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Men are not aware of and do not respond to their female partner's fertility status: Evidence from a dyadic diary study of 384 couples

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ABSTRACT

Understanding how human mating psychology is affected by changes in female cyclic fertility is informative for comprehending the evolution of human reproductive behavior. Based on differential selection pressures between the sexes, men are assumed to have evolved adaptations to notice women's within-cycle cues to fertility and show corresponding mate retention tactics to secure access to their female partners when fertile. However, previous studies suffered from methodological shortcomings and yielded inconsistent results. In a large, preregistered online dyadic diary study (384 heterosexual couples), we found no compelling evidence that men notice women's fertility status (as potentially reflected in women's attractiveness, sexual desire, or wish for contact with others) or display mid-cycle increases in mate retention tactics (jealousy, attention, wish for contact or sexual desire towards female partners). These results extend our current understanding of the evolution of women's concealed ovulation and oestrus, and suggest that both might have evolved independently.

1. Introduction

In humans, there is a short, recurring time span during which sexual decisions have critical reproductive consequences: women's fertile window. Spanning approximately five days before ovulation and the day of ovulation itself (Wilcox et al., 1998), the fertile window is the only time during which women can conceive and possibly increase their and their partner's direct reproductive fitness (i.e. number of offspring who can reproduce). Given the necessity of fertility for reproduction, mating behavior during the fertile window is assumed to have been strongly shaped by selection (Miller and Maner, 2011). According to Parental Investment Theory (Trivers, 1972), women and men face different pressures of sexual selection. Women's minimal parental investment including gestation, placentation, child birth and lactation clearly outweighs that of men. Consequently, compared to men, women's reproductive success is expected to be limited by access to resources and material benefits for them and their offspring, resulting in low reproductive variance across women. Men's reproductive success, however, is expected to be limited by access to fertile women, leading to intrasexual competition for reproductive opportunities and subsequent higher reproductive variance across men (*Bateman principle;* Bateman, 1948; but see Snyder and Gowaty (2007) for criticism and Jokela et al. (2010) for empirical support for this principle in humans). Following these divergent selection pressures, men and women have different strategies to optimise their reproductive success (Gangestad and Simpson, 2000). These differences result in intersexual conflict, whereby reproductive benefits for the one sex (e.g. long-term resource provision for women) comes at the cost of the other (e.g. less mating opportunities for men; Gangestad et al., 2007). Evolutionary psychologists posit that this intersexual conflict and the subsequent sexually antagonistic coevolution may have led to evolved psychological mechanisms of men, such that they a) notice women's fertility status across the cycle via so called cues to fertility (Haselton and Gildersleeve, 2011), and b) react in a specific manner to secure access to their fertile partners via so called

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mate retention tactics (Gangestad et al., 2002; Gangestad et al., 2014).

Cues to fertility should consist of differences in either physical appearance or manifest behavior (Buss and Schmitt, 2019) when women are fertile, as compared to when not fertile. It was long thought that women displayed no such within-cycle cues to fertility and that ovulation is rather concealed (Burley, 1979; Pawlowski, 2016; Schröder, 1993; Strassmann, 1981). Consequently, it has been assumed that women phylogenetically lost their oestrus (a phase of fertility characterised by heightened attractiveness as well as sexual proceptivity and receptivity) (Beach, 1976). However, this notion has been challenged by findings showing increases in women's attractiveness (Bobst and Lobmaier, 2012; Haselton and Gildersleeve, 2011; Roberts et al., 2004; Schwarz and Hassebrauck, 2008) and sexual motivation (Arslan et al., 2021; Bullivant et al., 2004; Gangestad and Thornhill, 2008; Jones et al., 2018; Roney and Simmons, 2013; Schleifenbaum et al., 2021b) during their fertile windows that might serve as cues to fertility to men.

Regarding women's attractiveness, several studies report that men rate women as more attractive around ovulation (Cobey et al., 2013; Schwarz and Hassebrauck, 2008) and might perceive ovulatory changes in women's facial shape and texture (Bobst and Lobmaier, 2012; Oberzaucher et al., 2012), vocal attractiveness (Pipitone and Gallup, 2008), body scent (Doty et al., 1975; Gildersleeve et al., 2012; Havlíček et al., 2006; Kuukasjarvi, 2004; Singh and Bronstad, 2001; Thornhill, 2003) and grooming behavior (Haselton et al., 2007; Schwarz and Hassebrauck, 2008), which might even affect women's earnings in the form of tips given by men (Miller et al., 2007). However, many of the cited studies suffered from methodological shortcomings that limited their informational value. One central limitation is that most studies employed small sample sizes that, in conjunction with widespread publication bias, can inflate false positive findings and artificially increase effect sizes (Gangestad et al., 2016). This problem is exacerbated by employing between-subject designs to estimate within-subject changes (Gildersleeve et al., 2012), or comparing only high- to low-fertility days, and using estimation methods for women's fertility with low validity (Gangestad et al., 2016). Importantly, recent replications failed to find predicted shifts in men's ratings of women's facial (Bleske-Rechek et al., 2011; Catena et al., 2019) and bodily attractiveness (Bleske-Rechek et al., 2011), women's body scent (Mei et al., 2022; Roney and Simmons, 2012), and women's voice pitch (Pavela Banai, 2017). Moreover, other findings question whether postulated shifts in facial shape or color exist or are even perceptible (Burriss et al., 2015; Marcinkowska and Holzleitner, 2020).

Regarding women's sexual motivation, earlier studies found that women's sexual desire for men outside of their committed relationships increased when they were fertile (Gangestad et al., 2002; Grebe et al., 2016; Haselton and Gangestad, 2006). Moreover, women reported more interest in going out to social gatherings to meet men on fertile days compared to nonfertile days (Haselton and Gangestad, 2006). However, these studies suffer from the same aforementioned methodological shortcomings, particularly, and most strikingly, low statistical power. Despite an ongoing debate about how to interpret these findings (Gangestad et al., 2019; Jones et al., 2018; Jünger et al., 2018; Marcinkowska et al., 2018; Roney, 2019; Stern et al., 2019; Stern et al., 2020), more recent studies employing large sample sizes have shown that women exhibit ovulatory increases in their general sexual motivation (Arslan et al., 2021; Jones et al., 2018; Schleifenbaum et al., 2021b; Stern et al., 2020). Besides an increase in general sexual motivation, it seems that sexual motivation regarding both their primary romantic partners (in-pair sexual desire) as well as other men (extra-pair sexual desire) increases in their fertile window (Arslan et al., 2021; Schleifenbaum et al., 2021b). Accordingly, ovulatory changes in women's sexual motivation might be observable, for example, through flirtatious behavior or reported increases in women's initiation of sexual activity (Bullivant et al., 2004). However, to our knowledge, no study has investigated whether men do indeed perceive women's ovulatory (mid-cycle) increases in sexual motivation.

So far, there is no consensus regarding the existence and the exact nature of possible cues to women's fertility that men might perceive. However, given that a single sexual encounter during the fertile window could increase men's relative reproductive success (Buss, 1988; Gangestad et al., 2002; Gangestad et al., 2014), reacting even to weakly valid cues and fending off potential competitors is assumed to be highly adaptive (Gangestad et al., 2007). Consequently, men are expected to increase their mate retention tactics when women are fertile (Gangestad et al., 2005). Men who fail at such mate retention tactics during the fertile window potentially pay steep reproductive costs of genetic cuckoldry, that is when their female partners are fertilised by a rival man (Buss, 2002). According to error management theory (Haselton and Buss, 2000), men should have further evolved a positive bias towards mate retention tactics because costs of displaying them (e.g. effort and potential conflict with female partners; Gangestad et al., 2014), even frequently without actual infidelity threat, are largely outweighed by costs of failing to employ them in actually threatening instances. Still, even though mate retention tactics should be particularly adaptive during women's fertile window, there is little research investigating ovulatory changes in men's mate retention tactics.

