Ovulatory cycle shifts in human mating psychology –

Implications for the evolution of concealed ovulation and female oestrus

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Lara Schleifenbaum

aus Kreuztal

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Betreuungsausschuss

Lars Penke

Biologische Persönlichkeitspsychologie, Georg-August-Universität Göttingen

Felix Schönbrodt

Psychologische Methodenlehre und Diagnostik, Ludwig-Maximilians-Universität München

Julia Ostner

Verhaltensökologie, Georg-August-Universität Göttingen

Mitglieder der Prüfungskommission

Referent:

Lars Penke

Biologische Persönlichkeitspsychologie, Georg-August-Universität Göttingen

Koreferent:

Felix Schönbrodt

Psychologische Methodenlehre und Diagnostik, Ludwig-Maximilians-Universität München

Weitere Mitglieder der Prüfungskommission:

Julia Ostner

Verhaltensökologie, Georg-August-Universität Göttingen

Margarete Boos

Sozial- und Kommunikationspsychologie, Georg-August-Universität Göttingen

York Hagmayer

Kognitionswissenschaft und Entscheidungspsychologie, Georg-August-Universität Göttingen

Annekathrin Schacht

Affektive Neurowissenschaften und Psychophysiologie, Georg-August-Universität Göttingen

Tag der mündlichen Prüfung: 21.01.2022

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Außerdem ein großer Dank an meine Familie, allen voran meinem Vater. Ich weiß, dass ihr stolz auf mich seid, ganz gleich, was ich in meinem Leben mache und auch, wenn ich mir selber nur mehr Arbeit und Ansprüche antue als nötig. Eure bedingungslose Liebe, eure Gelassenheit und euer Humor sind und werden immer meine Vorbilder im Leben sein.
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Preface

This dissertation is not a cumulative, publication-based dissertation, but follows it in form. It includes three manuscripts, of which one has been published and two are preprints of manuscripts that are currently under review.

Schleifenbaum, L., Driebe, J. C., Gerlach, T. M., Penke, L., Arslan, R. C. (2021). Women feel more attractive before ovulation: evidence from a large-scale online diary study. *Evolutionary Human Sciences*, 1-34, https://doi.org/10.1017/ehs.2021.44

Schleifenbaum, L., Stern, J., Driebe, J. C., Wieczorek, L. L., Gerlach, T. M., Arslan, R. C. Penke, L. (2021). *Ovulatory cycle shifts in motivational prioritisation of sex and food.* [Manuscript submitted for publication]. Department of Biological Personality Psychology, University of Goettingen.

Schleifenbaum, L., Stern, J., Driebe, J. C., Wieczorek, L. L., Gerlach, T. M., Arslan, R. C. Penke, L. (2021). *Men are not aware of and do not respond to their female partner's fertility status: evidence from a dyadic diary of 384 couples.* [Manuscript submitted for publication]. Department of Biological Personality Psychology, University of Goettingen.

In the present thesis, I integrate the theoretical background and discuss the broader implications of three separate manuscripts concerning ovulatory cycle shifts in human mating psychology. These manuscripts are attached in the Appendix (A, B, C). I am first author in all three manuscripts. The following table highlights my responsibilities and contributions to each manuscript. Please note that my co-authors were involved in each process as well, meaning that every step is not my contribution alone but the result of a shared project.

	Appendix A Manuscript 1	Appendix B Manuscript 2	Appendix C Manuscript 3
Study Design	-	✓	✓
Data Collection	-	✓	✓
Data Analysis	✓	✓	✓
Manuscript Writing	✓	✓	✓

I hereby declare that all parts of this dissertation were written by myself, that assistance of third parties was only accepted if scientifically justifiable and acceptable in regards to the examination regulations, and that all sources have been quoted.

Göttingen, 2021

Lara Schleifenbaum

0. Abstracts

0.1 English abstract

The existence of ovulatory cycle shifts in human mating psychology and their function for reproduction have been subject to a long-standing debate. Past research has provided initial evidence that women experience distinct shifts in their mating psychology during their fertile window and further suggested evolved counteradaptations in men's mating psychology as well. However, widespread methodological shortcomings in study design, sample size and analytical flexibility restrict the informational value of most of these studies. Using data from two large, preregistered diary studies, I sought to address these methodological shortcomings and thereby advance our understanding of the nature and function of ovulatory cycle shifts in human mating psychology with my three complementing manuscripts. In Manuscript 1, my co-authors and I found that women experienced several ovulatory increases in their self-perceived attractiveness and related constructs that had not been reported before. In Manuscript 2, we found that women also experienced robust ovulatory increases in their sexual motivation and behaviour as well as concurrent ovulatory decreases in their food intake. In Manuscript 3, we found that male partners of those women analysed in Manuscript 2 did neither perceive cues to women's fertility status nor showed increased mate retention tactics to secure access to their fertile partners. In the face of current debates about ovulatory cycle shifts, my dissertation provides empirical support for a possible adaptive shift in motivational priorities regarding sex and food in women. Results further question the validity of theoretical predictions of counteradaptations to women's fertile phase in men. While I stress the need for further theoretical and empirical work, one possible implication of this dissertation is that women might have retained an oestrus-like sexual phase which is not necessarily linked to perceptible cues to fertility. Thus, my dissertation advances the scientific discourse while easing the tension between research on

ovulatory cycle shifts and evolutionary theories based on concealment of women's fertility status.

0.2 Deutsche Zusammenfassung

Die Existenz von ovulationsbezogenen Zyklusveränderungen in der menschlichen Paarungspsychologie und deren Rolle für die menschliche Fortpflanzung wird seit langem diskutiert. Bisherige Forschung deutet darauf hin, dass Frauen spezifische Veränderung in ihrer Paarungspsychologie während ihrer fertilen Phase ihres Ovulationszyklus zeigen und Männer ebenfalls entsprechende Adaptationen in ihrer Paarungspsychologie aufweisen. Frühere Studien sind jedoch zu großen Teilen von methodischen Schwächen in Studiendesign und Stichprobengröße sowie von analytischer Flexibilität gekennzeichnet, was den Informationsgehalt dieser Studien stark beeinträchtigt. Das Ziel dieser Dissertation und meiner drei zugehörigen Manuskripte war es, diese methodischen Schwächen zu überwinden und somit unser Verständnis von der Natur und Funktion von ovulationsbezogenen Zyklusveränderungen zu erweitern. Die Ergebnisse in Manuskript 1 zeigen, dass Frauen in ihrer fertilen Phase Anstiege in selbst wahrgenommener Attraktivität und verwandten Konstrukten erleben, was zuvor in diesem Ausmaß nicht berichtet wurde. Die Ergebnisse in Manuskript 2 zeigen, dass Frauen zudem robuste Anstiege in ihrer sexuellen Motivation und ihrem sexuellen Verhalten berichten und gleichzeitig weniger Nahrung zu sich nehmen, wenn sie fertil sind. Die Ergebnisse in Manuskript 3 zeigen, dass die männlichen Partner der in Manuskript 2 untersuchten Frauen keine Hinweisreize zur fertilen Phase wahrnehmen. Außerdem zeigten Männer keine Anstiege in ihren Strategien zur Paarerhaltung, um Zugang zu ihren fertilen Partnerinnen zu sichern. Die Ergebnisse meiner Dissertation unterstützen die Theorie eines möglichen adaptiven Wechsels für Frauen in der motivationalen Priorisierung von Sex und Essen über den weiblichen Ovulationszyklus hinweg. Nullbefunde zu möglichen Anpassungen auf die weibliche fertile Phase in Männern hinterfragen jedoch andere aktuelle theoretische

Ansätze zur Erklärung von ovulationsbezogenenen Adaptationen bei Männern. Obwohl weitere theoretische und empirische Arbeit nötig ist bevor klare Aussagen getroffen werden können, deuten die Ergebnisse meiner Dissertation darauf hin, dass Frauen möglicherweise eine Oestrus-ähnliche sexuelle Phase besitzen, die jedoch nicht notwendigerweise mit wahrnehmbaren Hinweisreizen verbunden ist. Mit dieser Arbeit bringe ich die derzeitigen wissenschaftlichen Debatten voran und versuche, Widersprüche zwischen bisheriger Zyklusforschung und evolutionären Modellen zu lösen, die auf der Notwendigkeit einer versteckten Ovulation aufbauen.

1. Introduction

How does women's and men's mating psychology change during the fertile phase of women's ovulatory cycles? Given that women's fertile phase is crucial for human reproduction, this question is central to human evolutionary sciences. Humans as a sexually reproducing species need the sexual recombination of genes of both men and women which is only possible during a specific time span across women's ovulatory cycles, the so-called *fertile window* (Wilcox et al., 1998). As men and women are assumed to face different pressures of sexual selection (Trivers, 1972), evolutionary psychologists expect them to have evolved differential adaptations to women's cyclical fertility (e.g. Buss & Schmitt, 2019). Such *ovulatory cycle shifts*, defined as changes that specifically occur during with women's fertile windows, concern psychological, behavioural and physiological aspects. However, researchers do not agree on the specifics of these adaptations and multiple inconsistencies in theoretical and empirical work have led to an ongoing and partly heated debate in the literature (e.g. Arslan, Driebe, et al., 2021; Gangestad & Dinh, 2021; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Stern et al., 2019; Stern et al., 2020). Consequently, the aim of this dissertation is twofold: Firstly, I investigate how women's mating-related self-perceptions change across their ovulatory cycles and how these changes may constitute evolved psychological adaptations. Therefore, in the first manuscript, I focus on women's self-perceived attractiveness and related constructs such as sexual desirability. In the second manuscript, I concentrate on how women may have evolved shifting motivational priorities between sexual and somatic, food-related effort. Secondly, I focus on self- and partner-perceptions of assumed adaptations in men to notice and react to women's fertility status in the third manuscript. While these findings cannot conclusively answer whether and which ovulatory cycle shifts exist in human mating psychology, they offer methodological rigour and empirical evidence future debates about women's oestrus and concealed ovulation can build on.

1.1 Minimal parental investment and mating strategies differ between the sexes

Theoretical models on how women’s ovulatory cycles might affect both women and men largely build on theoretical approaches concerning evolved sex differences in human mating psychology. As in other sexually reproducing species, the fundamental sex difference in humans is *anisogamy*, that is the cost-intensive production of large, usually immobile gametes (eggs) in women and the less costly production of small, motile gametes (sperm) in men (Liker et al., 2015). Following anisogamy and internal fertilisation, the *Parental Investment Theory* (Trivers, 1972) states that women’s minimal parental investment including gamete production, gestation, placentation, child birth and lactation largely exceeds that of men. Hence, women’s reproductive success (i.e. number of offspring who can reproduce) is expected to be mostly limited by access to resources and material benefits for them and their offspring, whereas men’s reproductive success is expected to be limited by access to fertile women. Consequently, women and men face diverging pressures of sexual selection (Schärer et al., 2012). This results in so-called *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). This intersexual conflict is expected to have led to a sexually antagonistic coevolution, where men and women have evolved psychological adaptations as sex-specific mating strategies for optimising their reproductive success (Buss & Schmitt, 1993, 2016).

According to the *model of strategic pluralism* (Gangestad & Simpson, 2000), men and women have evolved condition-dependent mixed mating strategies that vary between and within the sexes. On average, men should be motivated to seek as many sexual encounters as possible, whereas women should benefit most from seeking both genetic quality and investment provision of the men they mate with. Yet, men differ in these qualities and those men with high genetic quality are expected to be less willing to invest because that would reduce their opportunities for mating with other women. Consequently, humans show mutual mate choice[1] and women have to make reproductive compromises where they are expected to engage in *short-term mating* (i.e. sexual affairs) with men indicating high genetic quality (mostly based on physical attractiveness), and in *long-term mating* (i.e. committed relationships) with men whose lower genetic quality limits their chances at short-term mating and who therefore resort to higher parental investment. Initially, the model of strategic pluralism aimed at explaining adaptive sex differences in human mating strategies as well as interindividual variation therein. However, since mating decisions relating to genetic quality have potentially critical reproductive consequences only when women are fertile, it later served as basis for predicting intraindividual changes in human mating psychology across women's ovulatory cycles.

1.2 Women's ovulatory cycles

Women's ovulatory cycles can be divided into two phases that serve different functions and are characterised by distinct underlying hormonal patterns: The *follicular phase* spans the time between the first day of menstrual bleeding until the day of ovulation and is followed by the *luteal phase* which spans the time after ovulation until the next onset of menstrual bleeding (Gangestad & Haselton, 2015). Whereas follicles and endometrium grow during the follicular phase until the dominant follicle ruptures and an egg is released into the fallopian tubes during ovulation, hormonal changes during the luteal phase enable the implantation of the possibly fertilised egg into the uterine lining (Gangestad & Haselton, 2015). Alongside multiple regulating hormones, these phases are dominated by intraindividual changes of the steroid hormones estradiol and progesterone: higher estradiol to progesterone ratios characterise the follicular and higher progesterone to estradiol ratios characterise the luteal phase (Roney, 2016). Importantly, across the ovulatory cycle, women can only conceive during the fertile window

[1] Details of how humans choose mates is beyond the scope of this dissertation. For overviews on the relevance of assortative mating and partner preferences see Conroy-Beam (2021), Buss and Schmitt (2019) and Eastwick et al. (2014).

that marks the late part of the follicular phase and spans approximately five days before ovulation and the day of ovulation itself (Wilcox et al., 1998). While many mammals exhibit such recurring reproductive cycles, the shedding of the endometrium by menstrual bleeding is rare and mostly limited to primates (Emera et al., 2012). Despite the similarities, however, human's reproductive cycles were long seen as unique compared to other primates.

