired sexual activity with me"), and the occurrence of a *sexual intercourse* (1 item; "I engaged in sexual activity (intercourse or other forms of genital stimulation) with my partner"; 0 = *No*, 1 = *Yes*). Finally, we assessed *personal well-being* (6 items; "My life was close to my ideal", "I felt good, mentally and emotionally", "My body felt good, physically", "My self-confidence was high", "I had a lot of respect for myself", "I had a clear idea of who I am and what I want"; $\alpha = .89$).

2.3.2. Hormonal assays

Participants were asked to collect a urine sample close to bed time. We chose to collect urine given the limited degree of control we had over participants' behavior immediately before sample collection. That is, we anticipated little control over participants' food, alcohol, and tobacco consumption, each of which would be more likely to contaminate salivary samples relative to urinary samples. And urinary samples capture hormone levels across a wider temporal span, and hence should better reflect variation across days, as opposed to momentary variation. We also chose to collect samples in the evening (a) to reduce study complexity (i.e., allow participants to complete all study tasks at one time daily), and (b) because relationships between testosterone and several other variables – including sleep deprivation, marital status, fatherhood status, and trait aggression – are stronger when samples are collected in the evening rather than in the morning (Book, Starzyk, & Quinsey, 2001; Gray et al., 2004; Leproult & Van Cauter, 2011; Muller, Marlowe, Bugumba, & Ellison, 2008). Participants were given small cups with which to collect urine, and they extracted the urine into 8 mL tubes. They then stored the tubes in their freezers before the researchers could collect the tubes and store them in a -20C freezer at Vrije Universiteit Amsterdam. Samples were then transported to the Kirschbaum lab at Technical University of Dresden, where they were assayed for creatinine, testosterone, progesterone, and estradiol (E2). Testosterone and progesterone were assayed via liquid chromatography mass spectrometry (LCMS) following the protocol described by Gao and colleagues (Gao, Stalder, & Kirschbaum, 2015). The LCMS protocol did not provide estradiol values for most participants. Hence, estradiol was later assayed using a 17β-estradiol enzyme immunoassay kit (Detect X via Arbor Assays), and creatinine was assayed on the basis of the Jaffé reaction (Detect X via Arbor Assays). Intra- and inter-assay CV's were both below 10.5%.

3. Results

Material, syntax of the analyses, and data can be found in the Open Science Framework (https://osf.io/28r7w/).

3.1. Analytic strategy

3.1.1. Hormone data

Urinary hormone concentrations vary by concentration of urine. As is standard procedure, then, testosterone, progesterone, and estradiol were divided by creatinine to arrive at hormone-to-creatinine ratios. These ratios were then log-transformed and within-person centered. To assess whether men's testosterone varies as a function of changes in women's hormones, we performed multilevel analyses in which we regressed men's testosterone onto women's estradiol, progesterone, and testosterone.

3.1.2. Dyadic data analyses

Because daily data from the same individuals and data within dyads are not independent, we used multilevel modeling to analyze our data. For continuous outcomes, dyadic data analyses were performed as recommended by Kenny, Kashy, and Cook (2006)) We employed a 2-level cross model in which participants and daily measurements within participants (i.e., time) were treated as crossed and nested within the dyad. In initial models, all intercepts and slopes were allowed to randomly vary (and covary). These models did not converge. We thus followed recommendations from Matuschek, Kliegl, Vasishth, Baayen, and Bates (2017))'s and excluded random effects for slopes that did not significantly vary across dyads ($p > .15$). Dyads were treated as distinguishable to test the predictions for men and women separately. For the dichotomous outcomes, we used the GENLINMIXED procedure. Dyads were treated as indistinguishable, and the simple effects of the interactions with gender were analyzed so to have a separate index for men and women. We performed two sets of analyses. In the first, women's daily estradiol and progesterone and women's and men's daily testosterone were entered as simultaneous predictors. In the second, we calculated (and log transformed) the ratio between estradiol and progesterone, which peaks the day before ovulation and is highest during the fertile phase of the cycle (Baird et al., 1991). This ratio and women's and men's daily testosterone were then entered as simultaneous predictors in the analyses. As $\ln(E/P) = \ln(E) - \ln(P)$, this analysis in fact examines the joint additive effects of ln(E) and ln(P), where weights for each are constrained to be equal in magnitude and opposite in sign (see Sollberger & Ehlert, 2016, on advantages of log hormone ratios). All predictors were within-person centered (Enders & Tofighi, 2007). Thus, these analyses examined whether day-to-day hormonal fluctuations from a participant's own mean were associated with corresponding