Past research on menstrual cycle shifts in men's mate retention tactics has yielded inconsistent results so far. In a within-subject study investigating 27 women and comparing high- to low fertility days, women reported higher proprietary (e.g. vigilance) and attentive (e.g. monopolisation of time) behavior of their male partners on high fertile days (Gangestad et al., 2002). Similarly, in a daily diary design, 23 women reported higher jealousy and possessiveness of their male partners when they were fertile (Haselton and Gangestad, 2006), with a large effect of 0.7 Cohen's *d* for women's reports of male jealousy (Haselton and Gildersleeve, 2011). However, a preregistered replication of the daily diary study that used the same items but employed a larger sample size of 429 naturally cycling women found no mid-cycle changes in reported mate retention (Arslan et al., 2021). The authors of this replication criticised the low reliability of their own items and concluded that this made detection of an effect unlikely in case it existed (Arslan et al., 2021). In addition, as these studies were only based on women's reports of men's behavior, they may be prone to several biases (e.g. over- or underperception) and do not necessarily reflect men's own perceptions. The very few studies that assessed both male and female reports of mate retention across women's menstrual cycles delivered contradictory results: In a within-subject study analysing 66 couples and comparing high- to low fertility days, both men and women reported higher proprietary behavior of men on women's high fertile days (Gangestad et al., 2014). In contrast, a diary study analysing 33 couples found no association of men's reported jealousy with women's hormonal status indicative of the fertile window (Righetti et al., 2020). Lastly, men's perceptions of women's changes in sexual motivation might also affect their own sexual motivation. Although not classically defined as a male retention tactic (Buss et al., 2008), male sexual motivation likely plays a considerable role in the occurrence of dyadic sexual behavior and such an increase during women's fertile window might not only yield direct reproductive fitness benefits but also deter women from seeking extra-pair mating. However, we know of no study that has investigated this association.

In summary, although men are expected to have evolved adaptations to notice and react to women's fertile window to increase their reproductive success, empirical evidence regarding existence of women's cues to fertility, men's perceptions thereof and their subsequent mate retention tactics is incomplete and inconsistent. Most previous studies suffered from small sample sizes and inappropriate study designs, and took no measures to constrain researcher degrees of freedom, such as preregistration or cross-validation (Arslan et al., 2021; Harris et al., 2014). To advance our understanding of how women's fertile window affects human's mating psychology, with this study, we sought to address these methodological shortcomings in several key aspects.

First, we conducted a highly powered, within-subject diary study with high ecological validity, which is recommended to test within-cycle changes (Schmalenberger et al., 2021). Second, we recruited romantic partners in heterosexual relationships, since women's romantic partners are not only expected to have the highest chances of perceiving women's within-cycle changes, but also to profit most from reacting to them (as they have already invested in long-term commitment; Puts et al., 2013). Third, where feasible, we collected data of both female and male perceptions of men's mate retention tactics. Fourth, by preregistering our hypotheses, study materials, variable transformations, sampling procedure and statistical analyses, we minimised researcher degrees of freedom. Fifth, since the kind and amount of contacts couples have on a specific day likely influences the degree to which cues to fertility can be noticed and reacted to, we controlled for both direct (i.e. physical proximity of couples) and indirect (e.g. texting, phoning) contacts of couples. Sixth, we used backward counting from the next observed onset of menstrual bleeding to determine the day of ovulation as a valid method to assess women's probability of being fertile (Gangestad et al., 2016). Seventh, we implemented a smallest effect size of interest (SESOI; Lakens, 2014) with a threshold of 0.10 to gauge the practical relevance of menstrual cycle shifts. Eighth, we employed a quasi-control group of women taking hormonal contraceptives (HC women) and their male partners (HC men), and compared them with naturally cycling women (NC women) and their male partners (NC men). Since HC women experience menstruation-like bleeding but no ovulation (Fleischman et al., 2010), significant differences between NC and HC groups further support the ovulatory nature of possible mid-cycle changes. Finally, we probed the robustness of our results for several exclusion criteria that might confound our findings (e.g. trying to become pregnant), different fertility estimators such as using discrete fertile windows, and different model specifications.

Following our preregistered hypotheses, we expected possible male perceptions of women's cues to fertility to manifest in mid-cycle increases in men's ratings of women's overall attractiveness (H1), in men's perceptions of women's general sexual desire (H2), and in the degree to which men perceived their female partners to wish for contact with other people (H3). Regarding men's mate retention tactics, we expected mid-cycle increases in male jealousy reported by men (H4.1) and women (H4.2). We also expected mid-cycle increases in the degree of male attention paid to women reported by men (H5.1) and women (H5.2), as well as in the amount of contact male partners would like to have to their female partners (H6). Finally, we expected increases in men's in-pair sexual desire towards their romantic female partners around women's mid-cycle (H7). Although we preregistered an additional hypothesis concerning mid-cycle increases in jealousy-related conflict reported by men and women, participants reported too few occasions of conflict to allow reliable analyses. Hence, we omitted this hypothesis but, for transparency, provide more details and analyses in the supplement (see Table S1-S2). We expected all changes to be higher in NC women and NC men, compared to baseline changes in our quasi-control groups of HC women and HC men, respectively. We made all materials including preregistration, survey files, data cleaning and analysis scripts as well as our codebook accessible online under https://osf.io/w43gq/. Anonymised data can be accessed as scientific use files under doi:https://doi.org/10.7802/2330.

2. Methods

We conducted a large-scale, preregistered online dyadic diary study which was implemented in the open source survey framework formr.org (Arslan et al., 2020a). This framework enabled the study's complexity and guaranteed anonymity of participants by automated handling of sensitive information. All participants signed a written consent form and the local ethics committee approved the study protocol (no. 228). Methods are partly overlapping with those described in Schleifenbaum et al. (2021b).

2.1. Sample size rationale

We predefined our sampling method and based our targeted sample size on a-priori power simulations (https://rubenarslan.github.io/ovulatory_shifts/1_power_analysis.html). Simulations indicated that for an unstandardised effect size of 0.26 that has been previously reported for women's mid-cycle increases in sexual motivation (Arslan et al., 2021), a statistical power of 99% can be achieved with an alpha rate of 0.01 when analysing data from 150 naturally cycling women across 30 diary days. As these power analyses did not include random slopes, however, we used them as a close approximation of overall statistical power in our study and sought to recruit a minimum of 150 naturally cycling women and their romantic partners. Assuming that rates of hormonal contraceptive use were similar to previous studies (Arslan et al., 2021), we expected 60% of recruited couples to be included in our quasi-control group, resulting in an expected overall sample size of 375 romantic couples.

2.2. Recruitment

We recruited romantic couples from October 2019 until April 2020 by distributing posters and flyers, using print and digital media (contacting mailing lists of German university students, posting advertisements on Facebook and on the study platform psytests.de), and by inviting participants who had taken part in similar studies before. As preregistered, we stopped data collection in May 2020 (so participants who began the study in April 2020 could finish all study parts) while blind to any results.

2.3. Exclusion criteria and participant flow

Since we were interested in menstrual cycle shifts that presumably evolved to serve reproductive functions, all participants had to confirm that they were predominantly heterosexual and in a heterosexual relationship before taking part in the study. Following our preregistration, of the 571 romantic couples that started the diary part of the study, we excluded 172 couples for reasons that affected women's menstrual cycles. We excluded those couples where the woman was likely not experiencing ovulation, i.e. because of pregnancy, breast-feeding, or menopause. We excluded couples where the woman switched to or from hormonal contraceptives during the study and who reported other irregular hormonal contraception such as morning-after pill use. Additionally, we excluded couples where either the man or woman was infertile or sterilised. We also excluded couples without data on women's menstrual bleeding (women who reported not to have a menstrual bleeding "sometimes or regularly" at all), and in case data were not sufficient to estimate fertility. Adding to our preregistered exclusion criteria but in line with our research plan, we excluded couples where women's menstrual cycles might have been affected by taking steroid hormones besides hormonal contraceptives. Besides criteria that affected both partners, considering individual diary entries, we excluded those that were not usable, i.e. unfinished diary entries, diary entries for which fertility could not be estimated and those where participants indicated to have answered dishonestly. Participants without any such usable diary entry were excluded completely (15 men and 9 women). Finally, if a participant had no usable diary entries at all, both partner's data were removed (15 couples), resulting in an overall sample size of 384 romantic couples. In Fig. 1, we provide a detailed participant flow showing the first of possibly multiple exclusion criteria. Robustness analyses including different exclusion criteria are described above (see Results section).