1.3 Do women exhibit oestrus and cues to their fertility?

Although other non-human primates show anisogamy and differential reproductive costs between the sexes, human reproduction was assumed to differ from that of non-human primates in many ways. Unlike human's closest relative, the chimpanzee (Deschner et al., 2004), women lack obvious cues to their fertile window (e.g. anogenital swellings). Additionally, many other non-human primate species engage in mating and sexual behaviour only during oestrus, which is defined as a "relatively brief period of proceptivity, receptivity, and attractivity in female mammals that usually, but not invariably, coincides with their brief period of fertility" (Symons, 1979, p. 97). Instead, human women exhibit *extended sexuality*, meaning that they actively engage in sex (sexual proceptivity) and accept male advances for sex (sexual receptivity) outside of their fertile window across the whole ovulatory cycle (Gangestad & Thornhill, 2008; Grebe et al., 2013). These distinct features of women's sexuality led researchers to believe that women have evolved a concealed ovulation and phylogenetically lost a (classically defined) oestrus (e.g. Burley, 1979; Symons, 1979).

There are various theoretical explanations for the presumed loss of cues to women's fertility and scientific debates are ongoing. One of the leading assumptions is that as part of the sexually antagonistic coevolution, concealed ovulation evolved in a polygynous mating system to enable long-term bonds and monogamy: It is possible that concealed ovulation led to paternity uncertainty in men who then benefitted more from investing into long-term mating and mate guarding instead of short-term mating (Alexander & Noonan, 1979), or that extended neoteny in humans made paternal investment by subordinate men more important for offspring success than genetic benefits of dominant men who spent more mating than paternal effort (Strassmann, 1981). Other theoretical explanations state that concealed ovulation and subsequent paternity uncertainty reduced the risk of infanticide (Hrdy, 1979), prevented women from consciously avoiding pregnancy and associated costs and risks (Burley, 1979), or enabled women to bond with investing partners but gain genetic benefits by extra-pair copulations (Benshoof & Thornhill, 1979). It is also possible that concealed ovulation reduced intrasexual competition in men for access to ovulating women (Schröder, 1993) and reduced intrasexual competition in women (Krems et al., 2021), thereby enabling the evolution of complex social bonds in humans (but see Pawlowski, 2016 for additional explanations and Rooker & Gavrilets, 2018 for more in-depth discussions of how various factors might have interacted for the evolution of concealed ovulation).

However, during the last two decades, empirical evidence made researchers question whether women have completely lost cues to their fertility and a phase of oestrus. Instead, multiple studies have reported ovulatory cycle shifts in various aspects: Early research has found that women show ovulatory increases in their attractiveness, for example, regarding their faces and bodies (Beaulieu, 2007; Puts et al., 2013; Roberts et al., 2004), body scent (Gildersleeve et al., 2012; Havliček et al., 2006; Singh & Bronstad, 2001), and voices (Pipitone & Gallup, 2008; Puts et al., 2013), which have been linked to changes in ovarian hormones, specifically in estradiol and progesterone (Puts et al., 2013). Women have also been shown to increase their grooming behaviour and to put more effort into their appearance when fertile (Durante et al., 2008; Haselton et al., 2007). More recent studies showed that women rate male bodies as more attractive when fertile (Jünger, Kordsmeyer, et al., 2018; Stern et al., 2021) which might resemble increased sexual receptivity in other species. Moreover, several studies reported that women show ovulatory increases in their sexual motivation[2] (e.g. Arslan, Schilling, et al., 2021; Gangestad et al., 2002; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016) and initiation of sexual behaviour (Adams et al., 1978; Bullivant et al., 2004), corresponding to increases in sexual proceptivity. Such findings led Gangestad and Thornhill (2008) to claim that "women possess a distinct fertile sexuality that is, in fact, functionally homologous with as well as functionally similar to oestrus observed in other vertebrae species" (p. 992). Together, these findings sparked theoretical and empirical debates about possible adaptations regarding women's fertile window in not only women's but also men's mating psychology that will be described in more detail below.

1.4 Debate about ovulatory cycle shifts in human mating psychology

There are several partly overlapping, partly contradictory theoretical approaches for evolved psychological adaptations to women's fertile window. In the following, I first discuss the most influential hypothesis so far, the so-called *Good Genes Ovulatory Shift Hypothesis* (GGOSH; Gangestad et al., 2004; Gangestad et al., 2007; Gangestad & Thornhill, 2008; Pillsworth & Haselton, 2006b), for explaining ovulatory cycle shifts in women and the presumed corresponding adaptations in men. Afterwards, I highlight mixed findings and several methodological shortcomings of previous studies, leading to a description of the current state of research and a promising alternative theoretical approach for changes in women's mating psychology, the *Motivational Priority Shifts Hypothesis* (Roney, 2016; Roney & Simmons, 2013, 2016, 2017).

1.4.1 The Good Genes Ovulatory Shift Hypothesis in women

Based on the model of strategic pluralism, the GGOSH describes that women show shifting mate preferences and targets of their sexual desire as an evolved adaptation to avoid

[2] In the following, the terms "sexual motivation" and "sexual desire" will be used interchangeably as different researchers use different terms I would like to adhere to, but all refer to the interest in or wish for sexual behaviour (Spector et al., 1996).

the necessity of reproductive compromises in weighing genetic quality and paternal investment of their mating partners. The GGOSH postulates that women experience shifting mate preferences towards men with higher genetic quality when they are fertile. Thus, shifting sexual attraction and desire are expected to facilitate short-term mating in women to reap genetic benefits by extra-pair copulations with men with "good genes" when fertile, while securing support from a long-term mate with possibly lower genetic quality but higher resource investment when outside the fertile window. Supposed indicators of genetic quality are mostly related to male features of physical attractiveness and symmetry[3], masculinity[4], and signs of dominance and intrasexual competitiveness (Gangestad et al., 2005a; Gangestad & Thornhill, 2008).

Several studies have provided evidence supporting the predictions of the GGOSH in women. Early research has shown that during their fertile window, women preferred men who possessed presumed indicators of genetic quality such as high developmental stability (Gangestad et al., 2005b) as well as more masculine and dominant features in faces (Penton-Voak et al., 1999; Penton-Voak & Perrett, 2000), voices (Feinberg et al., 2006; Puts, 2005, 2006), bodies (Little et al., 2007; Pawlowski & Jasienska, 2005) and behaviours (Gangestad et al., 2004; Gangestad et al., 2007). In a meta-analysis using 50 reports from 38 published and 12 unpublished studies, Gildersleeve et al. (2014) concluded that cycle shifts of mate preferences in short-term contexts were robust and not prone to publication bias or variability in study design and analytical strategy ("researcher degrees of freedom"). Other studies reported that the target of women's sexual desire shifted as well. Analysing 31 women in a

[3] This is based on the assumption that the interaction of genetic quality and environmental factors translates into developmental stability which should lead to low so-called fluctuating asymmetry that women should find attractive. For more details see Thornhill and Gangestad (1994) and Gangestad et al. (2005b).
[4] This is based on the assumption that testosterone as the primary sex hormone in men leads to masculinisation but is linked to decreased immune functions that only men with high genetic quality can afford to display (in line with the immunocompetence handicap hypothesis; Folstad and Karter, 1992). For more details see Penton-Voak et al. (2003) and Gangestad et al. (2007).

committed relationship and comparing high- to low fertility days, Gangestad et al. (2002) found that women reported higher sexual attraction to and more sexual fantasies about extra-pair mates (so-called *extra-pair sexual desire*), which did not hold for their primary partners (so-called *in-pair sexual desire*). Replicating the study with 43 women and comparing low- to high fertility days, Pillsworth and Haselton (2006a) showed that the ovulatory increase in extra-pair sexual desire was more pronounced in women who judged their partners as less sexually attractive und thus were expected to have lower genetic quality. A further within-subject study of 33 women linked extra-pair sexual desire to higher estradiol levels (indicative of the fertile phase in women) as opposed to a link of in-pair sexual desire with higher progesterone levels (indicative of the luteal phase in women, Grebe et al., 2016). Moreover, additional evidence that women felt more attractive when fertile was interpreted as a function of women's mating psychology to raise mate choice standards and facilitate short-term mating with more attractive (and assumed high genetic quality) men (Haselton & Gangestad, 2006).

1.4.2 Assumed male counteradaptations to shifting mate preferences in women

The hypothesised shifts in women's mate preferences and sexual desire towards short-term mating with men possessing better genetic quality entail the high risk of cuckoldry for men in long-term relationships. Besides a lost opportunity for reproduction with his female partner, a cuckolded man risks cost-intensive effort for raising another man's child, loses the opportunity of mating with other women and risks a damage to his reputation and social status (Buss, 2002). Hence, as part of the sexually antagonistic coevolution, men are expected to have evolved several counteradaptations to prevent their female partners from defecting (Gangestad et al., 2005a).

First, it is assumed that men were under selection to detect women's cues to fertility (Gangestad et al., 2005a) that might consist of changes in physical appearance and manifest behaviour (Buss & Schmitt, 2019). Several early studies have reported that men noticed, albeit subtle, ovulatory changes in women's facial shape and texture (Bobst & Lobmaier, 2012; Oberzaucher et al., 2012), vocal attractiveness (Pipitone & Gallup, 2008), body scent (Doty et al., 1975; Gildersleeve et al., 2012; Havliček et al., 2006; Kuukasjarvi, 2004; Singh & Bronstad, 2001; Thornhill, 2003) and grooming behaviour (Haselton et al., 2007; Schwarz & Hassebrauck, 2008). Given that women might have been under selection to suppress their fertility status, researchers deemed it unlikely that such ovulatory changes were actively signalled. Instead, it was assumed that women emit cues to their fertility because a full suppression of them would have been too costly for women's reproductive systems (*leaky cues hypothesis*, Gangestad et al., 2005a; Gangestad & Haselton, 2015).

Second, men are expected to show behaviour to secure access to their female partners and fend off potential competitors, so-called *mate retention tactics* (Buss & Shackelford, 1997) when women are fertile (Gangestad et al., 2005a). There are several mate retention tactics that have been described in the literature, ranging from resource provision, public displays of affection and appearance enhancement to monopolisation of partner's time, jealousy, partner derogation, threats and violence (Buss, 1988; Buss et al., 2008)[5]. However, only few studies have investigated whether men increase their mate retention tactics when their female partner is fertile. Among these, in a study investigating 27 women by comparing high- to low fertility days, early research showed that women reported higher proprietary (e.g. vigilance) and attentive (e.g. monopolisation of time) behaviour of their male partners on high fertile days (Gangestad et al., 2002). These female reports of ovulatory increases in proprietary behaviour also seemed to correspond to their male partners' reports (Gangestad et al., 2014). Similarly, in a diary across 35 days and comparing high- to low fertility days, 25 women reported higher jealousy and possessiveness of their male partners when they were fertile (Haselton &

[5] For more details on between-person variance and sex differences in mate retention tactics, see Buss (1988), Buss (2018) and Salkicevic et al. (2014).

Gangestad, 2006) and these effects for women's reports of jealousy were assumed to be large with a Cohen's *d* of 0.7 (Haselton & Gildersleeve, 2011).

1.4.3 Inconsistent evidence for the Good Genes Ovulatory Shift Hypothesis in women

Although previous studies seem to draw a clear picture of the nature and function of ovulatory cycle shifts in human mating psychology, inconsistent evidence of the past few years has raised serious doubts on the predictions and validity of the GGOSH as well as assumed male counteradaptations to it.

The ongoing debate regarding ovulatory cycle shifts in female mating psychology was sparked in 2014 when a second meta-analysis by Wood et al. about shifting mate preferences reached opposing conclusions to the one by Gildersleeve et al. of the same year. Analysing 58 reports from 45 published and 13 unpublished studies, Wood et al. (2014) concluded that evidence could not support ovulatory cycle shifts in women's preferences for high-testosterone, masculine, dominant or symmetrical men and attributed previous findings to publication bias and research artefacts. Coinciding with the replication crisis in psychology (Pashler & Wagenmakers, 2012) and the subsequent Open Science movement (Open Science Collaboration, 2015) that pointed out questionable research practices and emphasised methodological rigour, multiple researchers set out to collect new data and to thoroughly test the predictions of the GGOSH. Among these newer studies, most could not replicate previous evidence in favour of the GGOSH. Recent studies found no compelling evidence for preference shifts related to ovarian hormones or the fertile window for masculine or symmetrical faces (Dixson et al., 2018; Jones, Hahn, Fisher, Wang, Kandrik, Han, et al., 2018; Marcinkowska et al., 2018), masculine bodies (Jünger, Kordsmeyer, et al., 2018; Marcinkowska et al., 2018; Stern et al., 2019; van Stein et al., 2019), masculine voices (Jünger, Motta-Mena, et al., 2018), or men's behaviours (Stern et al., 2020). Given that the GGOSH expects ovarian hormone regulation of mate preferences, one would also expect inhibitory effects of progesterone as marker of the non-fertile phase on women's preferences for putative indicators of good genes in men, but such associations do not seem to exist (Ditzen et al., 2017; Jünger, Motta-Mena, et al., 2018; Stern et al., 2020). Moreover, recent studies did not find ovulatory increases in women's extra-pair sexual desire (Righetti et al., 2020), or reported ovulatory increases in both extra- and in-pair sexual desire based on new data (Arslan, Schilling, et al., 2021) as well as based on a re-analysis of previous research that supported the GGOSH (Shimoda et al., 2018; Shirazi et al., 2019). There is also no compelling evidence that proposed shifts in women's extra-pair sexual are moderated by men's physical attractiveness (Arslan, Driebe, et al., 2021; Arslan, Schilling, et al., 2021).