[2] The grouping of the variables was guided by a principal component analysis (PCA) on the 18 variables that assessed participants' self-perceptions. The scree plot indicated that presence of three components (top six eigenvalues = 5.96, 2.49, 2.14, 1.08, .84, and .74). PCA indicated that three components accounted for 59% of the total item variance.

changes in the outcome variables.[3]

3.2. Key analyses

First, did women and their male partners evaluate their relationships more negatively on days in which women have high estradiol levels and/or low progesterone levels? And do women and men perceive that their partners evaluate their relationships more negatively on those days? Results revealed that estradiol was negatively related to women's partner evaluation, and to both men and women's perceived partner evaluation (see Table 1). Progesterone, by contrast, was positively related to women's perceived partner evaluation (albeit at a marginal level of significance) (see Table 1). Log E/P ratio was negatively related to women's partner evaluation ($b = -.17$, $SE = .07$, 95% CI = [−.32, −.02], $p = .023$) and to women's perceived partner evaluation ($b = -.29$, $SE = .11$, 95% CI = [−.51, −.06], $p = .012$).

Second, did women and men experience lower sexual attraction to partners on days in which women had high estradiol levels and/or low progesterone levels? And did men perceive that their partners experience lower attraction to them on those days? Progesterone was positively associated with women's perception that their partner was sexually attracted to them. In addition, the effects of estradiol on women's physical attraction toward their specific partner, men's perceived partner sexual desire toward them, and men's sexual desire were in the predicted direction, although confidence intervals overlapped with zero (see Table 2). Sexual intercourse was not found to relate to any hormonal fluctuations. Log E/P ratio was negatively associated with women's perception of their partner's sexual attraction to them ($b = -.53$, $SE = .16$, 95% CI = [−.84, −.21], $p < .001$). The direction of the effects was the same for women and men's sexual attraction to partners ($b = -.21$, $SE = .11$, 95% CI = [−.44, .01], $p = .063$, and $b = -.18$, $SE = .10$, 95% CI = [−.38, .03], $p = .091$, respectively), and for men's perception of their partner sexual attraction to them ($b = -.29$, $SE = .16$, 95% CI = [−.61, .03], $p = .075$), although 95% confidence intervals overlapped with zero.

Third, did women experience greater attraction to individuals other than partners on days in which women have high estradiol levels and/or low progesterone levels? And did men experience greater jealousy with regard to partners on days in which women have high estradiol levels and/or low progesterone levels? Overall, we found little evidence for these associations. Testosterone, however, positively related to jealousy in both sexes. And there was a marginally significant positive association between estradiol and men's extradyadic attention (see Table 1). Log E/P ratio was also not significantly related to these variables.

Fourth, did women and their male partners experience lesser personal well-being on days in which women have high estradiol levels and/or low progesterone levels? And, if so, are these changes mediated by changes in relationship evaluations? Women's estradiol levels did indeed negatively predict men's well-being. Their progesterone levels predicted (marginally significantly) their own well-being (see Table 1). Mediation analyses revealed that women's partner evaluation mediated the relationship between estradiol and men's well-being (indirect effect = CI [−.13, −.01], see Fig. 1). Men's perception of their partner satisfaction also mediated the relationship between estradiol and men's well-being (indirect effect = CI [−.21, −.01]). Finally, men's perception of their partner's sexual desire for them mediated the relationship between estradiol and men's well-being (indirect effect = CI [−.10, −.01]). Log E/P ratio was negatively associated with both men and women's well-being, ($b = -.18$, $SE = .08$, 95% CI = [−.34, −.02], $p = .028$, and $b = -.20$, $SE = .08$, 95% CI = [−.37, −.04], $p = .017$, respectively). Mediation analyses revealed that women's partner

Table 1
Associations between women's estradiol, progesterone and women and men's testosterone and personal and relationship outcomes.