2.4. Sample characteristics

Our final sample consisted of 384 men and 384 women in romantic relationships (53.9% NC women and their male partners). Data of

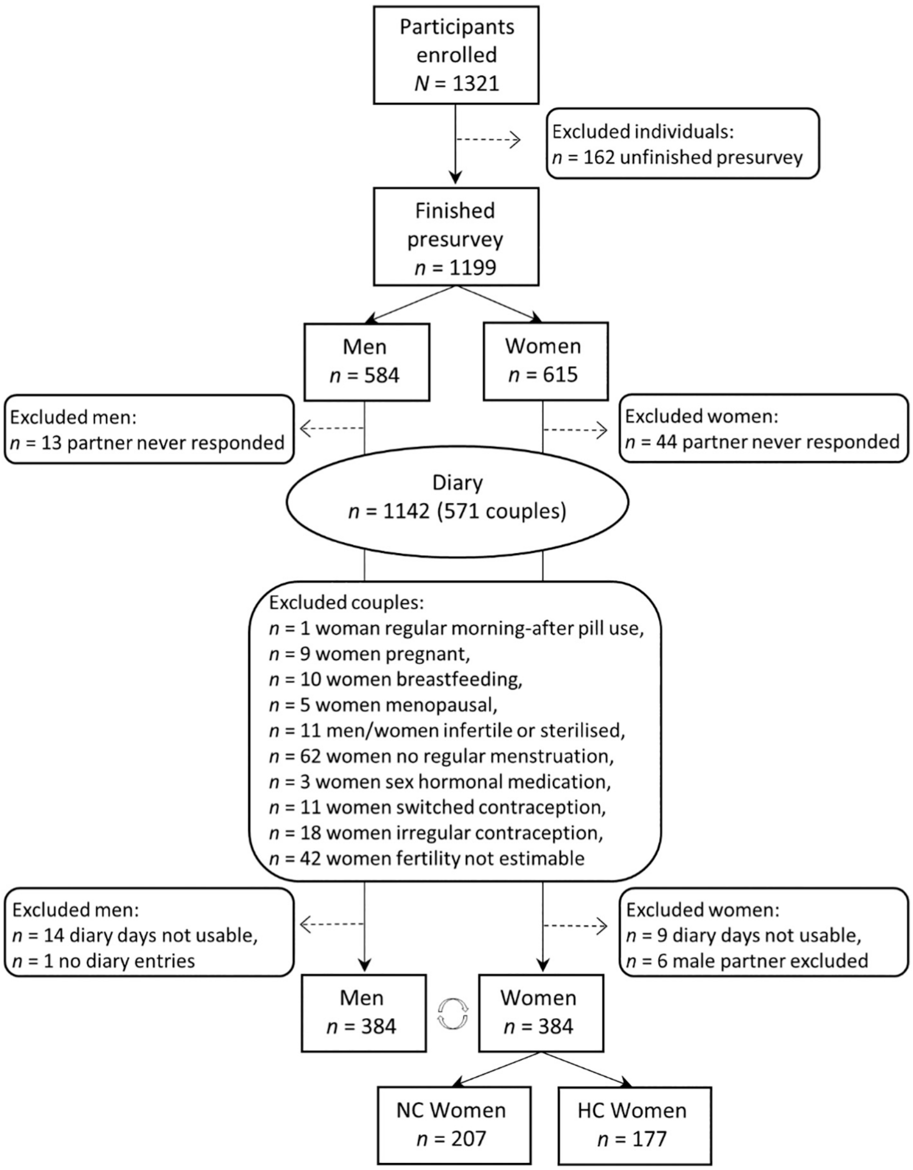

Fig. 1. Participant flow of the dyadic diary study. If participants were affected by multiple exclusion criteria, only the first criterion is shown. Exclusion criteria existed on both individual and dyadic levels. Firstly, data of participants were excluded who never finished the presurvey. Secondly, participants were excluded where no partner entered data. Thirdly, of romantic couples who entered the diary part of the study, both partners were excluded for reasons affecting women's fertility. Lastly, both partners were excluded if all entries of an individual partner could not be used, resulting in a final sample of 384 romantic couples where data of both romantic partners could be analysed. NC = naturally cycling women, HC = women using hormonal contraceptives.

female participants have been previously analysed for mid-cycle changes in motivational priorities (Schleifenbaum et al., 2021b). In total, men and women provided 24,896 analysable diary entries (48.5% of men) with, on average, $M = 31.24$ ($SD = 10.30$) diary entries per man and $M = 33.24$ ($SD = 9.32$) diary entries per woman. On average, men were $M = 25.2$ years old ($SD = 5.1$, range 18–51), and mostly students (61%) or employed (24%). On average, women were $M = 23.7$ ($SD = 4.2$, range 18–47) years old and mostly students (80%). Based on men's reports, couples had been, on average, in a relationship for $M = 3.1$ years ($SD = 3.1$), 94.8% of couples were in a monogamous relationship, 41% of couples lived together and 3% of couples had children. For women, the mean observed cycle length across the study was $M = 29.04$ days ($SD = 2.87$). We provide more details on different contraception methods of NC and HC women (Fig. S1) and comparisons between naturally cycling and quasi control groups for both men and women in the supplementary material (Table S3).

2.5. Procedure

Following the study link, participants received detailed information about the study entitled “Goettingen Couple's Study”. We introduced the study as a dyadic quiz investigating couple's perceptions of emotions and needs in romantic relationships. After having provided their informed consent, the first partner of the couple answered an initial survey that assessed demographic, personality and relationship information. Afterwards, they initiated a personalised email invitation to their partner. All personal and identifying data such as email addresses and mobile phone numbers were collected and stored separately using formr.org features to further guarantee anonymity.

Once the second partner had also answered the initial survey, the diary part of the study began on the next day. The diary encompassed 40 consecutive days and included, for example, daily self- and partner-ratings of well-being, health and stress as part of the study's cover story. The diary could be accessed by personalised invitation links that were sent at 5:00 pm every day via email and/or text messages and could be filled out until 3:00 am in the morning. We asked participants to answer diary entries by rating the time between the last entry and the current one if a previous diary entry was present. If no data entry was present from the day before, we asked participants to rate the time spanning the previous 24 h. Thus, we sought to cover the period of the diary continuously for users with high participation rates but to avoid aggregating across a longer time than one day. We randomised the order of the daily items within grouped-blocks in order to address possible measurement reactivity biases (Arslan et al., 2020b).

After completion of the diary part of the study, participants took part in three consecutive follow-up surveys. One day after the last diary entry, we asked participants to answer a first, general follow-up survey assessing, for example, illness and (hormonal) medication use, changes in contraceptive methods, and whether participants guessed the study's focus on the menstrual cycle. Afterwards, participants received compensation for their participation, such as illustrated feedback of their own data, course credit, chances of winning lottery prices or direct monetary compensation that depended on the amount of participation. Participants were fully debriefed once both partners had answered the follow-up surveys. Women who had not indicated an onset of menstrual bleeding within the last five days of the diary were directed to a second menstruation follow-up. We asked women to report the date of their next onset of menstrual bleeding every four days until they indicated a new onset. All men were automatically redirected and skipped this menstruation follow-up. Due to the COVID-19 pandemic, we launched an additional third COVID-19 follow-up survey in April 2020. In the final survey, we asked participants to report the extent to which COVID-19 affected their daily lives and their social and romantic relationships. A detailed overview of the study design for both romantic partners is given in our supplementary material (Fig. S2).

2.6. Measures

While a dyadic diary design is best suited to test within-cycle changes (Schmalenberger et al., 2021), it also came at the cost that some specific partner ratings regarding men's perceptions of women's extra-pair sexual desire or men's mate retention tactics could not be assessed without risking adverse effects for relationships during data collection (e.g. conflict, break-up or domestic violence). Hence, we asked for partner ratings of attractiveness, general sexual desire and jealousy directly, but used close approximations for the remaining partner ratings: for men's ratings of women's extra-pair sexual desire, we assessed how men perceived women's wish for contact with other people in general; for ratings of men's proprietary and attentive behavior, we assessed men's attention paid to their partners; and for men's monopolisation of women's time, we asked men how much contact men wished to have to their partners. Due to the high number of daily questions, we mostly used single-item measures to minimise participant burden and achieve a high compliance. For in-pair sexual desire, we used four items regarding sexual fantasies, sexual attraction, interest in intimacy and sexual behavior that have been used in previous studies (Arslan et al., 2021; Haselton and Gangestad, 2006). When phrasing men's ratings of women's wish for contact with others and their own wish for contact with female partners, comparable to previous studies (Haselton and Gangestad, 2006), we tried to adjust for time constraints that pose limitations on the amount of contact participants can have in everyday life by asking them to rate these contact variables independent of their time schedules. We computed multilevel reliability as generalisability of within-subject change averaged over items (Shrout and Lane, 2012) across all participants using the statistical software R 4.1.0 (R Core Team, 2021) and the psych (Revelle, 2021) and codebook (Arslan, 2019) packages. We provide results of generalisability estimates that are virtually identical when analysing female and male data separately in our supplementary material (Table S4). The main outcome measures of the diary part of this study and their reliabilities are documented in Table 1.