Besides such empirical inconsistencies, there are also theoretical considerations that are incongruent to the predictions of the GGOSH. Other researchers have criticised whether the supposed indicators of genetic quality actually inform of genetic differences (Arslan & Penke, 2015; Buss & Schmitt, 2019; Lee et al., 2014; Lidborg et al., 2021; Nowak et al., 2018) and could not replicate proposed associations of attractiveness ratings, testosterone levels and health in men (Kandrik et al., 2017). Furthermore, others have pointed out that extra-pair mating poses a high-risk - and therefore unlikely - strategy for women where associated risks range from loss of paternal investment by desertion to risking violence and death, and thus are expected to largely outweigh potential fitness benefits (Buss & Duntley, 2011; Daly et al., 1982).

1.4.4 Inconsistent evidence for assumed counteradaptations in men

Regarding ovulatory cycle shifts in male mating psychology, only a few recent studies have tried to replicate ovulatory cycle shifts in men's supposed awareness of cues to fertility and even fewer studies have replicated assumed ovulatory changes in mate retention tactics. Considering possible cues to women's fertility, several studies did not find proclaimed 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 scents (Roney & Simmons, 2012), and women's voice pitch (Pavela Banai, 2017). Moreover, other findings questioned whether postulated shifts in women's facial shape or colour exist or are even perceptible (Burriss et al., 2015; Marcinkowska & Holzleitner, 2020). Considering ovulatory increases in mate retention tactics, Righetti et al. (2020) analysed diary data of 33 heterosexual couples and found no association of men's reported jealousy with women's hormonal status indicative of the fertile window, but the small number of participants across the low amount of 15 repeated diary days restrict the study's informational value. Arguably the most convincing evidence so far comes from a preregistered diary study across 40 days by Arslan, Schilling, et al. (2021) who used data of 429 naturally cycling women and the same items for assessing mate retention tactics that were previously used by Haselton and Gangestad (2006). Unlike Haselton and Gangestad (2006), Arslan, Schilling, et al. (2021) found no ovulatory changes in women's reported mate retention tactics of jealousy, possessiveness, love, or attention. Instead, Arslan, Schilling, et al. (2021) criticised the low multilevel reliability of the items (which Haselton and Gangestad (2006) had not reported) and concluded that this made detection of an effect unlikely, thereby casting further doubt on previously reported significant findings. Nonetheless, so far, no study has provided convincing answers to the question whether men notice and react to women's cyclical fertility.

1.4.5 Methodological shortcomings in ovulatory cycle research

How come the majority of early and recent studies provide such inconsistent findings? One likely explanation for these incongruities is that past research largely suffered from methodological shortcomings that were exposed during and partly because of the Open Science movement. Most strikingly, early ovulatory cycle research employed small sample sizes that were likely underpowered and thus prone to false positive and false negative findings: Power analyses by Gangestad et al. (2016) showed that for achieving a minimum statistical power of 80% for detecting a medium-sized effect in a within-subject design, at least 55-71 participants would be needed (depending on whether high- to low-fertility days are compared or random samples of cycle days are analysed). Detecting the same medium-sized effect with a statistical power of 80% in a between-subject design would even require 900-1000 participants (Gangestad et al., 2016). However, very few early studies that were in line with the GGOSH met these criteria, for example, no between-subject study achieved a sample size anywhere near the required number and within-subject studies showing shifting preferences for facial masculinity that were published before 2018 had a mean sample size of 40 (Jones, Hahn, Fisher, Wang, Kandrik, Han, et al., 2018). Besides being heavily underpowered, between-subject designs are hardly suited to detect within-person changes because of high interindividual genetic differences (Arslan, Schilling, et al., 2021) that dwarf within-person variation (Zietsch et al., 2015). Yet, about 62% of all studies that were included in the meta-analyses of Gildersleeve et al. (2014) and Wood et al. (2014) were between-subject designs (Gonzales & Ferrer, 2016).

Moreover, early research on ovulatory cycle shifts showed high variability in estimating women's fertile windows (Harris et al., 2014). Defined lengths of women's fertile windows ranged from 3 days (Macrae et al., 2002) to 14 days (Penton-Voak et al., 1999). Additionally, early fertility estimators mostly relied on forward counting methods to determine the day of ovulation on day 14 after the start of menstrual bleeding, but forward counting methods have proven unreliable (Gangestad et al., 2016). Instead, simulation studies have shown that ultrasound and hormonal tests as well as a combination of a continuous fertility estimation (Stirnemann et al., 2013) with backward counting 15 days from the next observed onset of menstrual bleeding to estimate the day of ovulation are sufficiently accurate and valid (Gangestad et al., 2016). Furthermore, many previous studies did not account for effects of premenstrual or menstrual phases that might affect women independently of ovulation through, for example, feelings of anxiety, bloatedness or pain (Schoep et al., 2019; Yonkers et al., 2008).

Hence, many mid-cycle changes reported in the literature before might falsely follow absence of (pre-)menstrual symptoms and most studies have not controlled for these effects (Kiesner et al., 2020).

Finally, newly established Open Science research practices such as preregistration and opening material, data and analytic decisions for public scrutiny helped making research progress better and more transparent (Hoffmann et al., 2021; Nosek et al., 2018; Schönbrodt, 2019), but there remain intransparencies in early cycle research (Arslan, Driebe, et al., 2021) that make it hard to weigh the impact of questionable research practices on earlier findings.

1.4.6 The Motivational Priority Shifts Hypothesis and current state of research

If predictions of the GGOSH do not seem to withstand replications and new standards in research practices, how could we explain the extant literature about ovulatory changes in women's mating psychology? Those recent studies that overcame methodological shortcomings and provided more reliable information point in the direction that it is less target-specific in-pair or extra-pair sexual desire that shifts during women's fertile window. Instead, they report ovulatory increases in women's general attraction to men and their general sexual desire (Arslan, Schilling, et al., 2021; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016; Shirazi et al., 2019; Stern et al., 2020). While debates about interpretations of results that are not in line with the GGOSH are continuing (e.g. Arslan, Driebe, et al., 2021; Gangestad et al., 2019; Gangestad & Dinh, 2021; Jones et al., 2019; Jünger, Kordsmeyer, et al., 2018), an alternative theoretical approach that might better explain these ovulatory cycle shifts in women's mating psychology is the Motivational Priority Shifts Hypothesis (MPSH; Roney, 2016; Roney & Simmons, 2013, 2016, 2017).

Based on life history theory[6], the MPSH is part of an overarching theoretical framework for human behavioural endocrinology (Roney, 2016) where hormones are regarded as coordinating signals that evolved to allocate limited resources towards different adaptive problems. Since hormones are released into the general circulation of the body, they can do so by eliciting organism-wide adaptive responses to the environment or bodily states. The MPSH applies this logic to women's ovulatory cycles and postulates that women face two competing adaptive problems across their ovulatory cycles, namely reproductive and somatic effort. In a world with limited resources, ovarian hormones facilitate an adaptive motivational trade-off of reproductive and somatic effort that depends on their respective cost-benefit-ratios. More specifically, Roney (2016) states that the steroid hormones estradiol and progesterone act as a two-signal code of fertility to the brain where the high estradiol to progesterone ratio during the fertile window elicits increased sexual motivation and decreased eating motivation. Thus, women are expected to show increased sexual motivation when costs related to sexual behaviour (e.g. mating effort, risk of injury, risk of infection and opportunity costs with regard to e.g. foraging and feeding) are outweighed by its potentially large fitness benefit of conception and pregnancy. After ovulation, women can no longer conceive and sexual motivation and sexual behaviour cannot yield a direct reproductive fitness benefit. Consequently, Roney (2016) argues that the high progesterone to estradiol ratio during the luteal phase signals the non-fertile phase of the cycle during which cost-benefit ratios favour eating over sexual motivation to secure survival and future reproductive opportunities. This should result in adaptively decreased sexual motivation but increased eating motivation during the luteal phase until the start of a new ovulatory cycle and a new fertile window. Taken together, the MPSH states that ovarian hormones not only regulate women's ovulatory cycles but also enable alternating re-

[6] While not within the scope of this dissertation, life history theory "addresses how organisms are designed to manage tradeoffs in the investment of finite resources across the lifecourse in order to promote lifetime reproductive success" (Roney, 2016, p. 99).

allocations of resources from sexual to eating motivation. Importantly, however, the MPSH does not expect hormonal effects to be the only influences on women's sexual motivation. Besides the proposed pathway of a phylogenetically conserved hormonal mechanism, the MPSH leaves open a second pathway of social input variables such as relationship dynamics that affect women's sexual motivation independent of cycle phase, thereby facilitating extended sexuality and the formation of long-term pair bonds.

The current state of research showing ovulatory increases in women's general as well as both in-pair and extra-pair sexual desire is consistent with the predictions of the MPSH. In addition, a reduction in feeding and foraging is present during species-specific fertile windows of various other animals (see Schneider et al., 2013 for a review) which implies a common physiological mechanism. Accordingly, women show a nadir in food intake when they are fertile (Fessler, 2003) which is even more pronounced in sexually active women (Fleischman & Fessler, 2007). Moreover, after ovulation, women report increased food intake, appetite and food cravings in their luteal phases, especially of highly caloric, protein-rich and sweet food (Asarian & Geary, 2006; Barr et al., 1995; Gorczyca et al., 2016; Pliner & Fleming, 1983) and also gain weight during their luteal phases (Kammoun et al., 2017; Pliner & Fleming, 1983). In support for the hormonal regulation of these shifts, Roney and Simmons (2013) showed that estradiol likely exerts excitatory effects on sexual motivation in women, whereas progesterone exerts inhibitory effects, and this pattern is reversed for eating motivation (Roney & Simmons, 2017). Yet, while these findings provide initial evidence for the MPSH, most studies on changes in eating motivation suffer from low statistical power. Furthermore, sexual and eating motivation were mostly investigated separately. Given that the MPSH assumes a trade-off between motivational priorities, it is crucial to investigate both constructs in the same sample of women. So far, however, only one small sample of 43 women was analysed for ovulatory changes in sexual motivation and an even smaller proportion of 24 of the same women were analysed for concurrent ovulatory changes in eating motivation (Roney & Simmons, 2013, 2017).

1.5 Theoretical conclusion

There is a long strand of research that debates whether women show oestrus and cues to their cyclical fertility. Findings of ovulatory cycle shifts in women's appearance and mating psychology have opened up a fruitful field of research that might advance this debate. However, results have largely been dominated by the GGOSH that proclaims shifting mate preferences in women and served as basis for the assumption of corresponding counteradaptations in men to prevent their female partners from defecting. Newer findings contradict the predictions of shifting mate preferences in women but so far, profound empirical support for a promising alternative, the MPSH, is missing. In addition, evidence regarding men's awareness to their female partner's fertility status is mixed and whether men show ovulatory increases in mate retention tactics has not been tested rigorously so far. In this dissertation, I sought to contribute to this scientific discourse about ovulatory cycle shifts in both women's and men's mating psychology. Therefore, my colleagues and I conducted two large-scale online diary studies. First, we assessed women (regardless of relationship status) across a time-span of 70 days to investigate ovulatory changes in their mating related self-perceptions with a focus on attractiveness and related constructs. Second, we conducted a dyadic diary across 40 days with heterosexual, romantic couples to analyse ovulatory changes in women's self-perceived motivational priorities and also investigate ovulatory changes in their partner's awareness and reactions to women's fertility status. To add methodological rigour, in all studies, we controlled for (pre-)menstrual phases and implemented a quasi-control group of women (and their romantic partners) using hormonal contraceptives and consequently experiencing menstruation-like bleeding but no ovulation to infer the ovulatory nature of presumed mid-cycle shifts. In addition, we preregistered our study designs, data collection procedures, hypotheses as well as our analytical approaches, made our study materials and analysis scripts public on the Open Science Framework, and shared our study data where possible.