	b	*SE*	95% CI
Women's partner evaluation			
Estradiol	-.32*	.13	−.58, -.05
Progesterone	.12	.11	−.10, .34
Testosterone	−.16	.12	−.39, .07
Men's partner evaluation			
Estradiol	−.12	.11	−.35, .11
Progesterone	.09	.08	−.06, .24
Testosterone	−.02	.14	−.30, .26
Women's perceived partner evaluation			
Estradiol	-.43*	.21	−.84, -.03
Progesterone	.24†	.13	−.01, .49
Testosterone	−.26	.19	−.64, .12
Men's perceived partner evaluation			
Estradiol	−.42*	.20	−.81, -.02
Progesterone	−.01	.13	−.26, .26
Testosterone	.14	.27	−.38, .70
Women's extradyadic attention			
Estradiol	.08	.11	−.14, .31
Progesterone	-.01	.07	−.14, .14
Testosterone	−.06	.11	−.28, .16
Men's extradyadic attention			
Estradiol	.25†	.13	−.01, .50
Progesterone	.03	.08	−.14, .20
Testosterone	.20	.18	−.15, .55
Women's jealousy			
Estradiol	-.12	.07	−.26, .03
Progesterone	-.06	.07	−.20, .08
Testosterone	.13†	.07	−.01, .28
Men's jealousy			
Estradiol	−.06	.06	−.18, .06
Progesterone	.02	.06	−.09, .14
Testosterone	.17*	.09	.01, .34
Women's personal well-being			
Estradiol	−.13	.15	−.44, .17
Progesterone	.25†	.13	−.02, .51
Testosterone	.09	.15	−.16, .41
Men's personal well-being			
Estradiol	−.34*	.14	−.61, -.07
Progesterone	.11	.09	−.06, .29
Testosterone	.23	.19	−.13, .60

Note. Hormones were within-person centered. All results are obtained from multilevel analyses, using unstandardized estimates.
† $p < .10$, *$p < .05$; **$p < .01$.

[3] We also sought to calculate how many cycles were ovulatory in our data using criteria modified from Santoro et al. (2003). We took a three-day moving average of progesterone for each day for each participant. We estimated ovulation as having occurred when this average was three times larger than the minimum observed value for three consecutive days. According to that procedure, 20 out of 30 cycle were ovulatory. Given that hormones themselves – rather than the actual release of an egg – are posited to affect behavior, we believe that hormonal fluctuations should drive the effects, independently of the ovulatory status (see Roney & Simmons, 2013, for the same argument; despite 33% anovulatory cycles, as assessed by luteal progesterone peaks, they included all cycles in hormonal analyses). We thus tested for moderating effects of whether ovulation was estimated to have occurred on our main analyses. None of the findings were moderated by our calculation of whether ovulation occurred (with the exception of two significant interactions: one with progesterone and one with the ratio for men's partner evaluation). Furthermore, results were not affected by the inclusion in the model of this variable and its interactions with the hormones. Finally, one could also examine associations with between-woman levels of hormones. In light of small number of individual couples and hence low power to detect these effects, we did not include these terms in our models.

Table 2
Associations between women's estradiol, progesterone and women and men's testosterone and sexual desire and behavior.

	b	*SE*	95% CI
Women's general sexual desire			
Estradiol	.01	.33	−.65, .67
Progesterone	.08	.21	−.32, .49
Testosterone	−.14	.32	−.76, .49
Men's general sexual desire			
Estradiol	$-.45^{\dagger}$	.26	−.97, .07
Progesterone	−.04	.17	−.38, .30
Testosterone	−.46	.35	−1.15, .23
Women's physical attraction toward partner			
Estradiol	$-.39^{\dagger}$	.21	−.80, .02
Progesterone	.15	.13	−.10, .41
Testosterone	−.14	.20	−.53, .26
Men's physical attraction toward partner			
Estradiol	−.29	.17	−.63, .06
Progesterone	.14	.12	−.09, .37
Testosterone	−.13	.24	−.60, .34
Women's perceived partner sexual desire			
Estradiol	-.39	.29	−.96, .18
Progesterone	.57**	.18	.22, .92
Testosterone	-.96**	.27	−1.48, 1.44
Men's perceived partner sexual desire			
Estradiol	$-.52^{\dagger}$	.27	−1.06, .02
Progesterone	.21	.18	−.15, .57
Testosterone	−.16	.36	−.86, .54

Note. Hormones were within-person centered. All results are obtained from multilevel analyses, using unstandardized estimates.
† $p < .10$, *$p < .05$; **$p < .01$.

Table 3
Associations between men's testosterone and women's hormones.

	b	*SE*	95% CI
Women's testosterone	.13**	.04	.06, .21
Women's estradiol	-.02	.02	−.07, .02
Women's progesterone	.02	.04	−.06, .09

Note. Women's hormones were within-person centered. All results are obtained from multilevel analyses, using unstandardized estimates.
*$p < .05$; **$p < .01$.