2.7. Estimating women's fertile window

Since hormonal measurements to determine the day of ovulation were not possible for this online study, we followed the recommendations by Gangestad et al. (2016) to operationalise women's fertile window as a continuous estimator of fertility, i.e. the probability of being in the fertile window (PBFW). Specifically, we first estimated each woman's day of ovulation by backward counting 15 days from the next observed onset of menstrual bleeding. We collected information on menstrual bleeding continuously throughout all study parts. We asked women to enter the exact dates of onsets and offsets of their menstrual bleeding in the presurvey, as well as in the daily diary. Thus, information on menstrual bleeding could be collected even if women skipped diary entries in-between. At the end of the diary, women who had not reported menstrual bleeding within the last five days of the diary were directed to the menstruation follow-up described above. That way, we collected data on the next onsets of menstrual bleeding after the diary ended and could use backward counting to assess the day of ovulation for all diary days. In order to compute women's PBFW as a predictor variable for men's ratings, we transferred women's data of menstrual onsets to their respective male partners. Thus, we were able to analyse men's data independent of whether couples had entered diary entries on the same day.

Table 1
Overview of measures in the dyadic diary.

Construct	Item (English translation)	Response format	Target	Rcn
Onset of menstrual bleeding	After having indicated to have had menstrual bleeding since the last diary entry: "The first day of menstruation was on… "	Date entered	Women	–
Women's attractiveness	"I found my partner attractive."	5-point Likert scale "not at all" – "very much"	Men	0.85
Women's general sexual desire	"My partner was interested in sexual activity."	5-point Likert scale "not at all" – "very much"	Men	0.86
Women's wish for contact with others	"If my partner had as much time as she had wanted, she would have liked to have had contact with other people besides me."	5-point Likert scale "not at all" – "very much"	Men	0.85
Men's jealousy	"I was jealous."	5-point Likert scale "not at all" – "very much"	Men	0.86
Men's jealousy	"My partner was jealous."	5-point Likert scale "not at all" – "very much"	Women	0.86
Men's attention to their partners	"I paid attention to my partner."	5-point Likert scale "not at all" – "very much"	Men	0.86
Men's attention to their partners	"My partner paid attention to me."	5-point Likert scale "not at all" – "very much"	Women	0.86
Men's wish for contact with partner	"If I had as much time as I had wanted, I'd have liked to have had contact with my partner."	5-point Likert scale "not at all" – "very much"	Men	0.86
In-pair sexual desire	"I had fantasies about sex with my partner." "I had fantasies about being intimate with my partner." "I felt sexually attracted to my partner". "I was interested in being sexually active with my partner."	5-point Likert scale "not at all" – "very much"	Men	0.74

Rcn = Reliability of change or generalisability of within person variations averaged over items.

As a second step, we calculated a continuous estimate of the PBFW for every woman's individual cycle, based on day-specific probabilities of being in the fertile window that Gangestad et al. (2016) provided. These estimates were calculated on the basis of the work of Stirnemann et al. (2013).[1] An exemplary demonstration of how we applied PBFW based on data of menstrual bleeding is provided in the supplementary material (Table S5). Whereas the flexibility in estimating women's fertile windows questions validity of earlier findings (Harris et al., 2014), the combination of backward counting of known cycle lengths with a continuous estimator of fertility has been shown to achieve high accuracy with a validity of estimating fertility as high as ~0.70 (Gangestad et al., 2016). Providing additional support for the validity of the PBFW as a measure of fertility, a number of previous studies using this procedure found robust mid-cycle changes in women (e.g. mid-cycle increases in sexual desire or self-perceived desirability; Arslan et al., 2021; Gangestad et al., 2016; Schleifenbaum et al., 2021a; Schleifenbaum et al., 2021b). Moreover, a recent study reports strong associations of backward counted cycle day with serum estradiol and progesterone in the expected direction across women's menstrual cycle (Arslan et al., 2022), further highlighting validity.

Third, since ovulatory cycles naturally show considerable inter- and intraindividual variation (Bull et al., 2019), we controlled for grave cycle irregularities by only considering cycles that were between 20 and 40 days long and did not count further back than 40 days from the next onset of menstrual bleeding. However, using a continuous fertility estimator includes days of the premenstrual phase and menstruation, which might affect our outcomes independently of fertility, for example via mood changes and somatic complaints (Yonkers et al., 2008). Therefore, we dummy-coded premenstrual phase (six days preceding menstrual onset) and menstruation (calculated by menstrual onset and offset dates per woman) to control for them in our analyses.

2.8. Data analysis

According to our preregistration, we employed linear mixed effects models to account for the hierarchical data structure of diary entries nested in participants for all of our outcomes. For all models, the main predictor was women's probability of being in the fertile window (PBFW) which was used to predict male and female ratings of the different outcomes.[2] We added women's premenstrual and menstrual days, and amount of direct and indirect contact the couples had on a specific day as control variables to all models given their potential effect on our outcomes independent of fertility (models with and without controlling for contact were virtually identical, see robustness analyses below).

Hormonal contraceptive users and their male romantic partners (i.e. HC women and HC men) served as a quasi-control group to distinguish changes related to ovulation from other mid-cycle changes such as absence of pre-, peri- and/or post-menstrual symptoms. Therefore, we added women's hormonal contraceptive use (for both her and her partner) as a dummy variable (0 = NC women and men, 1 = HC women and men) interacting with all predictors to properly apply interaction controls (Rohrer and Arslan, 2021). We included random intercepts, random slopes and their correlation for PBFW, premenstrual phase and menstruation to account for interindividual variation between persons and the repeated measurement of our outcome variables. In Wilkinson notation (Wilkinson and Rogers, 1973), our main models were specified as follows and run separately for men and women:

*outcome ~ (PBFW + premenstrual_phase + menstruation) * no_hormonal_contraception + contact_direct + contact_indirect + (1 + PBFW + premenstrual_phase + menstruation| person)*

Since we conducted multiple analyses for effects that are highly correlated with each other, a Bonferroni adjustment for multiple testing would have been too conservative. Instead, we set the significance threshold to an adjusted alpha rate of 0.01 with two-tailed statistical testing. Additionally, we sought to extend the current debate about menstrual cycle shifts in human's mating psychology by also evaluating the effect sizes of our outcomes for practical relevance. Hence, we defined a smallest effect size of interest (SESOI; Lakens, 2014), for unstandardised regression coefficients. Since no theoretical approach of menstrual cycle shifts makes any predictions about minimal effect sizes that are needed to have biological relevance so far, we adopted the conventional SESOI of 0.10 and a 90% confidence interval as the threshold for negligibility. Thus, if an effect size of PBFW and its 90% confidence interval is below the SESOI, the effect is deemed as negligible and the hypothesis is discarded irrespective of its statistical significance. If an effect size of PBFW is above 0.10, but its confidence interval includes the SESOI, the respective hypothesis can neither be accepted nor discarded. Our main analyses were conducted using the statistical software R 4.1.0 (R Core Team, 2021) and the respective R packages lme4 (Bates et al., 2015) for handling mixed effects models and sjPlot (Lüdeke, 2021) for calculating *p*-values of our predictors using the Kenward-Rogers approximation.

3. Results

For all models, we followed our preregistered analysis plan. We assumed that men should be able to perceive cues to fertility regardless of relationship type but that mate retention tactics might differ, for example, between open and monogamous relationships. Since we expected too few participants with non-monogamous relationships in our sample for reliable analyses, we analysed only the data of men in monogamous relationships (94.8%) for mid-cycle changes in men's mate retention tactics.

We ran all models separately for men and women, comparing NC men to HC men and NC women to HC women. As described above, we defined three conditions that needed to be fulfilled in order to infer a mid-cycle increase in all outcomes: 1) PBFW shows a significant influence of fertility according to our preregistered alpha rate of 0.01 and a corresponding 99% confidence interval, 2) the cross-level interaction of PBFW and hormonal contraception is significant and indicates higher mid-cycle changes in NC compared to HC women or men, and 3) the 90% confidence interval lower-bound on the effect size of PBFW is at least 0.10. Since we preregistered comparing unstandardised estimates to the SESOI, we report and base our conclusions on unstandardised estimates. However, we also provide standardised estimates in the supplementary material that do not change interpretation of results (Table S6-S14). As explained in the data analysis section, note that statistical inference is based on 99% confidence intervals, whereas comparisons of estimates with the SESOI follow the conventional 90% confidence intervals.

3.1. Men's awareness of cues to fertility

Analysing data of all 384 men, we found no significant mid-cycle increases in men's ratings of women's attractiveness, women's sexual desire, or women's wish for contact with others. Detailed results of these models are shown in Table 2, more details on random effects can be found in the supplementary material (Table S15). Descriptively, men's ratings of women's attractiveness and women's wish for contact with

[1] We sought to include other recent estimates of conception probability such as the ones by Faust et al. (2019) as an alternative predictor for cross-validating our findings. Unfortunately, the values kindly provided by Faust et al. (2019) only spanned a 9-day range around the fertile window which we could not use as an alternative continuous estimator across the whole cycle. Hence, we implemented other robustness analyses such as alternative counting methods to estimate women's day of ovulation as described below.