2. Summary of Manuscript 1

In the first manuscript, we focused on a specific aspect of ovulatory changes in women's mating psychology and investigated whether their self-perceived attractiveness and related constructs changed during their fertile window. In women, self-perceived attractiveness is the most relevant component of, and has been used interchangeably with, women's self-perceived mate value (Singh, 2002), that is "the total value of the characteristics that an individual possesses in terms of the potential contribution to his or her mate's reproductive success" (Waynforth, 2001, p. 207). These self-perceptions have been shown to be relevant for women's mating decisions (Penke et al., 2008) and therefore have critical reproductive consequences during women's fertile window in particular. Yet, empirical evidence regarding ovulatory changes in self-perceived attractiveness remains mixed (Haselton & Gangestad, 2006; Schwarz & Hassebrauck, 2008). Moreover, self-perceived attractiveness is strongly related to sexual desirability (Wade, 2000) and to grooming behaviour as possible mate value enhancement (Haselton et al., 2007). Mating-related self-assessments also include affective-evaluative components of self-esteem (Penke et al., 2008) and influence women's mood (Cattarin et al., 2000). However, previous research on changes across women's ovulatory cycles mostly suffered from aforementioned methodological shortcomings and was often limited to single aspects of related constructs, thereby missing possibly broader ovulatory changes in women's mating psychology. Hence, we conducted a large-scale within-subject diary study (including both single and partnered women) where we assessed the aforementioned attractiveness-related self-perceptions in 580 naturally cycling women across 70 days and compared these to 292 women using hormonal contraceptives. Following current recommendations, we estimated the day of ovulation by backward counting 15 days from the observed onsets of menstrual bleeding and used a continuous predictor of the probability of being in the fertile window (Gangestad et al., 2016; Stirnemann et al., 2013). Supporting our results with several robustness analyses regarding different exclusion criteria, different estimators of women's fertility and different modelling decisions, we found robust small to medium-sized ovulatory increases in women's self-perceived attractiveness that were only present in naturally cycling women. Similarly, we found medium-sized mid-cycle increases in self-perceived sexual desirability that were robust across researcher degrees of freedom, but while the effect was descriptively diminished in women using hormonal contraceptives, the group comparison did not reach our preregistered significance level of p = .01. Although this questions the ovulatory nature of this effect, the non-significant group comparison might also be due to reduced statistical power in the analyses concerning self-perceived sexual desirability (because of a coding error, sexual desirability was only assessed in 576 partnered women making up only 66% of the whole sample). Contrary to our expectations, we found no compelling evidence for previously reported ovulatory increases in grooming as neither the effect of fertility nor group comparisons were significant. However, we found a small, moderately robust ovulatory increase in women's self-esteem that was significantly diminished in women using hormonal contraceptives. Similarly, we found small mid-cycle increases in women's positive mood but these were not significantly different between naturally cycling women and women using hormonal contraceptives, and robustness across researcher degrees of freedom was low. In sum, while we encourage future replications of our work, these results clear previously mixed findings by showing ovulatory increases in women's self-perceived attractiveness and presumably sexual desirability. Moreover, we add new evidence of a potential increase in self-esteem when women are fertile and call for more research to investigate possible ovulatory increases in positive mood. However, we find no evidence for increased grooming behaviour when women are fertile.

3. Summary of Manuscript 2

In the second manuscript, we sought to test the predictions of the MPSH (Roney, 2016; Roney & Simmons, 2013, 2016, 2017) of a motivational prioritisation of sexual motivation over eating motivation when women are fertile. Since previous studies have mostly tested sexual and eating motivation separately and employed small sample sizes, the informational value of studies in support for the MPSH is limited. We sought to address this gap by conducting a large-scale online dyadic diary study across 40 days with one daily measurement of 390 women in heterosexual relationships and comparing 209 naturally cycling women to 181 women using hormonal contraceptives (women's male romantic partners also participated in the diary but are not part of the analyses for this manuscript). We broadened our investigation to not only include self-reported sexual and eating motivation but also analyse corresponding behaviour as the goals the motivations should be directed at. As in study 1, following current recommendations, we estimated the day of ovulation by backward counting 15 days from the observed onsets of menstrual bleeding and used a continuous predictor of the probability of being in the fertile window (Gangestad et al., 2016; Stirnemann et al., 2013). Additionally, given the interrelations of multiple mating-related constructs, it is difficult to distinguish substantial ovulatory effects from secondary ones that are just a consequence of ovulatory changes. Therefore, we implemented a smallest effect size of interest (SESOI) set at .10 as threshold for negligibility. Supporting our results with several robustness analyses regarding different exclusion criteria, different estimators of women's fertility and different modelling decisions, we found substantial and robust ovulatory increases in women's self-reported general sexual desire, in-pair sexual desire and initiation of dyadic sexual behaviour at the same time with ovulatory decreases in food intake. While we also found significant mid-cycle increases in extra-pair sexual desire, the effect fell below the SESOI and non-significant differences between naturally cycling women and those using hormonal contraceptives did not allow inference of an ovulatory effect. Descriptively, solitary sexual desire and behaviour, dyadic sexual behaviour and satiety increased, whereas appetite decreased mid-cycle. Yet, these changes did not reach our preregistered conditions of a statistically significant fertility effect and a statistically significant difference to the quasi-control group and comparisons with the SESOI did neither allow inference of negligible nor substantial effects. In sum, we found evidence for ovulatory increases in sexual motivation and sexual behaviour that were primarily directed at women's romantic partners. Together with the finding of ovulatory decreases in food intake, our results are in line with the predictions of shifting motivational priorities of sex and food across women's ovulatory cycles.

4. Summary of Manuscript 3

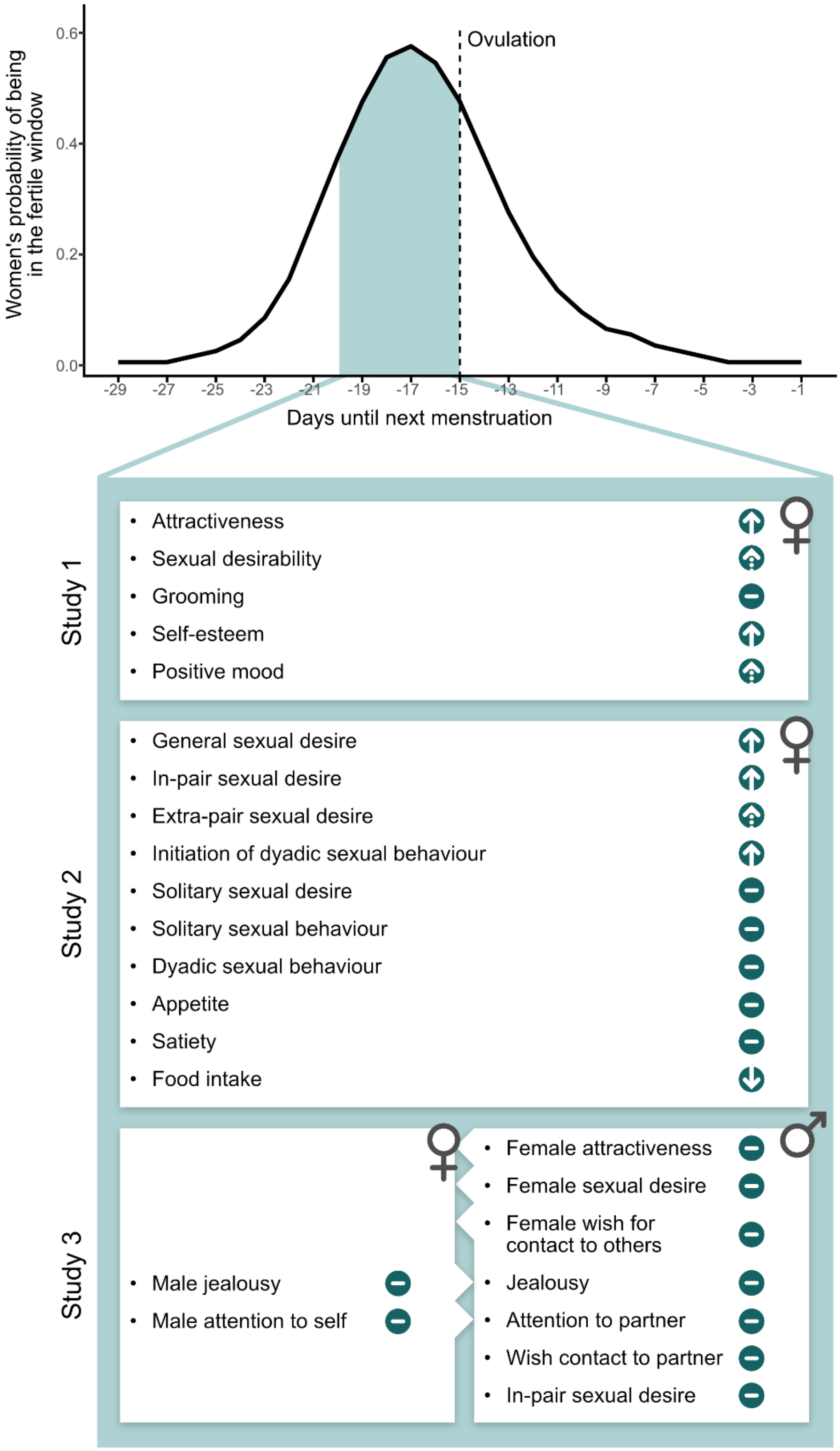
In the third manuscript, we sought to test whether men perceive cues to women's fertility and concurrently show ovulatory increases in mate retention tactics as has been proposed as counteradaptations to women's presumed shifting mate preferences across the cycle. While previous replications have questioned the existence of such shifting mate preferences and primary ovulatory increases in extra-pair sexual desire in women (e.g. Arslan, Schilling, et al., 2021; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Jünger, Kordsmeyer, et al., 2018; Jünger, Motta-Mena, et al., 2018), studies investigating corresponding ovulatory changes in men's mating psychology have been few and inconclusive (e.g. Gangestad et al., 2002; Haselton & Gangestad, 2006). Moreover, most studies have only investigated women's reports of men's mate retention tactics that might not generalise to men's own perceptions. Therefore, we conducted a large-scale online dyadic diary study with one daily measurement, where we analysed data of 384 heterosexual romantic couples across 40 days (this sample of women is the same as the one previously included in the analyses for the second manuscript except for six women whose male partners had no usable diary entries). First, we assessed men's perceptions of women's general attractiveness, sexual desire and women's wish for contact with other people (as feasible approximation for extra-pair sexual desire without risking adverse effects on the relationship). Second, we measured both women's and men's perceptions of men's mate retention tactics concerning male jealousy and male attention paid to their female partners and assessed men's perceptions of their wish for contact with their female partners and their in-pair sexual desire towards them. Analogous to study 1 and 2, we used backward counting to calculate a continuous estimator of women's fertility. Comparable to study 2, we implemented a SESOI set at .10 as threshold for negligibility and compared ratings of naturally cycling women and their male partners to those of women using hormonal contraceptives and their respective male partners. In addition, since the kind and amount of contact 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) contact of couples. Supported by several robustness analyses regarding different exclusion criteria, different estimators of women's fertility and different modelling decisions, our results indicate that men do not notice women's fertility status nor react to it. Men did neither rate women as more attractive nor rate women's wish for contact with other people as higher when women were fertile and as both effects fell below the SESOI, they were deemed as negligible. Although men's ratings of women's general sexual desire showed a mid-cycle increase descriptively, the effect failed to reach our preregistered conditions of a statistically significant fertility effect and a statistically significant difference to the quasi-control group and comparison with the SESOI did neither allow inference of a negligible nor substantial effect. Similarly, we found no evidence for ovulatory increases in men's jealousy, attention, wish for contact to or in-pair sexual desire for their female partners, and results did not differ between women's and men's ratings. In sum, our results cannot support previously assumed counteradaptations in men and cast further doubt on the predictions of the GGOSH and alleged relationship dynamics. Instead, these results align with our inconclusive evidence for women's extra-pair sexual desire reported in the second manuscript.

5. General Discussion

The question whether women's and men's mating psychology changes during women's fertile window has been the topic of extensive debate in the literature. With the beginning of the replication crisis and in light of severe methodological shortcomings of early studies, doubts on previous findings have been raised, but so far, theoretical and empirical work has remained inconsistent. To advance the scientific discourse, I addressed several former methodological shortcomings and investigated whether women's mating-related self-perceptions change during their fertile window (Manuscript 1 and 2) and whether women's romantic partners perceive such ovulatory changes and react to them (Manuscript 3). Result support the existence of several ovulatory changes in women's self-perceptions which might function as an adaptive motivational trade-off in sexual and eating motivation as proposed by the MPSH. However, we found no evidence that women's male romantic partners perceive possible cues to women's fertility or show corresponding mate retention tactics to prevent women from defecting as suggested by the GGOSH. This lack of ovulatory cycle shifts in men's mating psychology casts further doubt on the predictions of the GGOSH and subsequent male counteradaptations. However, given that the MPSH does not assume intersexual conflict on a within-cycle level, these null-findings are not in contradiction to the MPSH. Rather, results indicate that while women exhibit robust ovulatory changes in their mating psychology, they either exhibit no cues to fertility or men cannot perceive such changes. The main findings of the present studies are summarised in Figure 1. In the following sections, I will discuss these findings separately for women and men, highlight possible implications for the evolution of concealed ovulation and oestrus in women, and point out alternative explanations, limitations and possible directions for future research.