4. Discussion

Our findings showed that increases in estradiol negatively impacted women and men's romantic relationships. Specifically, as estradiol increased, women evaluated their partner less positively, and they were less physically attracted to their partner. These decreases in relationship satisfaction and physical attraction were detected by men, who rated their partners as less attracted to them and less satisfied with the relationship. Finally, men experienced lower well-being when women's estradiol increased, and mediation analyses revealed that this was due, in part, to women's negative changes in partner evaluation and physical attraction. Increases in progesterone (which peaks after ovulation) were associated with more positive perceived relationship evaluations and personal well-being in women. Testosterone fluctuations predicted jealousy, such that both men and women reported stronger jealousy at higher level of testosterone.

Results for log E/P ratio tended to mimic the ones described above. When the ratio of estradiol to progesterone was high, women's partner evaluations were more negative, as were their perception of how their partner evaluated them. Furthermore, at high levels of log E/P ratio, both men and women experienced lower well-being; mediation analyses revealed that these effects were partially due to a decrease in women's partner evaluation.

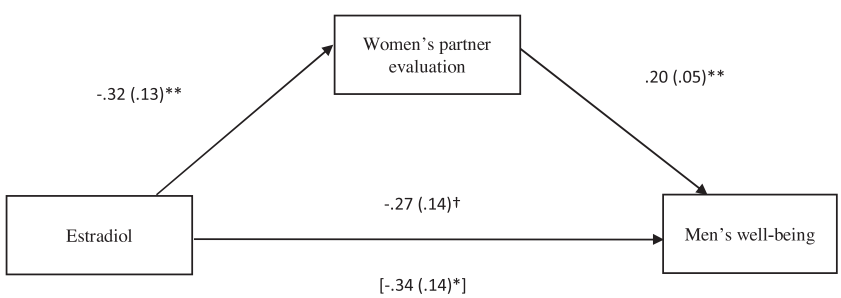

Fig. 1. Men's perceived partner evaluation as a mediator of women's partner evaluation and men's well-being.
Note. All reported values are unstandardized estimates (*b* values), with their standard errors reported between brackets.
† $p < .10$, *$p < .05$; **$p < .01$.

evaluation mediated the relationship between E/P ratio and men's well-being (indirect effect = CI [−.12, −.01]). Similarly, women's partner evaluation mediated the relationship between log E/P ratio and women's well-being (indirect effect = CI [−.15, −.01])

Finally, do women's and men's general sexual desire change as a function of hormonal changes? There was no evidence of changes in general sexual desire as a function of hormonal changes.

We also tested whether men's testosterone levels vary as a function of women's hormonal changes across the. As can be seen in Table 3, results revealed that changes in women's testosterone related to changes in men's testosterone. This association remained significant when controlling for whether the partners had sex or conflict that day ($p < .001$), which could arguably affect both partners' testosterone levels (e.g., Dabbs & Mohammed, 1992). Importantly, analyses detected no robust association between women's estradiol or progesterone and men's testosterone.

The present research provides a first illustration of the importance of taking a dyadic perspective to better understand not only women's reactions to their hormonal changes but also men's responses. Our findings suggest that men were able to detect changes in women's relationship evaluation and experienced, as a consequence, lower well-being. These dyadic processes deserve future examination as they add new knowledge to the relational implications of hormonal fluctuations, such as when and why some dissatisfaction in relationships occur – dissatisfaction that could potentially challenge the stability of the relationship.

Our findings also contribute to the debate about whether hormonal shifts across the ovulatory cycle influence sexual desire toward one's own partner and other men differently (Grebe et al., 2016; Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018; Roney & Simmons, 2016). Contrary to previous work (Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018; Roney & Simmons, 2016), we detected no robust relationship between hormonal fluctuations and general sexual desire. However, consistent with Grebe et al. (2016), we found that *decreases* in estradiol coincided with increased physical attraction toward one's current partner. Naturally, we do not assert that the pattern we detect is real and that contrasting patterns emerging in other studies are not real. Inconsistency across studies may suggest that variables moderate hormonal associations. Grebe et al. (2016) explicitly noted that couples in their study (recruited to participate together) may have been especially invested in their relationships. Couples who agreed to participate together in our study too may have been relatively invested in their relationships. By contrast, about half of the couples in Roney and Simmons (2016) sample had not been together at the beginning of the study or were no longer together by its conclusion. One possibility, then, is that women's and/or men's investment in their relationships affect patterns of hormonal association across the cycle (e.g., consistent with ideas about extended sexuality; e.g., Grebe et al., 2013). Our sample was too small to examine, with adequate power, between-couple moderators of hormonal associations. But in light of contrasting findings, we suggest that potential moderators may be examined in future work.