[2] Please note that women's and men's data were not analysed in the same models, as we use the same predictor variables for both partners, but different outcome variables.

Table 2
Overview of male ratings of women's cues to fertility across the menstrual cycle.

	Model 1				Model 2				Model 3			
	Men rate women's attractiveness				Men rate women' sexual desire				Men rate women's wish for contact with others			
	Estimates	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*
Level 1												
PBFW	−0.12	0.07	−0.29, 0.06	0.081	0.21	0.10	−0.05, 0.48	0.039	−0.10	0.09	−0.33, 0.13	0.280
Premenstrual phase (yes)	−0.06	0.03	−0.14, 0.01	0.032	−0.12	0.04	−0.24, −0.01	0.005	−0.06	0.04	−0.16, 0.03	0.097
Menstruation day (yes)	−0.09	0.03	−0.17, −0.01	0.004	−0.23	0.05	−0.36, −0.11	<0.001	−0.12	0.04	−0.22, −0.01	0.004
Direct partner contact	0.03	0.00	0.02, 0.03	<0.001	0.05	0.00	0.04, 0.05	<0.001	−0.01	0.00	−0.02, −0.01	<0.001
Indirect partner contact	0.02	0.01	0.01, 0.03	<0.001	0.03	0.01	0.01, 0.05	0.001	−0.00	0.01	−0.02, 0.01	0.457
Level 2												
Hormonal contraception (yes)	0.05	0.07	−0.14, 0.23	0.512	0.31	0.09	0.06, 0.55	0.001	0.09	0.08	−0.12, 0.30	0.275
Cross-level interaction												
PBFW:Hormonal contraception	0.06	0.10	−0.19, 0.32	0.518	−0.28	0.15	−0.67, 0.12	0.072	0.25	0.13	−0.09, 0.59	0.060
Premens:Hormonal contraception	0.04	0.04	−0.07, 0.15	0.351	0.10	0.06	−0.07, 0.26	0.134	0.14	0.05	0.00, 0.28	0.009
Mens:Hormonal contraception	0.05	0.05	−0.07, 0.17	0.273	0.08	0.07	−0.11, 0.27	0.272	0.15	0.06	−0.00, 0.30	0.012
ICC	0.51				0.38				0.43			
N	384_{men}				384_{men}				384_{men}			
Observations	11,855				11,855				11,855			
Marginal R^2/Conditional R^2	0.023 / 0.519				0.051 / 0.411				0.014 / 0.440			

Outcomes of linear mixed effects models with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Data of all men regardless of relationship type were analysed. All estimates are unstandardised and outcome variables are uncentered. PBFW = women's probability of being in the fertile window, Premenstrual phase = dummy-coded six days preceeding women's menstruation (0 = false, 1 = true), Menstruation day = dummy-coded whether women had menstrual bleeding on diary day (0 = false, 1 = true), Hormonal contraception = dummy-coded whether men's female partners use hormonal contraceptives or not (0 = false, 1 = true), SE = standard error, CI = confidence interval, N = number of participants, ICC = intraclass correlation. All models used PBFW as predictor variable, predicting men's ratings of women's overall attractiveness (Model 1), women's general sexual desire (Model 2), or women's wish for contact with other people (Model 3).

others were negatively associated with PBFW, showing non-significant mid-cycle decreases as opposed to the expected mid-cycle increases. Comparing effects of PBFW in NC to HC men, effects were weaker in HC men for men's ratings of women's attractiveness, and even slightly positive for men's ratings of women's wish for contact with others. However, as the cross-level interaction testing this difference was not significant, we cannot conclude that ratings of NC and HC men differed significantly from each other. Comparing the effect sizes of PBFW to the SESOI, neither upper nor lower limits of the confidence interval for women's attractiveness (90% CI [−0.23, −0.01]) nor women's wish for contact with other people (90% CI [−0.25, 0.05]) included the SESOI of 0.10. Thus, while we cannot distinguish the effect of PBFW from zero, we can confidently rule out an effect size of 0.10 or higher in our data.

Men's ratings of women's general sexual desire were positively associated with PBFW, but the effect did not reach our preregistered alpha rate of 0.01 (p = .039). The effect of PBFW was negatively associated with ratings of female sexual desire in HC men, such that their ratings of HC women's sexual desire decreased with increasing PBFW. However, as this cross-level interaction was non-significant, we cannot conclude that ratings of NC and HC men differed from each other. Given that lower limits of the confidence interval of the PBFW (90% CI [0.04, 0.38]) fell below the SESOI of 0.10, we can neither regard the effect of fertility in NC men's ratings of their partner's sexual desire as practically relevant nor discard it as negligible. Consequently, although men's ratings of women's sexual desire followed our expected pattern descriptively, none of these results of women's cues to fertility fulfilled any of our preregistered conditions for mid-cycle increases. All findings are illustrated in Fig. 2.

3.2. *Men's mate retention tactics*

Analysing only data of the 364 men and 364 women in monogamous relationships, we found no significant mid-cycle increases in men's jealousy (neither male nor female reports), men's attention paid to their

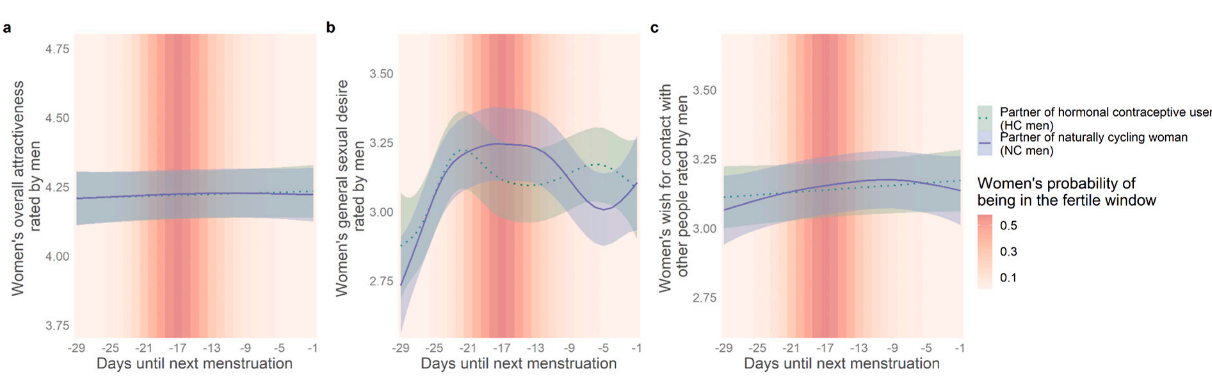

Fig. 2. Men's ratings of women's cues to fertility across the menstrual cycle. a,b,c Smoothed curves were calculated by generalised additive models, no control variables are included here. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleeding of women. Bands represent a 99% confidence interval. Since outcomes had different means, we always displayed a y-axis range of one standard deviation around respective means. The possible range of outcome values was 1 to 5 for all outcomes. Data of all men regardless of relationship type were analysed.

partners (neither male nor female reports), men's ratings of their wish for contact with their female partners, or men's ratings of their in-pair sexual desire. Detailed results of these models are shown in Table 3, more details on random effects can be found in the supplementary material (Table S16). While all outcomes were positively associated with PBFW at a descriptive level, these effects were small and non-significant. Comparing ratings of NC men and NC women to HC men and HC women, for men's jealousy, men's attention paid to their partners and men's ratings of their in-pair sexual desire, effects of PBFW were zero or even negatively associated with PBFW in HC men and women. For men's wish for contact with their female partners, results of the cross-level interaction indicated the opposite direction than expected, such that the effect of PBFW was higher in HC men, albeit still near zero. Since none of these cross-level interactions were significant, however, we cannot conclude that both groups differed significantly from each other. Comparing the effect sizes of PBFW to the SESOI, confidence intervals of all outcomes included the SESOI but lower limits of all outcomes including men's ratings of male jealousy (90% CI [−0.03, 0.14]), women's ratings of male jealousy (90% CI [−0.00, 0.13]), men's ratings of male attention to women (90% CI [−0.00, 0.23]), women's ratings of male attention to them (90% CI [−0.12, 0.14]), men's wish for contact with their female partners (90% CI [−0.13, 0.14]), and men's ratings of

Table 3
Overview of male and female ratings of men's mate retention tactics across the menstrual cycle.