Figure 1

Overview of ovulatory cycle shifts in women and men reported in the three manuscripts



Note. The blue area under the curve represents the fertile window (main predictor was the continuous probability on the y-axis). Symbols ♀♂ indicate whether outcomes were assessed in women (♀) or men (♂). As long as outcomes are not preceded by (fe-)male, they represent self-ratings, else, they indicate that men and women rated their romantic partners. Filled arrows indicate significant ovulatory cycle shifts, dotted arrows indicate that the ovulatory nature of the mid-cycle change is uncertain, and hyphens indicate that the fertility effect was not significant (and not substantial for Study 2 and 3).

5.1 Ovulatory cycle shifts in women’s mating psychology

We found ovulatory cycle shifts in several aspects of women’s mating psychology that include a wider range of thoughts, feelings and behaviours than previously assumed and which might function to regulate a trade-off in women’s resource allocation. In the following, I point out the most important implications of these findings.

5.1.1 Ovulatory cycle shifts in women’s attractiveness-related self-perceptions

Adding methodological rigour to former studies with mixed findings (e.g. (Haselton & Gangestad, 2006; Röder et al., 2009; Schwarz & Hassebrauck, 2008)), we showed that naturally cycling women felt more attractive when fertile. Consistent with previous studies (Arslan, Schilling, et al., 2021; Haselton & Gangestad, 2006; Röder et al., 2009), women also reported to feel more sexually desirable. As feeling attractive and desired has been reported to be positively associated with women’s sexual desire (Graham et al., 2004; Woertman & van den Brink, 2012), these changes might be related to a possible motivational prioritisation of sexual motivation during women’s fertile window as predicted by the MPSH. Given that self-perceived attractiveness and desirability are related to women’s mood (Cattarin et al., 2000) and a cardinal component of women’s self-esteem (Bale & Archer, 2013), possible concurrent ovulatory increases in positive mood and self-esteem are not surprising. Yet, as only few studies investigated ovulatory changes in positive mood (McFarlane et al., 1988; Rossi & Rossi, 1977) or self-esteem (Arslan, Schilling, et al., 2021; Hill & Durante, 2009), and because results were only moderately robust and evidence for positive mood was limited, we hope for future replications to confirm the scope of ovulatory cycle shifts. Contradicting previous studies (Durante et al., 2008; Haselton et al., 2007; Röder et al., 2009; Saad & Stenstrom, 2012), women did not show significant ovulatory increases in grooming when fertile. Since our study is the second preregistered and highly-powered diary study to not find ovulatory increases in grooming (Arslan, Schilling, et al., 2021), it seems unlikely that women actively enhance their chances at attracting more attractive men. Similarly, it seems unlikely that men are able to use external cues of grooming to detect women's fertile window as had been previously suggested (Haselton & Gildersleeve, 2011).

Overall, our work emphasises the existence of multiple ovulatory cycle shifts in women's attractiveness-related self-perceptions. Given that the highest and most robust effect in ovulatory cycle research has been increases in women's sexual motivation when fertile, it is possible that ovulatory cycle shifts affect mating-related constructs like sexual desirability and self-perceived attractiveness more directly and other less mating-related aspects such as self-esteem and positive mood secondarily. However, we did not investigate possible directionalities or causal associations between these constructs. While such an untangling of causal structures between these multiple interrelated changes would advance the theoretical debate about ovulatory cycle shifts, we could not justify the assumptions for causal inference in observational data such as complete assessment of all variables that are relevant to a causal effect (Rohrer, 2018; Rohrer & Arslan, 2021). Therefore, we hope that our work serves as an incentive for more rigorous theoretical and causally informative work in the future.

5.1.2 Ovulatory cycle shifts in women's motivational priorities

While a connection between ovulatory changes in attractiveness-related self-perceptions and sexual motivation is a plausible interpretation of the results of Manuscript 1, we focused on sexual as well as eating motivation in Manuscript 2 specifically. Our findings regarding a robust, medium-sized ovulatory increase in women's general sexual desire is in line with multiple recent studies (Arslan, Schilling, et al., 2021; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016; Shirazi et al., 2019; Stern et al., 2020; van Stein et al., 2019). In addition, our findings of a dominant ovulatory increase in in-pair sexual desire as opposed to a smaller, inconclusive mid-cycle increase in extra-pair sexual desire might follow the logic of the MPSH of changes in general sexual desire that then mostly translate into increased in-pair sexual desire in partnered women. Yet, since another highly-powered and preregistered diary study reported robust ovulatory increases in both in-pair and extra-pair sexual desire in partnered women (Arslan, Schilling, et al., 2021), we do not reject the existence of shifts in extra-pair sexual desire. Instead, we expect that our study design of a *dyadic* diary led to self-selection of couples who were more committed and satisfied than average (supported by the fact that the mean report of participant's relationship satisfaction was very high), leading to a selection bias that diminished occurrence and variance of extra-pair sexual desire (see Pillsworth et al. (2004) for findings of a negative association of relationship commitment and satisfaction with extra-pair sexual desire).

Consistent with the predictions of the MPSH, we also found ovulatory increases in women's initiation of dyadic sexual behaviour. Thus, we add rigorous empirical evidence to previously mixed findings in the literature (Adams et al., 1978; Bullivant et al., 2004; Harvey, 1987) that often used basal body temperature to assess ovulatory timing which has proven unreliable (Bauman, 1981). While this supports a goal-related function of ovulatory cycle shifts as the MPSH suggests, comparable to Arslan, Schilling, et al. (2021) and Brewis and Meyer (2005), we found no ovulatory increase in the actual frequency of dyadic sexual behaviour. Yet, dyadic sexual behaviour also depends on various external factors such as time constraints and relationship dynamics (Arslan, Schilling, et al., 2021; Dewitte & Mayer, 2018). Consequently, women's initiation of dyadic sexual behaviour might be considerably affected by an internal, hormone-regulated pathway to increase the possibility of sexual behaviour. The actual occurrence of dyadic sexual behaviour, however, might be more strongly affected by a social input pathway which interacts with hormonal regulations in predicting women's sexuality as the MPSH suggests.

Contrary to the robust changes in dyadic desire, we only found descriptive increases in solitary sexual desire and solitary sexual behaviour. Given that solitary sexual behaviour cannot yield direct reproductive fitness benefits, it might be that ovarian hormones are not a decisive factor for solitary sexuality. Instead, it is possible that testosterone as another steroid hormone is more strongly associated with women's masturbation frequency (Macdowall et al., 2021). Moreover, there might exist several other relevant variables that affect solitary sexual desire and behaviour. For example, it might be that women seek out masturbation as a mean for stress relief or for achieving orgasmic pleasure (Rowland et al., 2020), which is more frequent in masturbation than in heterosexual intercourse for women (Frederick et al., 2018). Furthermore, it might rather be that women resort to solitary sexual behaviour when they experience ovulatory increases in general sexual desire but do not have access to a sexual partner (Arafat & Cotton, 1974, but see Goldey et al., 2016 for an overview about possible diverging goals for engaging in solitary and dyadic sexual behaviour in women). As we only assessed women in romantic relationships, and days where couples did not see each other were too few to analyse moderating effects of partner accessibility, we encourage future researchers to define predictors and moderators for women's solitary sexual desire and behaviour.

Importantly, the principal prediction of the MPSH is not only an ovulatory increase in sexual motivation but a concurrent motivational trade-off with eating motivation. Whereas several studies investigated ovulatory changes in women's sexual motivation as seen above, little research focused on ovulatory changes in eating motivation. As one central contribution to the scientific discourse, our study adds methodological rigour to support previous findings that women show ovulatory decreases in self-reported food intake when they are fertile (Fessler, 2003; Fleischman & Fessler, 2007; Roney & Simmons, 2017). Given the overabundant food supply in Western societies where effort for foraging and preparing food is minimised but omnipresent food stimuli might lead to overconsumption, the fact that we found an ovulatory decrease in food intake supports a robust effect which might be even higher in societies where food is less abundant (Fessler, 2003). However, while descriptively self-reported appetite and satiety showed the expected ovulatory decrease and increase respectively, we cannot conclude with certainty that these are motivational mechanisms behind the observed drop in food intake. To our knowledge, no study had previously reported ovulatory changes in eating motivation, therefore, we mostly based these hypotheses on theoretical models (Buffenstein et al., 1995) and findings of neuroendocrinological mechanisms in animal models (Asarian & Geary, 2006). Hence, it is possible that we missed other important motivational factors such as food cravings (Dye & Blundell, 1997; Gorczyca et al., 2016). It could also be that a prioritisation of sexual over eating motivation when women are fertile does not necessarily need a decrease in eating motivation. Instead, it might be that time and energy that are spent on mating effort deplete resources for foraging and feeding behaviour despite constantly high eating motivation. Consequently, an even broader test of the MPSH is to additionally assess whether eating motivation and food intake increase after ovulation which we only did in exploratory analyses (see supplementary material of Manuscript 2). Yet, various studies already provide support for the prediction of post-ovulatory, luteal increases in eating motivation and behaviour in humans (Barr et al., 1995; Dye & Blundell, 1997; Gorczyca et al., 2016). Nonetheless, as women also face a between-cycle trade-off of eating and sexual motivation and experience menstrual dysfunction, anovulation or secondary amenorrhoe when their nutritional status is too low (Gordon et al., 2017), it is also possible that these shifts are only present in a well-nourished Western sample who could afford such a within-cycle trade-off. More research is needed that considers this interaction of nutritional status on the effects of ovulatory changes in food intake, preferably using a sample with a high variety in nutritional status.

Taken together, it seems that women exhibit increases in various aspects of their mating motivation and behaviour that result in concurrent decreases in women's eating motivation and behaviour as predicted by the MPSH. In the face of the costs that sexual reproduction entails regarding both physiological (e.g. gamete production, building of endometrium and regulation of ovulatory cycle) and psychological effort (e.g. partner search), such a trade-off might be a fundamental way of adaptively balancing these costs as shown in various other species including invertebrates, amphibians, reptiles, birds, and mammals (Schneider et al., 2013).

5.2 Ovulatory cycle shifts in men's mating psychology

Unlike multiple ovulatory cycle shifts in women's mating psychology, we found no convincing evidence for changes in men's mating psychology during the fertile windows of their female partner's ovulatory cycles. In the following, I discuss the implications of our findings separately for men's awareness to possible cues to women's fertility and men's mate retention tactics.

5.2.1 Men's awareness to possible cues to women's fertility

Although the finding that men did not rate women as more attractive when women were fertile contradicts early studies (e.g. Bobst & Lobmaier, 2012; Pipitone & Gallup, 2008; Puts et al., 2013; Roberts et al., 2004; Singh & Bronstad, 2001), it is in line with a growing body of research that questions the existence of perceptible ovulatory increases in women's attractiveness (Bleske-Rechek et al., 2011; Burriss et al., 2015; Catena et al., 2019; Marcinkowska & Holzleitner, 2020; Pavela Banai, 2017; Roney & Simmons, 2012). Importantly, our study extends previous research in two central aspects: First, while previous studies were mostly based on laboratory settings, we investigated couples in their everyday lives, thereby ensuring higher ecological validity. Second, most previous studies employed external raters for assessing ovulatory cycle shifts in women, whereas we provide evidence from women's male romantic partners who are expected to be most likely to perceive such changes because of repeated exposure (Puts et al., 2013; Roberts et al., 2004). We did not assess subcomponents of women's attractiveness such as facial or vocal attractiveness since we expected very little variation in single aspects over repeated daily ratings. When formulating our hypotheses, we rather expected previously reported ovulatory increases in multiple aspects of attractiveness to add up to an overall attractiveness perception that should show the highest likelihood of perceptible change. Although we cannot rule out that single aspects of attractiveness might still vary across the cycle, it seems unlikely that women's attractiveness changes to a perceptible degree and serves as diagnostic criteria for men to assess women's fertility status. Instead of within-cycle differences in attractiveness, research has repeatedly shown that men can perceive between-women differences in attractiveness (Bovet et al., 2016; Bovet, 2019; Rhodes, 2006) and these are strongly related to women's fertility and reproductive value, that is a woman's age-specific expectation of future offspring (Andrews et al., 2017; Buss & Schmitt, 2019; Lassek & Gaulin, 2019). Given that men's perceptions of women's between-person attractiveness guides their mating choices (Buss & Schmitt, 2019; Todd et al., 2007), our results suggest that men's adaptations to assess women's attractiveness might be restricted to inter- and not intraindividual variation.

Moreover, despite robust ovulatory increases in women's self-reported sexual desire and initiation of dyadic sexual behaviour, men only showed small concurrent increases in their ratings of women's general sexual desire that did not meet our preregistered conditions for substantial effects (i.e. statistical significance and SESOI). It is possible that these conditions were too strict for an effect that needs to originate in women before being transferred to men and thus might be substantially diluted and smaller than expected. However, albeit only partly related to sexual desire, previous research has shown that perception of one's partner's desire for closeness can be perceived accurately both explicitly and implicitly (Pusch et al., 2021). Together with the fact that this study was the first to test whether male romantic partners perceive ovulatory changes in women's general sexual desire, we strongly encourage future replications. However, our study highlights the need to differentiate between whether subtle physical or behavioural cues lead to men's ratings (as proposed by the idea of male adaptations to sexual conflict) or whether it follows other factors such as direct verbal communication and cycle-awareness of the couples. As robustness analyses showed, the effect of women's fertility on men's ratings of female general sexual desire was considerably lower in couples where men or women were unaware of the timing of women's fertile window (but not when excluding couples who were trying to become pregnant). This indicates that women's and men's cycle-awareness might considerably affect their ratings. Given that 39% of women used digital cycle apps that informed them of their fertile windows, it is likely that factors such as verbal communication between couples influenced men's ratings of their partner's sexual desire. Yet, as we did not assess more specifically how men became aware of women's cycle, we cannot distinguish whether men inferred ovulatory timing by observing cycle shifts in their partners or whether they were informed of ovulatory timing by their partners which then in turn affected men's ratings. In the face of the widespread use of cycle-awareness apps, we hope our research will guide future studies to consider and more thoroughly examine their impact on ovulatory cycle research.