Our analyses did not detect hormonal associations with extradyadic attention (Arslan et al., 2018; Gangestad et al., 2002, 2005; Haselton & Gangestad, 2006) or extradyadic physical desire (Roney & Simmons, 2016). In light of previous research, these null findings should be interpreted with caution given limited sample size/power and the possibility that the women in our sample simply did not have interactions with many (or any) attractive men in those days. In fact, while we are certain that they had daily interactions with their current partner, we cannot be sure that they encountered attractive men. Furthermore, women may be reluctant to report about extradyadic attraction in a study in which they participate together with their partner.

Our results showed that women's changes in estradiol related to changes in evaluations of their partner. Future work could aim to better understand whether such changes are an antecedent or a consequence of women's openness to other men during the peri-ovulatory phase. On the one hand, women might find other men more attractive and, as a consequence, disengage from their current partner. On the other hand, women might pre-emptively disengage from their partner to be open and attentive to identify alternative partners in their environment that have higher genetic fitness. Our data may be more consistent with the latter reasoning, although future research should attempt to clearly distinguish these processes.

Notably, we found no evidence to suggest that men's jealousy increased with partner estradiol or progesterone (cf. Gangestad et al., 2014). Furthermore, we also assessed whether men's testosterone changed as a function of their partner's hormonal levels. In fact, previous research has found that men's testosterone can be sensitive to women's ovulation (Miller & Maner, 2010; but also see Roney & Simmons, 2012). In our data, men's testosterone did not change as a function of women's estradiol or progesterone, but it did change as a function of women's testosterone. This association held when controlling for sexual intercourse or conflict. We did not predict such association and future research is needed to replicate these findings and to elucidate the nature of such association.

Limitations of the current work should be acknowledged. Given the difficulties of recruiting dyads who matched all our inclusions criteria, our sample size was small, yet similar to much recent research examining hormonal associations across the cycle (Grebe et al., 2016; Roney & Simmons, 2013; see, e.g., Jones, Hahn, Fisher, Wang, Kandrik, Han et al., 2018; Jones, Hahn, Fisher, Wang, Kandrik, Kandrik, De Bruine et al., 2018 for an exception). We used a within subject design in which hormonal and psychological changes were assessed daily for 15 days, resulting in a design that could detect moderate to large within-participant main effects. At the same time, as noted above, our sample size did not permit sensitive tests of between-woman moderation effects (e.g., Eastwick & Finkel, 2012; Grebe et al., 2013; Pillsworth & Haselton, 2006); again, future research should seek to further explore such moderators.

Future research should also seek to replicate the findings with diverse samples in terms of age, race, and life stages. In our study, for example, we did not include couples that were actively trying to conceive. Future work should examine whether such couples display similar patterns of results or whether the explicit goal of reproducing with one's long-term partner overrides any negative impact of estradiol on relationship evaluations.

Several strengths of the current work should also be recognized. Going beyond research designs that have been commonly used (e.g., between-participants or within-participant designs with only two data points), we have adopted a rigorous methodology by assessing daily hormonal changes for fifteen days. We have also tested the partial effect of one hormone while controlling for the others, to gain insight into the unique role played by each hormonal change. Finally, we have adopted a dyadic perspective, to gauge whether changes in thoughts and behaviors were only in one partner's mind or were also detected by the other partner.

4.1. Conclusions

While previous research has shown that hormones that fluctuate across the ovulatory cycle impact women's cognition, emotions, and behaviors, little was known about the impact of hormonal changes on romantic relationships, as previous studies have mostly collected reports from women or inferred hormone levels from indirect indicators. We have conducted the first dyadic study to assess how hormonal changes during the ovulatory cycle associate with romantic relationship dynamics by gathering data not only from women but also from their male partners. Results suggest that hormonal fluctuations do not operate in a vacuum. In the service of reproduction, women experience hormonal fluctuations that appear to affect not only the way they feel toward their relationship partner, but also their partner's feelings and thoughts about the relationship. These findings underscore the importance of taking a dyadic perspective to study the consequences of women's hormonal changes. If the relationship boat sinks, the partners sink together.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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