	Model 1				Model 2				Model 3			
	Men rate male jealousy				Women rate male jealousy				Men rate their attention towards female partners			
	Estimates	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*
Level 1												
PBFW	0.06	0.05	−0.08, 0.19	0.278	0.06	0.04	−0.04, 0.17	0.126	0.12	0.07	−0.07, 0.30	0.106
Premenstrual phase (yes)	0.01	0.02	−0.05, 0.06	0.761	−0.01	0.02	−0.06, 0.04	0.639	0.01	0.04	−0.08, 0.10	0.728
Menstruation day (yes)	−0.01	0.02	−0.06, 0.05	0.816	−0.02	0.02	−0.06, 0.03	0.336	−0.01	0.04	−0.11, 0.08	0.730
Direct partner contact	0.00	0.00	−0.00, 0.00	0.275	−0.00	0.00	−0.00, 0.00	0.750	0.08	0.00	0.07, 0.08	<0.001
Indirect partner contact	−0.00	0.00	−0.01, 0.01	0.757	0.00	0.00	−0.00, 0.01	0.196	0.07	0.01	0.05, 0.08	<0.001
Level 2												
Hormonal contraception (yes)	0.05	0.04	−0.06, 0.17	0.231	0.01	0.03	−0.08, 0.09	0.871	0.08	0.06	−0.08, 0.25	0.179
Cross-level interaction												
PBFW:Hormonal contraception	−0.06	0.08	−0.25, 0.14	0.438	−0.06	0.06	−0.21, 0.10	0.345	−0.10	0.10	−0.37, 0.17	0.342
Premens:Hormonal contraception	0.00	0.03	−0.08, 0.09	0.957	0.01	0.03	−0.06, 0.09	0.620	0.03	0.05	−0.11, 0.16	0.627
Mens:Hormonal contraception	0.00	0.03	−0.09, 0.09	0.968	0.01	0.03	−0.06, 0.08	0.618	0.05	0.06	−0.09, 0.20	0.338
ICC	0.36				0.26				0.32			
N	364_{men}				364_{women}				364_{men}			
Observations	11,433				11,945				11,433			
Marginal R^2/Conditional R^2	0.002/0.362				0.001/0.258				0.157/0.428			

	Model 4				Model 5				Model 6			
	Women rate male attention to them				Men rate their wish for contact with female partners				Men rate their sexual desire towards female partners			
	Estimates	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*	*Estimates*	*SE*	*99% CI*	*p*
Level 1												
PBFW	0.01	0.08	−0.20, 0.21	0.923	0.00	0.08	−0.21, 0.22	0.966	0.07	0.09	−0.16, 0.30	0.403
Premenstrual phase (yes)	−0.06	0.04	−0.16, 0.04	0.131	−0.04	0.04	−0.14, 0.06	0.301	−0.08	0.04	−0.18, 0.03	0.053
Menstruation day (yes)	−0.05	0.04	−0.15, 0.05	0.170	0.00	0.04	−0.10, 0.10	0.929	−0.12	0.04	−0.24, −0.01	0.004
Direct partner contact	0.07	0.00	0.06, 0.07	<0.001	−0.01	0.00	−0.01, −0.00	<0.001	0.04	0.00	0.04, 0.05	<0.001
Indirect partner contact	0.06	0.01	0.05, 0.08	<0.001	0.03	0.01	0.01, 0.04	<0.001	0.05	0.01	0.03, 0.07	<0.001
Level 2												
Hormonal contraception (yes)	0.13	0.06	−0.03, 0.29	0.031	0.10	0.08	−0.10, 0.31	0.199	0.22	0.09	−0.01, 0.46	0.015
Cross-level interaction												
PBFW:Hormonal contraception	−0.09	0.12	−0.39, 0.21	0.452	0.01	0.12	−0.30, 0.32	0.929	−0.20	0.13	−0.54, 0.14	0.128
Premens:Hormonal contraception	0.06	0.06	−0.09, 0.20	0.301	0.08	0.06	−0.07, 0.22	0.175	0.01	0.06	−0.14, 0.16	0.846
Mens:Hormonal contraception	0.03	0.06	−0.12, 0.18	0.578	0.00	0.06	−0.14, 0.15	0.944	−0.01	0.06	−0.17, 0.15	0.863
ICC	0.31				0.44				0.51			
N	364_{women}				364_{men}				364_{men}			
Observations	11,945				11,433				11,307			
Marginal R^2/Conditional R^2	0.126/0.400				0.009/0.447				0.045/0.533			

Outcomes of linear mixed effects models with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men and women in self-reported monogamous relationships were analysed. All estimates are unstandardised and outcome variables are uncentered. PBFW = women's probability of being in the fertile window, Premenstrual phase = dummy-coded six days preceeding women's menstruation (0 = false, 1 = true), Menstruation day = dummy-coded whether women had menstrual bleeding on diary day (0 = false, 1 = true), Hormonal contraception = dummy-coded whether men's female partners use hormonal contraceptives or not (0 = false, 1 = true), SE = standard error, CI = confidence interval, N = number of participants, ICC = intraclass correlation. All models used PBFW as independent variable, predicting men's ratings of male jealousy (Model 1), women's ratings of male jealousy (Model 2), men's rating of their attention paid to their female partners (Model 3), men's ratings of attention their male partners paid to them (Model 4), men's ratings of their wish for contact with their female partners (Model 5) and men's ratings of their sexual desire towards their female partners (Model 6).

their in-pair sexual desire (90% CI [−0.07, 0.22]) fell below the SESOI. Thus, we can neither accept effect sizes of practical relevance nor discard these as negligible. In sum, none of these results of men's mate retention tactics fulfilled any of our preregistered conditions for mid-cycle increases. All findings are illustrated in Fig. 3.

3.3. Robustness analyses

We conducted several preregistered and additional analyses to probe our results for robustness. We investigated how results of our main predictor PBFW varied depending on different analytical decisions regarding exclusion criteria (e.g. women or men who were cycle-aware), estimators of fertility (e.g. using discrete fertile windows), and model specifications (e.g. omitting direct and indirect contact as control variables, modelling aggregated contact as a moderator variable). Moreover, since the COVID-19 pandemic emerged during the end of our data collection, we sought to gauge its impact on our results. By the time of the first nation-wide shutdown in Germany on March 16th, 2020, we had collected 76.7% of all diary entries. Consequently, we additionally compared our main analyses using all data to those only using data before the first shutdown.

Overall, results were largely robust to different exclusion criteria, different estimators of fertility and different modelling decisions. Effect sizes remained relatively constant and the vast majority of all 99% confidence intervals included zero. Additionally, results were virtually identical when omitting both direct and indirect contact as control variables and moderating effects of contact on PBFW were close to zero for all outcomes. Results did not change when comparing all data to only those collected before the first COVID-19-related shutdown. However, two noteworthy patterns emerged: First, we found considerably larger, significant effect sizes regarding an increase in men's ratings of women's sexual desire with increasing PBFW when only analysing the 8881 days at which couples had any direct contact ($b = 0.36$, 99% CI [0.06, 0.66]), or only considering couples where women self-reported highly regular cycles within a two-day range ($b = 0.39$, 99% CI [0.01, 0.76]). For the former effect, the confidence interval exceeded the SESOI (90% CI [0.17, 0.55]). Second, for all models, we found that effect sizes for PBFW were always considerably lower, sometimes even negative or nearly zero, when only analysing data where the women or their partners were cycle-unaware (i.e. not using an awareness-based contraception approach or cycle-tracking apps, see Fig. S3-S10). In Fig. 4, we depict an overview of our robustness analyses for men's ratings of women's sexual desire since this outcome descriptively showed the highest associations with PBFW, but provide detailed overviews for all outcomes in our supplement (Fig. S3-S10, Table S17-S25).

4. Discussion

Using almost 25,000 diary entries of heterosexual romantic couples, we found no compelling evidence that men notice women's fertility status: Comparing couples with NC women to couples with HC women, we found no mid-cycle increases in men's ratings of women's attractiveness, women's sexual desire, or women's wish for contact with other people. Similarly, we found no compelling evidence for mid-cycle increases in mate retention tactics, as neither men nor women reported that men were more jealous or more attentive when women were fertile, and men did not report to seek more contact with or have higher in-pair sexual desire towards their female partners.