In addition, our robustness analyses revealed that the effect of fertility on men's ratings peaked when only analysing 8,881 days where the couple had direct contact. Hence, it is possible that we were too rash to integrate direct contact as a control variable but should have considered other causal effects beforehand. Contact unlikely poses as a confounding variable because it does not cause women's fertility. In principle, however, contact might also function as a collider, moderator or mediator variable instead. First, a collider variable (Rohrer, 2018) is causally affected by both the independent and dependent variable. Consequently, if women increase contact to their partners when fertile and men's perceptions of women's sexual desire also lead to increased contact, controlling for contact as a collider variable might have resulted in a spurious correlation between women's fertility and men's ratings. However, as models without contact as control variables did not differ from our controlled models, we found no evidence for a collider effect. Second, our robustness analyses showed that moderating effects of contact on women's fertility are close to zero. Thus, we found no evidence of a moderator effect either. Third, a possible mediator effect of contact might exist if women increase contact to their male partners and this increased contact leads to increased male ratings of women's sexual desire. However, as mentioned above, since uncontrolled and controlled models did not differ from each other, we found no evidence for a linear mediator effect where controlling for it would have diminished the effect of fertility on men's ratings. Yet, as our robustness analyses showed that men's ratings of women's sexual desire increased when only analysing days with direct contact of couples, it is possible that direct contact is needed for men to perceive any ovulatory changes but that this pattern does not follow a linear trend (e.g. one hour of direct contact might be sufficient to notice changes, further contact does not change results patterns). Unfortunately, research has not fully considered the causal structure of how men should perceive women's cues to fertility and provided no grounds to base modelling decisions on. Therefore, we not only strongly encourage future replications of our finding but also recommend that future studies incorporate more detailed assessments of cycle-awareness and communication of couples about the fertile window, and account for the various causal impacts direct contact might have for the couple.

We also found no empirical support that men perceive ovulatory increases in women's wish for contact with other people. This construct was used as ethically feasible approximation to assess men's perceptions of women's extra-pair sexual desire which has been assumed as leading cause for men's mate retention tactics (Gangestad et al., 2005a; Gangestad et al., 2014). However, it is possible that this approximated measure did not work because, for example, women might have increased desire for other men but concurrently decreased desire for meeting female friends, thus cancelling out in men's overall perception of women's wish for contact. Nonetheless, this null-finding aligns with inconclusive evidence for women's self-reported, small mid-cycle increases in their extra-pair sexual desire. On the contrary, as women mainly reported increased in-pair sexual desire, men’s ratings of women’s wish for contact with others besides them might have been accurate. It would be important for future research to assess men’s ratings of women’s wish for contact with others in a more diverse setting with more variance in women’s extra-pair sexual desire. However, a direct assessment of men’s ratings of their female partner’s extra-pair sexual desire will remain an ethical challenge.

In sum, our findings advance previous research by showing that women either emit no cues to fertility regarding their attractiveness, sexual desire, and wish for contact to others, or that their male romantic partners do not consciously perceive these cues in couple’s everyday lives. These results contradict the leaky cues hypothesis (Gangestad et al., 2005a; Gangestad & Haselton, 2015) but are in line with the idea that even if cues to fertility existed in women, these are not large enough to be diagnostic of ovulatory timing (Roney & Simmons, 2012).

5.2.2 Men’s mate retention tactics during women’s fertile window

In line with the finding that men did not perceive cues to women’s fertility across the cycle, we found no concurrent increases in men’s mate retention tactics during women’s fertile windows. Men neither showed increased jealousy nor increased attention paid to their partners, independent on whether men rated themselves or women rated their male partners. Furthermore, men did neither show increases in their wish for contact with their female partners nor increased in-pair sexual desire when women were fertile. While this contradicts earlier diary studies on within-cycle changes in men’s mate retention tactics both in women’s (Gangestad et al., 2002; Haselton & Gangestad, 2006) and men’s reports (Gangestad et al., 2014), these findings are consistent with recent other replications using diary designs that showed no ovulatory increases in jealousy (Arslan, Schilling, et al., 2021; Righetti et al., 2020) or broader mate retention tactics of possessiveness, love or attention (Arslan, Schilling, et al., 2021). However, since women predominantly exhibited ovulatory increases in their in-pair sexual desire, it is possible that men simply had no need to show concurrent mate retention tactics. Additionally, couples who participate in dyadic studies differ from couples where only one partner participates, for example, in regard to a smaller break-up likelihood (Park et al., 2021). Consequently, our null-findings might not generalise to all romantic couples where ovulatory cycle shifts in mate retention might possibly be more functional for men. While it is difficult to address selection bias particularly in dyadic research, we recommend future replications in a more diverse setting, for example, by framing the study goal as a very broad investigation of everyday life or by targeting couples with many years of relationship duration.

Nevertheless, particularly in a highly committed sample, it is surprising that men did not show increases in their in-pair sexual desire when women were fertile since already one sexual encounter during women's fertile window might increase men's reproductive fitness. Yet, previous studies have shown that sexual desire is not necessary for the occurrence of sexual behaviour (Vannier & O'Sullivan, 2010). Furthermore, such ovulatory increases in men's sexual desire would still require a detection of women's fertility which might have been too costly to evolve (for both men and women). Instead of within-cycle shifts in men's sexual desire, it is possible that men rather evolved higher sexual desire than women in general (Baumeister et al., 2001) as the less costly adaptation to women's fertile window.

Taken together, our results question the predictions that men show within-cycle changes in their mate retention tactics. These null-findings cast further doubt on the predictions of the GGOSH which is based on the existence of intersexual conflict on a within-cycle level. Instead of within-cycle adaptations to women's fertile window that would still require the likely costly detection of women's fertility status, it is possible that men have rather evolved between-person adaptations in mate retention tactics and sexual desire.

5.3 Implications for the evolution of concealed ovulation and female oestrus

As described above, one could argue that early ovulatory cycle is affected by problems arising from flexibility in methodological and analytical approaches as evident in the replication crisis in psychology. Consequently, more rigorous research is needed before clear conclusions of ovulatory cycle shifts for human's evolutionary history can be drawn. However, the present findings might already hint at a general picture we hope future research will consolidate or advance.

Although no theoretical consensus has been reached, most long-standing evolutionary theories that deemed the concealment of women's ovulation as necessary for the evolution of human's current social and mating structures (see section 1.3) stood in stark contrast to previous empirical findings that men perceived cues to women's fertility. For example, assuming that men did perceive cues to women's fertility, it is likely that intrasexual competition in men for mating opportunities with fertile women would in turn increase, possibly disrupting human coalitions (following the logic of Schröder, 1993) and diminishing investment from male partners that would be particularly harmful for offspring success in humans with extended neoteny (following the logic of Strassmann, 1981). However, research proclaiming men's perception of women's cues to fertility hardly tried to solve these contradictions. As one solution, Puts et al. (2013) argued that ovulation might be rather hidden from extra-pair mates and less from in-pair mates, given that cues to fertility are subtle and would need repeated exposure to be detected, thereby allowing, for example, a basis for long-term bonds in humans. Yet, we find no empirical support for this suggestion. Instead, our findings show that male romantic partners are mostly unaware of and do not respond to women's fertile windows. In addition, mathematical models have shown that transition to monogamy and long-term bonds is rather associated with decreased advertising of ovulation (Rooker & Gavrilets, 2018). Furthermore, other researchers doubt the assumption that conspicuous cyclical changes were the ancestral state for humans (Burt, 1992), but that these evolved newly in common ancestors of chimpanzee and bonobos million years ago (Havliček et al., 2015; Pawlowski, 2016). Hence, it is questionable whether women have retained but evolved to suppress cues to fertility as suggested by the leaky cues hypothesis (Gangestad et al., 2005a; Gangestad & Haselton, 2015). On the contrary, by adding methodological rigour and ecological validity, our findings indicate that men do not perceive women's fertility status, thereby easing the tension between ovulatory cycle research and leading evolutionary models about concealed ovulation.

Nevertheless, while concealed ovulation and absence of oestrus have often been treated as equivalent, as the co-occurrence of both varies widely among primate species, they seem to be independent of each other (Pawlowski, 2016; Rooker & Gavrilets, 2018). Unlike null-findings on cues to women's fertility, we did replicate multiple ovulatory cycle shifts in women's mating psychology that might indicate an oestrus-like phase such as robust increases in women's self-perceived attractiveness and sexual proceptivity (sexual desire and initiation of dyadic sexual behaviour). Additionally, our results support the existence of ovulatory trade-offs in food intake and sexual motivation that is characteristic of oestrus in many other species (Schneider et al., 2013). Yet, terming these observed changes in women's mating psychology oestrus might be too strong in the face of women's extended sexuality, absence of perceptible changes in attractiveness and lack of ovulatory increases in dyadic sexual behaviour. Instead, our findings support the previously framed idea of a *sexual phase* in women (Bullivant et al., 2004). This sexual phase seems to be characterised by motivational trade-offs to facilitate sexual behaviour (as suggested by the MPSH) more within romantic relationships than outside of them (as suggested by the GGOSH), thereby avoiding risks of desertion or violence by cuckolded males (Buss & Duntley, 2011; Daly et al., 1982) and agreeing with the assumption that long-term bonds and paternal care were central to the evolution of humans (Eastwick, 2009).

5.4 Alternative explanations for ovulatory cycle shifts in women's mating psychology

Based on shifts in women's mate preferences suggested by the GGOSH, we tested the predictions that men have evolved counteradaptations to detect women's fertility status and prevent women from defecting. Our null-findings on changes in men's mating psychology indirectly question the existence of shifting mate preferences in women which we expect the proponents of the GGOSH to explain. To my knowledge, there is currently no alternative theoretical prediction of possible adaptations to women's ovulatory cycle shifts in men, which might be restricted to inter- instead of intraindividual variation in women's fertility (compare section 5.2.1). However, there are alternative explanations for our reported ovulatory cycle shifts in women's mating psychology, including the GGOSH, the *Perceptual Spandrel Hypothesis* (Havliček et al., 2015) and the *Between-Cycle Hypothesis* (Lukaszewski & Roney, 2009; Roney & Simmons, 2008, 2013). In the following, I will discuss how our findings in women's mating psychology relate to these alternative theoretical approaches and to which extent they might be compatible to them as well. Given that our study was designed to test the predictions of the MPSH, however, it did not allow a full test of the other hypotheses. Consequently, these interpretations of findings regarding women's mating psychology have to be considered with caution.

5.4.1 Good Genes Ovulatory Shift Hypothesis

In principal, the observed ovulatory increases in self-perceived attractiveness and related constructs might be in line with both the GGOSH and the MPSH. Ovulatory increases in self-perceived attractiveness might follow increased sexual motivation (see section 5.1.1) but these changes might also coincide with shifting mate preferences as predicted by the GGOSH. As past research has shown that one's own mate value assessments guide mating decisions (Penke et al., 2008) and are positively associated with one's mate selection standards (Kenrick et al., 1993), ovulatory increases in women's attractiveness and sexual desirability might also function to facilitate sex with higher mate value, highly attractive men when fertile as proclaimed by the GGOSH. Nonetheless, other research has shown that only long-term, not short-term, mate value was related to women's mate selection criteria when fertile (Beaulieu, 2007). Hence, it seems that specifically long-term mate value guides mating decisions and not short-term, within-cycle changes. Moreover, more attractive (albeit externally rated) women are less willing to make compromises in preferred partner qualities including genetic quality as well as economic and paternal investment (Buss & Shackelford, 2008). Therefore, a specific change in attractiveness and desirability that predominantly facilitates extra-pair copulations to reap only genetic benefits seems not convincing. Yet, more theoretical and empirical work is needed to embed the finding of multiple attractiveness-related increases when women are fertile into any theory on the nature and function of ovulatory cycle shifts.

Similarly, ovulatory increases in general sexual desire might be compatible with both the MPSH and the GGOSH as well, assuming an increase in general sexual desire with an even more pronounced increase in sexual desire for men possessing “good genes”. However, proponents of the GGOSH have argued against the existence of such a general desire shift (Gangestad et al., 2002; Haselton & Gangestad, 2006). In addition, our findings of a dominant ovulatory increase in in-pair sexual desire as opposed to a smaller, inconclusive mid-cycle increase in extra-pair sexual desire contradict the predictions of the GGOSH. Importantly, however, we did neither preregister nor test whether effects in in-pair or extra-pair sexual desire were moderated by partner short-term attractiveness as reported before in the literature (Gangestad et al., 2005b; Pillsworth & Haselton, 2006a). As the GGOSH assumes that women display mate preference shifts to obtain high male genetic quality and high male investment at the same time, it is still possible that women in this sample predominantly displayed ovulatory increases in in-pair sexual desire because they had both extraordinarily attractive and investing partners. Yet, we deem this possibility as highly unlikely since the GGOSH assumes that men with good genes are rare and less willing to form long-term bonds, and on average, women reported moderate short-term attractiveness of their partners. Moreover, the study by Arslan, Schilling, et al. (2021) provides no compelling evidence for such a moderator effect (also see

Arslan, Driebe, et al., 2021 and Gangestad & Dinh, 2021 for a current discussion). Finally, as the GGOSH only addresses changes in sexual motivation but does not offer explanations for other motivational constructs, it is ill-suited as alternative explanation for the overall pattern of ovulatory cycle shifts including robust decreases in food intake.

5.4.2 The Perceptual Spandrel Hypothesis

The Perceptual Spandrel Hypothesis (Havliček et al., 2015) states that fertility-linked changes in women's mating psychology might simply be spandrels of between-women variability in ovarian hormones, i.e. "an inevitable by-product of the development of another adaptive trait, without itself being a direct product of selection" (Havliček et al., 2015, p. 1249). The Perceptual Spandrel Hypothesis focuses on earlier findings of ovulatory changes in women's attractiveness and shifts in women's mate preferences towards extra-pair mates which are described to be by-products of general hormone-dependent mate-choice mechanisms instead of within-cycle effects: Following the hypothesis, women's attractiveness is largely influenced by between-women differences in hormones, particularly by estradiol levels. Hence, mid-cycle increases in estradiol levels should lead to increased self-perceived attractiveness and it is rather this increase in women's attractiveness and subsequent increase in mate value and mate standards that drives an increased desire for extra-pair mating with high quality men. While I have followed the same logic to explain that reported ovulatory cycle shifts in women's self-perceived attractiveness might be part of both the MPSH and GGOSH (compare section 5.4.1), the Perceptual Spandrel Hypothesis states that this mid-cycle increase is only a generalisation of between-women hormonal effects on women's attractiveness and not an ovulatory effect in itself. However, there is no evidence that more attractive women have higher estradiol levels (Jones, Hahn, Fisher, Wang, Kandrik, Lao, et al., 2018), so the idea of a generalisation of between-women to within-women effects is doubtful. Moreover, Roney and Simmons (2013) specifically showed that estradiol levels covaried positively with women's general sexual desire on a within-cycle, not on a between-women level. Additionally, the Perceptual Spandrel Hypothesis only offers alternative explanations to shifts in mate preferences and extra-pair mating (as proposed by the GGOSH), but cannot address the variety of ovulatory cycle shifts reported here, including increased in-pair sexual desire and ovulatory decreases in food intake.

5.4.3 The Between-Cycle Hypothesis

While the Between-Cycle Hypothesis (Lukaszewski & Roney, 2009; Roney & Simmons, 2008, 2013) has been largely framed as an alternative to the GGOSH, following its logic to the end, it might also pose an alternative account for the MPSH. The Between-Cycle Hypothesis is similar to the spandrel idea in that ovulatory cycle shifts might be a by-product of other adaptations, but unlike the perceptual spandrel hypothesis, this adaptation is rather on a between-cycle than a between-women level. According to the hypothesis, estradiol levels regulate the level of fertility between different cycles of women, where high fertile cycles are characterised by higher levels of estradiol. Lower estradiol and higher progestogen levels might indicate infertility such as during pregnancy, when sexual behaviour cannot yield direct reproductive fitness benefits, or during times with low nutritional status or high stress when women face secondary amenorrhea to secure their survival and prioritise it over costly and likely wasted reproductive effort (compare section 5.1.2). Hence, hormone-mediated within-cycle trade-offs of sexual and eating motivation might simply follow existing between-cycle trade-offs of sexual and eating motivation. However, higher estradiol levels do not necessarily translate into higher fertility. It seems that estradiol rather shows a curvilinear relationship with fertility, since overproduction of estradiol can also lead to endometriosis and possible infertility (Chantalat et al., 2020). Additionally, between-cycle effects of estradiol have mostly been investigated in few studies that focused on facial attractiveness ratings of men, yielding mixed results (Jünger, Motta-Mena, et al., 2018; Roney & Simmons, 2008). The only study that investigated both within- and between-women effects of steroid hormones on women's sexual desire showed that between-cycle effects only accounted for 2.7% of variance in women's sexual desire versus 65.9% of explained variance due to within-cycle hormonal changes. Yet, to further disentangle these within- from between-cycle motivational trade-offs, future research should ideally measure serum hormone levels, compare sexual and eating motivation in cycles with different productions of estradiol and progesterone, assess women across multiple cycles and compare women of different nutritional status.

5.5 Limitations and future directions

Despite multiple strengths of the studies reported in this dissertation (e.g. high statistical power and preregistration of study design and analyses), there are several important limitations. First, we did not specifically test the causal structures underlying the reported ovulatory cycle shifts, for example, whether cyclical changes in estradiol and progesterone are the expected hormonal mechanisms behind the observed changes. As measuring hormones in these large-scale online diary studies was not feasible, we implemented the quasi-control group design of women using hormonal contraceptives (and respective male partners) who experienced menstruation but no ovulation to infer causal effects. However, as this approach is only an approximation, we hope future research combining high statistical power with biological markers of ovulation will replicate our findings. Given current challenges of measuring steroid hormones in saliva because of extremely low concentrations (Schultheiss & Mehta, 2018), we recommend future researchers to use mass spectrometry or assess serum hormone concentrations. Similarly, we did not test causal structures between various ovulatory cycle shifts to see, for example, whether attractiveness-related changes follow dominant increases in sexual motivation. Since such an untangling of these closely related constructs would advance our understanding of the nature and function of ovulatory cycle shifts, more theoretical and more causally informative work is needed, such es experimental set-ups (as far as ethically responsible) or lagged analyses with multiple daily assessments to investigate time sequence of changes.

Second, although many scientists expect ovulatory cycle shifts to pose as an adaptive function, the biological significance of effects is hardly discussed. So far, ovulatory cycle research lacks clear predictions of effect sizes needed to result in biologically relevant outcomes. For example, no theoretical approach has tried to answer which increase in sexual motivation during women's fertile window is needed to yield an increase in reproductive success and potential fitness benefit. We tried to advance previous research by implementing a SESOI to at least differentiate negligible from small effect sizes, but without theoretical grounds, the SESOI used here remains arbitrary and might have been too strict for ovulatory cycle shifts in men in particular.

Third, as the focus of this project was to assess whether ovulatory cycle shifts exist in the first place, we did not concentrate on interindividual differences in these effects although they are likely to exist (Kiesner et al., 2020). Consequently, we did not investigate possible moderator effects such as age, health or relationship duration. While we addressed several possibly relevant influences in our robustness analyses and do not expect these to change our result patterns, exploring how both endogeneous (ovulatory cycle shift) and exogenous (hormonal contraception) hormonal effects differ between women is a fruitful and vital topic for future research.

Fourth, there are other aspects possibly related to the MPSH that we did not consider, for example, whether ovulatory cycle shifts in the motivational prioritisation of sex and food also exist in single women. Effects of relationship status on previous ovulatory cycle research has been mixed, with some studies showing that only partnered and not single women reported increased sexual desire when fertile (Pillsworth et al., 2004; Roney & Simmons, 2016), whereas Jones, Hahn, Fisher, Wang, Kandrik, and DeBruine (2018) could not find evidence for a moderator effect of relationship status on women's ovulatory increases in sexual desire in a large sample. In general, costs of pregnancy might be higher than its benefits when women lack a committed long-term partner (Pillsworth et al., 2004). However, the MPSH does not predict a specific increase in sexual behaviour but rather a general increase in mating effort which could also include increased partner search and attraction to men in single women (but see Jünger, Kordsmeyer, et al. (2018) and Jünger, Motta-Mena, et al. (2018) for diverging effects of relationship status on mate attraction to male bodies and voices). Thus, investigating whether single women show similar trade-offs in their overall sexual and eating motivation would be a necessary next step to test the MPSH. Importantly, women also face other reproduction-linked adaptive problems such as child-rearing and inbreeding-avoidance (Cosmides & Tooby, 2013). Although so far, preliminary evidence shows no changes in inbreeding-avoidance across women's ovulatory cycles (Holzleitner et al., 2017), given that organisms need to adaptively allocate resources to multiple adaptive problems, it would be an interesting venture for future research to incorporate more adaptive problems into the predictions of the MPSH and test its specificity.

Finally, as separately discussed in the three manuscripts, all of the reported studies analysed data of German-speaking participants. Since these participants fulfil all criteria of a Western, educated, industrialised, rich and democratic sample (WEIRD; Henrich et al., 2010), generalisability of results to other cultures and environments is limited. Moreover, as all results are purely based on self-reports, generalisability to other measures might be limited as well. Hence, universality of ovulatory cycle shifts in women and non-existing ovulatory cycle shifts in men has yet to be established before clear implications of ovulatory cycle shifts can be drawn for human's evolutionary history.

6. Conclusion

In this dissertation, I sought to investigate the existence, scope and possible adaptive functions of ovulatory cycle shifts in women's and men's mating psychology. In the face of widespread methodological shortcomings in the literature, the present studies add methodological rigour and informational value by using high sample sizes, preregistration of hypotheses and analyses, within-subject designs, multiple robustness analyses and comparisons to quasi-control groups to approximate causality. We found that women experienced robust ovulatory increases in their attractiveness-related self-perceptions that were broader than previously assumed. Women also showed robust ovulatory increases in their sexual motivation and behaviour that were primarily directed at women's romantic partners and concurrent decreases in their food intake. These findings are in line with the predictions of a hormone-regulated motivational prioritisation of sexual over eating motivation as the MPSH predicts and so far, these cannot be fully explained by other theoretical approaches. Regarding men's mating psychology, we did not replicate assumed counteradaptations in men to detect women's fertility status nor to show concurrently increased mate retention tactics as would have been expected following shifting mate preferences in women as the GGOSH suggests. Taken together, the work of my dissertation corroborates the existence of ovulatory changes in women's mating psychology that might constitute an oestrus-like, sexual phase, and supports the notion that women's ovulation is concealed and not perceptible to their long-term partners. Although several open questions remain such as validation of the hormonal basis and untangling of causal structures between various ovulatory changes, I believe this dissertation advances our understanding of ovulatory cycle shifts and provides several directions for future research to build on.

7. References

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Appendix A

Manuscript 1

Schleifenbaum, L., Driebe, J. C., Gerlach, T. M., Penke, L., Arslan, R. C. (2021). Women feel more attractive before ovulation: evidence from a large-scale online diary study. *Evolutionary Human Sciences*, 1-34, https://doi.org/10.1017/ehs.2021.44

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RESEARCH ARTICLE

Women feel more attractive before ovulation: evidence from a large-scale online diary study

Lara Schleifenbaum[1,2]*, Julie C. Driebe[1], Tanja M. Gerlach[1,2], Lars Penke[1,2] and Ruben C. Arslan[2,3,4]

[1]Georg August University, Goettingen, Germany, [2]Leibniz ScienceCampus Primate Cognition, Goettingen, Germany, [3]University of Leipzig, Leipzig, Germany and [4]Max Planck Institute for Human Development, Berlin, Germany
*Corresponding author. E-mail: lara.schleifenbaum@uni-goettingen.de

Abstract

How attractive we find ourselves decides who we target as potential partners and influences our reproductive fitness. Self-perceptions on women's fertile days could be particularly important. However, results on how self-perceived attractiveness changes across women's ovulatory cycles are inconsistent and research has seldomly assessed multiple attractiveness-related constructs simultaneously. Here, we give an overview of ovulatory cycle shifts in self-perceived attractiveness, sexual desirability, grooming, self-esteem and positive mood. We addressed previous methodological shortcomings by conducting a large, preregistered online diary study of 872 women (580 naturally cycling) across 70 consecutive days, applying several robustness analyses and comparing naturally cycling women with women using hormonal contraceptives. As expected, we found robust evidence for ovulatory increases in self-perceived attractiveness and sexual desirability in naturally cycling women. Unexpectedly, we found moderately robust evidence for smaller ovulatory increases in self-esteem and positive mood. Although grooming showed an ovulatory increase descriptively, the effect was small, failed to reach our strict significance level of .01 and was not robust to model variations. We discuss how these results could follow an ovulatory increase in sexual motivation while calling for more theoretical and causally informative research to uncover the nature of ovulatory cycle shifts in the future.

Keywords: ovulatory cycle shifts; self-perception; attractiveness; hormonal contraception; diary study; evolutionary psychology

Social media summary: Women report higher attractiveness, desirability, self-esteem and positive mood but not more grooming when fertile.