Regarding cues to fertility, we found no evidence that men rate women's attractiveness as higher when women are fertile, contradicting large positive associations reported before (Haselton and Gildersleeve, 2011). Besides methodological differences such as this study's larger sample size, another likely explanation for discrepancies in results is that many previous studies relied on laboratory settings, often including experimentally manipulated stimuli that likely exaggerate natural variability, whereas our study enabled high ecological validity in

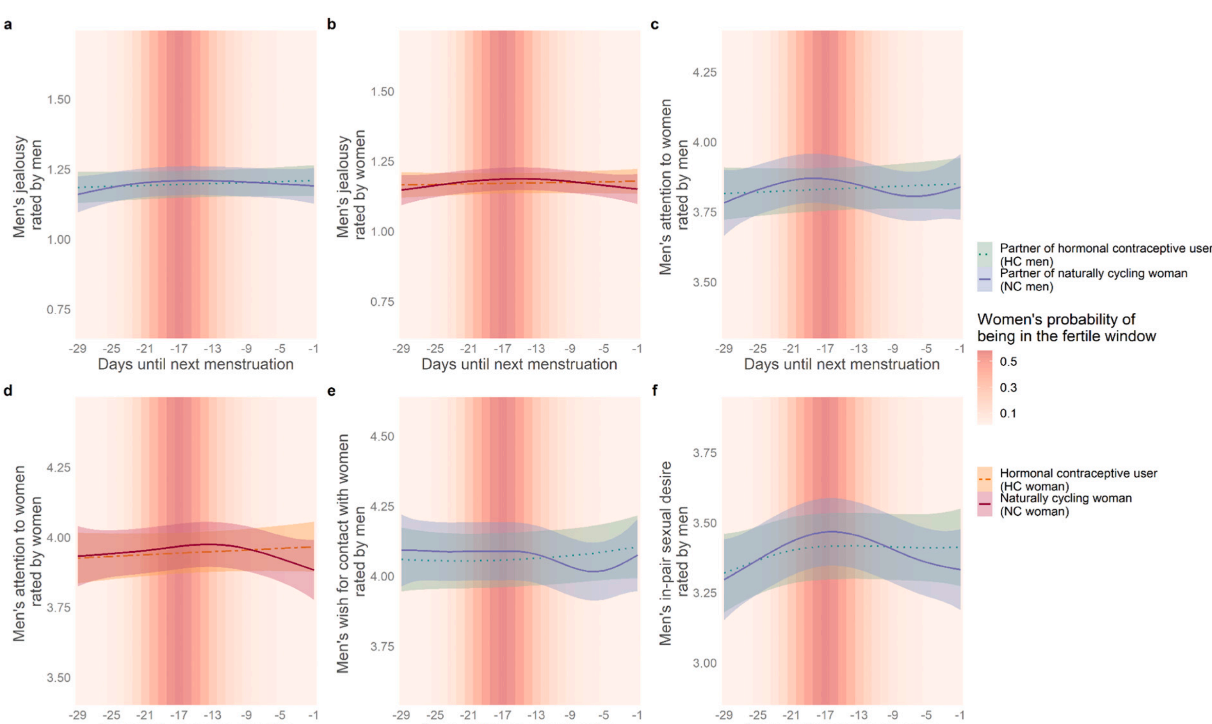

Fig. 3. Men's and women's ratings of men's mate retention tactics across the menstrual cycle. a,b,c,d,e,f Smoothed curves were calculated by generalised additive models, no control variables are included here. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleeding of women. Bands represent a 99% confidence interval. Since outcomes had different means, we always displayed a y-axis range of one standard deviation around respective means. The possible range of outcome values was 1 to 5 for all outcomes. Only data of men and women in monogamous relationships were analysed.

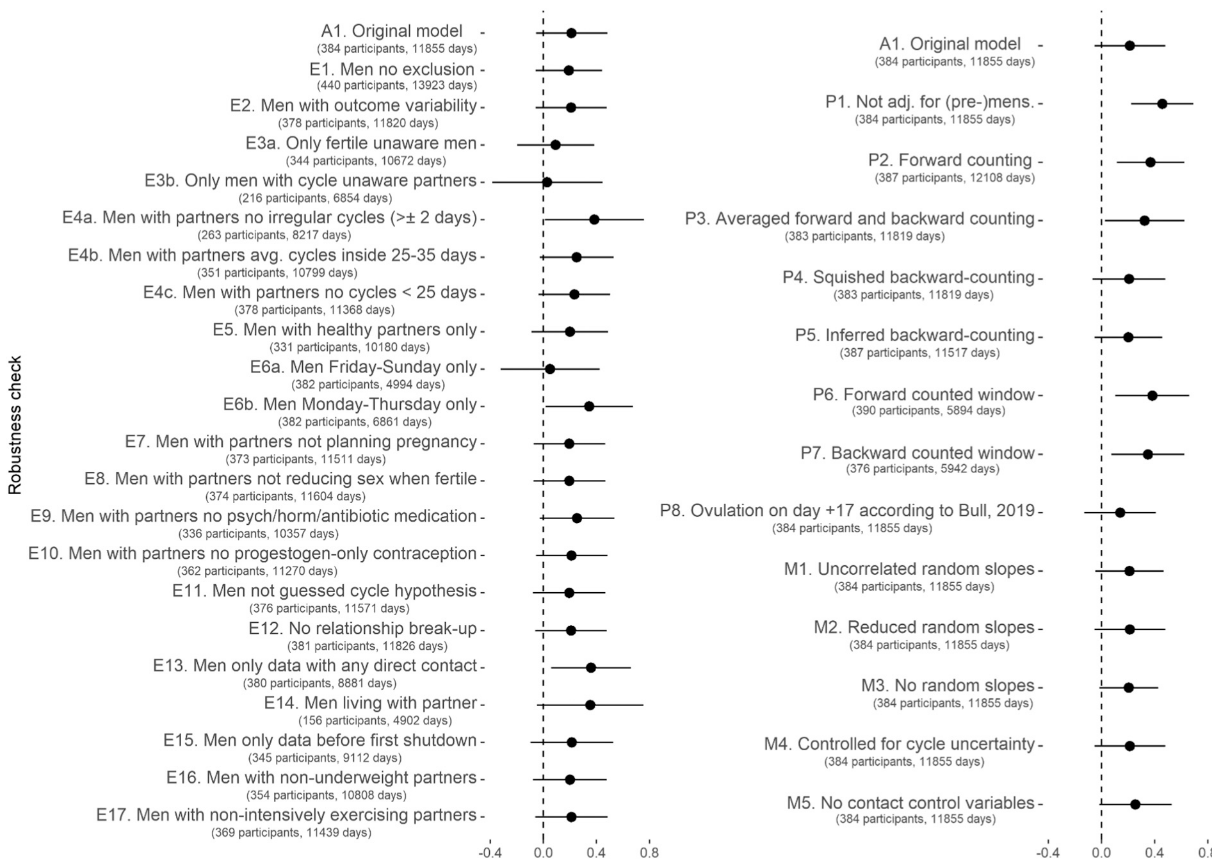

Fig. 4. Robustness analyses for men's ratings of women's sexual desire across the menstrual cycle. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness analyses with different exclusion criteria. Models starting with P are robustness analyses with different specifications of the fertility predictor. Models starting with M are robustness analyses with different model specifications. Avg. = average, psych/horm/antibiotic = psychopharmacological, hormonal or antiobiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

couple's everyday lives. Hence, our results question the extent to which mid-cycle changes in women's attractiveness are of biological relevance in real life.

Although women of the same sample self-reported robust mid-cycle increases in their sexual desire (Schleifenbaum et al., 2021b), this increase was not perceived by their partners: Men's ratings only showed descriptive increases which neither reached our strict significance level, nor exceeded our threshold of negligibility, and were not significantly higher in NC compared to HC men. There are several possibilities for this discrepancy in women's self-reports and men's ratings. First, it might be that women's mid-cycle changes in sexual desire do not translate into perceptible cues or that these changes are too small to be noticed by others. Second, it might be that women do not communicate or that they differ from men in the way they communicate sexual desire (Muise et al., 2013; Perilloux and Kurzban, 2015) and hence men might miss women's mid-cycle increases. Third, as suggested by our robustness analyses, men might require direct contact to their partners to detect mid-cycle changes (e.g. for noticing not only explicit but also implicit motives that are hard to verbalise; Pusch et al., 2021). Future research might consider the influence of direct contact as a possible moderator (the more contact, the stronger the effect of PBFW), mediator (when fertile, women increase contact and this increased contact leads to increased male ratings) or collider (Rohrer, 2018) variable (when fertile, women increase contact to their partners and men's perceptions of women's sexual desire also lead to increased contact). Although these results are purely exploratory and should be interpreted with caution, we hope our study serves as a starting point for more rigorous theoretical predictions and future empirical work that focuses on disentangling causal structures.

Additionally, we found no mid-cycle increases in men's ratings of women's wish for contact with others. Hence, while previous studies reported that women displayed increases in their wish for social gatherings to potentially meet other men and concurrent increases in extra-pair sexual desire (Gangestad et al., 2002; Haselton and Gangestad, 2006), our results indicate that men do not perceive such changes. Faced with the constraints of a dyadic diary study, where we could not assess some questions in order to avoid adverse effects to the relationship (see method section), it is possible that this approximate measure of extra-pair sexual desire was insufficient to assess such changes. For example, it might have been that women's wish for contact with other men increased at the same time as their wish for contact with female friends and families decreased, leading to false conclusions. However, in a previous study on women's self-reports in this sample, their extra-pair sexual desire yielded only small mid-cycle increases (Schleifenbaum et al., 2021b). Consequently, it is likely that men's perceptions of women's wish for contact were accurate and reflect low cycle variability in the sexual desire of women for men other than their committed partners.

Regarding men's mate retention tactics, we found no corresponding mid-cycle increases in men's jealousy, wish for contact with or attention paid to their female partners, despite the high costs men face when failing to detect risks of cuckoldry (Buss, 1996). While these findings contradict earlier research (Gangestad et al., 2002; Gangestad et al., 2014; Haselton and Gangestad, 2006), they are in line with other recent null-findings on mid-cycle changes in mate retention (Arslan et al., 2021; Righetti et al., 2020). Previous research has shown that jealousy in particular is linked to a perceived infidelity risk of one's partner (Barbaro et al., 2019; Buss, 2002; Kupfer et al., 2021) and associated with an anxious attachment style (Barbaro et al., 2019). Given the small and inconclusive mid-cycle increases in extra-pair sexual desire reported by the women in this sample (Schleifenbaum et al., 2021b), it is likely that men perceived no such infidelity threat which rendered jealousy and other mate retention tactics obsolete. Although men are expected to be overly sensitive to even remote cues to infidelity (Gangestad et al., 2002; Haselton and Buss, 2000), women in this sample primarily displayed increases in their in-pair sexual desire and initiation of dyadic sexual behavior (Schleifenbaum et al., 2021b), which might have counteracted such a male bias. Moreover, because the cover story was framed as a couple's quiz to investigate needs and emotions of one's romantic partner, it is possible that mainly those couples participated who were highly satisfied with their relationship (compare Table S23), and who were, for the most part, securely attached and committed to each other (Park et al., 2021), which might have further reduced the necessity of mate retention tactics.

Although there might have been no need for men for mate retention tactics to prevent their partners from defecting, showing increased in-pair sexual desire when female partners are not only fertile but also interested in sexual behavior could yield a direct reproductive fitness benefit. However, since our results indicate that women either do not emit or men cannot perceive cues to fertility, our null-finding for mid-cycle increases in men's in-pair sexual desire is in line with the other results. Additionally, sexual desire is not necessary for the occurrence of dyadic sexual behavior and sexual compliance is common in committed relationships in particular, so men could still gain reproductive fitness benefits by complying to women's sexual advances (Vannier and O'Sullivan, 2010). Moreover, men exhibit a higher sexual desire than women in general, with more frequent and spontaneous sexual thoughts, fantasies and arousal (Baumeister et al., 2001), which is less affected by contextual or relationship dynamics than women's (Basson, 2001; Dewitte and Mayer, 2018). Instead of within-cycle adaptations that might require resources for the detection of women's fertility status first, it might have been more cost-efficient for men to have evolved a higher baseline sexual desire than women that facilitates sexual behavior throughout the whole cycle, thereby increasing the likelihood of sexual behavior during women's fertile window as well.

Taken together, whereas women of the same sample reported mid-cycle increases in sexual desire and decreases in food-intake (Schleifenbaum et al., 2021b), our results question the notion that women display perceptible cues to fertility across their menstrual cycles which men have evolved to notice and react to. Previous research has debated whether women signal within-cycle fertility, "leak" such cues because complete suppression would have been too costly for their reproductive systems, or whether women signal overall reproductive capacity independent of cycle phase (Gangestad and Haselton, 2015; Haselton and Gildersleeve, 2016). Since men in this sample should have had the highest likelihood and motivation for perceiving within-cycle changes because they are repeatedly exposed to their female partners and already invested into the relationship, it might be that women either do not display cues or that men cannot perceive them in everyday life. Given that men can perceive between-women differences in women's parity and reproductive value (Bovet et al., 2018; Bovet, 2019) which guides their mating choices (Buss and Schmitt, 2019; Todd et al., 2007), our results suggest that cues to fertility might be restricted to interindividual variation.

However, our study also has limitations that deserve mentioning. First, we did not assess separate aspects of women's attractiveness such as facial, bodily, vocal or olfactory attractiveness. While we expect these cues to enter into an overall perception, it is still possible that men perceive facets of attractiveness differently. Second, we decided not to assess men's perceptions of women's extra-pair sexual desire directly to avoid adverse effects to the relationship during data collection. Moreover, assessment of mate retention tactics was only feasible for some of multiple tactics investigated in earlier studies (Buss, 1988; Buss et al., 2008). Third, we relied on couples' self-reports, which might be affected by measurement reactivity, desirability bias, or recall error. For example, participants might have had difficulties to perceive or admit their own jealousy, as the concept of jealousy has a negative connotation.

Fourth, it is possible that this study's results attained in a sample of highly satisfied couples may not generalise to all other relationships. Given that our sample fulfils all criteria of a WEIRD (Henrich et al., 2010) sample, generalisability to other cultures and norms may be limited as well. For example, in our sample, strong cultural norms in favour of (serial) monogamy (Henrich et al., 2012) and related constructs, such as cohabitation customs and disapproval of extra-pair copulations might pose a cultural institution of mate retention in themselves and thereby limit intraindividual variation in mate retention behavior. In contrast, men in more polygynous societies might rather show mid-cycle increases in mate retention tactics: In these societies, the number of unpartnered men who might mate poach is comparably higher and women possibly face trade-offs between resource provisioning and genetic quality of potential partners more regularly. As a related point, most women in our sample were highly committed and satisfied with their romantic relationships and therefore likely to be very choosy with regard to potential mating alternatives (Buss et al., 2017). This might have reduced the likelihood to observe both extrapair desire in the women of sample and mate retention tactics in their partners. A replication of our study in a more culturally diverse setting and in a sample with higher variability in relationship satisfaction and commitment would be desirable.

Finally, although backward counting from women's last observed onset of menstrual bleeding to estimate women's fertility struck a methodological balance between feasibility, ecological validity and high statistical power, it is likely still outperformed by ultrasound or hormonal tests (Gangestad et al., 2016). Thus, we cannot rule out that results might differ when using more valid fertility estimates. While, for this online study, it was impossible to assess women's hormone levels, we still tried to reach a maximal level of validity for our fertility estimates by reducing measurement error through high test power, employing a continuous measure of fertility (as recommended by Gangestad et al., 2016) and a number of robustness analyses accounting for potential variability in cycle lengths. Together with the fact that we report expected patterns of a mid-cycle increase in sexual desire and a decrease in food intake in the same participants elsewhere (Schleifenbaum et al., 2021b) and previous research provides more evidence for the validity of our measure (e.g. Arslan et al., 2021, 2022; Schleifenbaum et al., 2021a), we are confident that the results of our study are reliable. Nevertheless, we encourage researchers to replicate our findings using a more valid indicator of fertility.

While we strongly encourage future replications in more diverse samples and cultures that address these limitations, our results have several important theoretical implications. In general, our findings are consistent with multiple, albeit partly disagreeing, theoretical accounts stating that concealed ovulation was necessary for the evolution of our current social structures, for example by reducing infanticide (Schröder, 1993), male (Schröder, 1993) and female (Krems et al., 2021) intrasexual competition, or by increasing long-term bonds (Alexander and Noonan, 1979) and paternal investment (Strassmann, 1981). Importantly, although concealed ovulation has traditionally been equated with a lost oestrus in women, both are not necessarily equivalent (Pawlowski, 2016). While we found no evidence for cues to fertility in this sample, it has been shown that women exhibit robust increases in their sexual desire (Arslan et al., 2021; Jones et al., 2018; Roney and Simmons, 2013, 2016; Shirazi et al., 2019; Stern et al., 2020) and their self-perceived attractiveness and desirability (Arslan et al., 2021; Haselton and Gangestad, 2006; Schleifenbaum et al., 2021a) which might nudge women towards sexual behavior when the possibility of conception maximises the benefit-cost ratio (Roney, 2016) and thus may constitute an oestrus-like phase. By applying high methodological rigour, this work advances our understanding of how menstrual cycle changes are perceived by women's long-term partners and offers implications for the vibrant debate about the evolution of concealed ovulation and oestrus in women.

CRediT authorship contribution statement

L.S., J.S., J.C.D., T.M.G., R.C.A. and L.P. planned the study. L.S. and L.L.W. implemented the study with support from R.C.A. L.S. coordinated the study, collected the data and based on prior work by R.C.A, cleaned and analysed the data. L.S. wrote the manuscript; all authors edited and approved the final version of the manuscript.

Ethical standards

The authors assert that participants provided written consent and that all procedures contributing to this work were approved by the local ethics committee and comply with national legislation and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki).

Declaration of competing interest

None.

Data availability

I have shared the links to both data and code.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.yhbeh.2022.105202.

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