Introduction

There is an ongoing debate about whether the fertile phase in a woman's ovulatory cycle warrants being called an oestrus, a phase of fertility which is typically characterised by heightened sexual proceptivity, receptivity and attractiveness (Beach, 1976; Gangestad & Thornhill, 2008). Alongside other aspects such as increased sexual motivation when fertile that might indicate an oestrus-like phase (Arslan, Schilling et al., 2018; Jones et al., 2018; Roney & Simmons, 2013), it appears that women's attractiveness increases around ovulation as a possible cue to fertility (Haselton & Gildersleeve, 2011). Some studies find that various aspects of attractiveness change along with cyclical hormonal fluctuations, including body scent (Gildersleeve et al., 2012; Singh & Bronstad, 2001), vocal pitch (Pipitone & Gallup, 2008; Puts et al., 2013) and facial attractiveness (Puts et al., 2013; Roberts et al., 2004). While studies largely report that men rate women's attractiveness as higher around ovulation (Bobst & Lobmaier, 2012; Haselton & Gildersleeve, 2011; Roberts et al., 2004; Schwarz & Hassebrauck, 2008), it remains unclear whether women's self-perceived attractiveness follows the same pattern.

Since self-perceptions can guide mating decisions (Penke et al., 2008), they are relevant from an evolutionary perspective on human behaviour: within human mating markets that are characterised by mutual partner choice and assortative mating (Johnstone et al., 1996; Robinson et al., 2017), individuals are expected to calibrate their mating decisions (i.e. mating goals and mating tactics) according to their self-perceived mate value in order to avoid costs (e.g. wasted mating efforts or lost opportunities in finding other mates). Humans face trade-offs regarding different mate qualities (e.g. regarding preferred condition and attachment of partners), and one's own self-perceptions can guide the necessary degree of these trade-offs (Penke et al., 2008), meaning that individuals who deem themselves as highly valuable mates strive for higher quality partners, where less trade-offs of preferences are needed. The most relevant component of women's mate value is their physical attractiveness (Buss & Shackelford, 2008; Singh, 2002) since it is assumed to be an indicator of their youth and reproductive value (Bovet, 2019; Lassek & Gaulin, 2019). Consequently, it has been shown that women adjust their mate choices according to their self-perceived attractiveness, with women who perceive themselves as more attractive showing higher mate choice standards and choosiness, at least in short-term contexts (Little et al., 2001; Todd et al., 2007, but see Gerlach et al. (2019) for a null finding on moderation of mate preferences and actual long-term mate choice). Hence, understanding how women's self-perceived attractiveness changes across the cycle is crucial, particularly during the fertile window when conception is possible and mating decisions have a direct impact on reproductive fitness.

Using diary study designs that track within-subject changes in self-reported thoughts and behaviours over the ovulatory cycle, several studies have investigated ovulatory cycle shifts in self-perceived attractiveness but yielded mixed results: Haselton and Gangestad (2006) first presented empirical evidence in 38 heterosexual and naturally cycling women who provided daily self-reports for 35 days. These women felt both more attractive and more sexually desirable when they were fertile compared with other days of their cycles. However, Schwarz and Hassebrauck (2008) did not replicate these results using a diary design across 31 days. Analysing data from 40 naturally cycling women and comparing high- with low-fertility days, they did not find increases in self-perceived attractiveness around ovulation. In a preregistered, highly powered online diary study across 40 days using over 26,000 diary entries from 1054 women, Arslan, Schilling et al. (2018) applied a quasi-control group design that compared women taking hormonal contraceptives (625 HC women) with naturally cycling women (429 NC women). They found a robust increase in self-perceived sexual desirability that was absent in HC women. These results were supported by a wide range of robustness analyses, for example comparing different fertility estimates. Arguably, this study provides the best evidence to date that self-perceived sexual desirability indeed increases around ovulation. Since HC women do not experience ovulation and a corresponding fertile phase, the finding that cycle shifts in sexual desirability were only present in NC women supported the claim that these shifts are related to hormonal fluctuations across the natural ovulatory cycle.

As shown here, a distinction of attractiveness and sexual desirability is difficult and evolutionary psychologists often use the terms interchangeably (Wade, 2000). Addressing this issue, Wade (2000) showed that, for women, perceptions of their own attractiveness are based on their self-perceived figure, eyes and sex appeal. While their perceptions of their sexual desirability were based on their figure as well, they were also predicted by their self-perceived physical strength and sexual motivation, and less by their facial features. Whereas more research is needed to replicate these results, it seems that attractiveness and sexual desirability are closely related constructs that differ mainly in their association with sexual activity.

Owing to our limited understanding of ovulatory changes in self-perceived attractiveness and sexual desirability, the aim of the current study was not only to investigate these potential ovulatory shifts but also to investigate other closely related self-perceptions. Firstly, some studies report that women change their grooming behaviour and clothing style to appear more attractive around ovulation, possibly to attract more potential sexual partners as a form of intrasexual competition (Durante et al., 2008; Haselton et al., 2007). In a study comparing photographs taken during the high- and low-fertility phases of the ovulatory cycles of 30 partnered women, Haselton et al. (2007) found that women attempt to look more attractive when fertile. Using a similar design, but also asking women to draw illustrations of their outfits when invited to attend an imaginary social event, Durante et al. (2008) showed that 88 women wore and wanted to wear sexier clothing on high-fertility days. Other diary studies also report that women spend more time grooming when they are fertile (Röder et al., 2009; Saad & Stenstrom, 2012).

Yet, diary studies that assessed self-perceptions in grooming and attractiveness concurrently reached opposing conclusions. Whereas Röder et al. (2009) found ovulatory increases in both variables, Schwarz and Hassebrauck (2008) reported ovulatory increases only with more provocative clothing choices, and the highly powered study by Arslan, Schilling et al. (2018) only found ovulatory increases in self-perceived desirability. While grooming effort can potentially explain ovulatory increases in attractiveness ratings by men, evidence for ovulatory increases in self-perceived grooming is mixed and it remains unclear whether they co-occur with changes in self-perceived attractiveness and self-perceived desirability.

Secondly, it has been shown that feeling attractive and desirable is positively related to general self-esteem in women (Bale & Archer, 2013; Brase & Guy, 2004; Leary & Baumeister, 2000). However, past research indicates no significant ovulatory changes (Arslan, Schilling et al., 2018) or even ovulatory decreases (Hill & Durante, 2009) in general self-esteem. In line with oestrus in other species, it is possible that hormonal changes are more specifically connected to changes in directly mating-related constructs such as sexual motivation or attractiveness, but not general self-esteem. Additionally, it has been speculated that ovulatory changes are associated with reduced self-esteem to simultaneously promote women's mate-value enhancement when mating efforts are most critical (Hill & Durante, 2009). Given these conflicting results and the small number of studies, whether and how women's self-esteem varies across the cycle remains largely unclear.

Lastly, another aspect that is connected to both self-perceived attractiveness and self-esteem (Brown & Mankowski, 1993; Datta Gupta et al., 2016), but shows inconsistent changes across a woman's ovulatory cycle, is positive mood. Although findings on changes in mood across the cycle are generally mixed (Romans et al., 2012), most studies focus on mood as a part of premenstrual symptoms (Bäckström et al., 1983; Tschudin et al., 2010). There are fewer studies focusing on changes in positive mood across the whole cycle or specifically addressing ovulatory changes (Almagor & Ben-Porath, 1991). Among these, studies using daily self-reports show no differences in positive mood between different cycle phases (Almagor & Ben-Porath, 1991; Wilcoxon et al., 1976).

In conclusion, there is no clear picture of whether women's self-perceived attractiveness and desirability change across the ovulatory cycle and whether there exist ovulatory cycle shifts in related self-perceptions such as self-reported grooming behaviour, general self-esteem and positive mood. Previous ovulatory cycle research probably suffered from methodological problems such as incorrectly using between-subject designs for investigating within-subject effects, using a discrete instead of a continuous fertility estimator and low statistical power that can inflate type 1 error rates and false-positive findings (Gangestad et al., 2016).

We aimed to address this by conducting a preregistered and highly powered diary study comparing naturally cycling women with women using hormonal contraceptives. By investigating several attractiveness-related outcomes at the same time, this study also provides an insight into the different magnitudes of ovulatory cycle shifts. We predicted ovulatory increases in self-perceived attractiveness, desirability and grooming that are only present in the group of women not taking hormonal contraceptives. Based on the assumption that ovulatory changes are phylogenetically rooted in the oestrus that is observed in many other species, we expected ovulatory changes to be much stronger in mating-related self-perceptions. We expected no ovulatory increases in the broader domains of general self-esteem and positive mood. Our aim with this paper is to give an empirical overview of possible ovulatory changes in attractiveness-related self-perceptions in the same sample. As our data were observational, we do not aim to uncover associations between the different outcomes nor to imply a certain causal graph. We preregistered our study design, sampling methods, stopping rule and exclusion criteria as well as analytical steps. A detailed overview of all deviations from our preregistration that were necessary to refrain from falsely implying causality is shown under Table S1 in the Supporting Information.

Methods

Since ovulatory cycle shifts are intraindividual changes, we used an online diary design as the appropriate assessment method for within-subject effects (Blake et al., 2016; Schmalenberger et al., 2021). This online diary is the second Goettingen Ovulatory Cycle Diary Study and was implemented using the online survey framework formr (Arslan, Walther & Tata, 2020). This framework enabled the complexity of the study design and also the automation of study parts with sensitive information to establish the anonymity of participants. All materials are accessible online, including survey files, data cleaning and codebooks (Arslan, Driebe et al., 2020, see also https://osf.io/d3avf/); the relevant analysis code for the study can be found at https://osf.io/2g4rc/. Owing to the intimate nature of data and because it cannot be fully anonymised, we will share data upon request.

Recruitment and incentive structure

We recruited participants between May 2016 and January 2017 via a range of different digital strategies, such as social media (advertising via mailing lists of German university students and posting advertisements on okCupid.com, Facebook and on the study platform psytests.de), inviting eligible participants who had taken part in similar studies before and advertising the study in a first-year psychology lecture. Data collection ended in May 2017.

In order to compensate for the considerable effort of participation, the incentive structure was diverse. Participants received either a direct payment (between €25 and €45) or, alternatively, course credits for students of the University of Goettingen. All participants were given chances of winning lottery prizes with a total amount of €2000, and illustrated feedback on their own data. Prior to their involvement, participants were fully informed that their access to incentives depended on their participation rate and completion of the study.

Procedure

After following an online study link, participants received detailed information about the study entitled 'Everyday Life and Sexuality', which was introduced as a study investigating the interaction of romantic relationships, sexuality and well-being. After providing their informed consent, participants answered the two initial surveys that assessed demographic and personality information. All personal and identifying data were collected and stored separately using formr features to further ensure anonymity.

The diary part began on the next day and encompassed a period of 70 consecutive days with daily self-reports. During this time, participants received email invitations and, if allowed, text message reminders with their personal study links every day at 5:00 p.m. Diary entries could be filled out until 3:00 a.m. the following morning. Daily questions asked for mood, health, daily activities and sexuality. If participants had already filled out a diary entry the day before, they were asked to rate the time between the last entry and the current one. If participants had skipped at least one entry beforehand, they were asked to rate the time spanning the previous 24 h. This method was used to cover the period of the diary continuously for users with high participation rates while avoiding responses where participants who had skipped entries would have aggregated across a much longer time than 24 h. To account for possible measurement reactivity biases (Arslan, Reitz et al., 2020), the order of the daily items was randomised within grouped blocks. As an additional strategy to facilitate high participation rate, the number of daily items was held low by applying a planned missing design: the probability of single items to be displayed on a specific day varied between 20 and 100% and for broader constructs with multiple items a subset of items was drawn randomly every day (see Table 1).

After the diary, participants were asked to fill out three follow-up surveys: first, single participants answered a social network survey that is not part of the present study; second, all participants filled out a general follow-up survey assessing, among other questions, the use of hormonal medication and changes in contraception methods during the study; and third, those women who had not indicated menstrual bleeding within the last 5 days of the diary received an email invitation every 5 days to take part in the last follow-up survey that assessed the date of their next onset of menstrual bleeding. Following completion of the study, participants were fully debriefed and received personal feedback along with their respective compensations. A detailed overview of the study design is depicted in Figure 1.

Measurements and variable transformations

Measurements

All variables of interest for the current study that were assessed in the diary part are shown in Table 1 with their corresponding response format and their display probabilities on each given day. Owing to an unfortunate coding error when designing the study, only women in heterosexual relationships were asked how sexually desirable they felt (66% of total sample, 355 women not using hormonal contraceptives, 221 women using hormonal contraceptives). All other variables were presented to the whole sample.

Estimating women's fertility status

In order to obtain information about the ovulatory cycle during the diary, women were asked every 3 days, or after having skipped at least two consecutive diary entries, to indicate whether they had had menstrual bleeding during the previous 3 days or since their last diary entry, respectively. If they had, women were asked to report whether that entry day was the first day of menstrual bleeding or otherwise indicate the exact date of the onset (see Table 1). We also obtained the date of women's last onset of menstrual bleeding in the demographic survey at the beginning of the study as well as the date of their next onset of menstrual bleeding in the follow-up survey described above. Following Arslan, Schilling et al. (2018), we computed our main predictor of the ovulatory cycle using this information, the probability of being in the fertile window (PBFW), by backward counting from the next confirmed onset of menstrual bleeding. This method was recommended by Gangestad et al. (2016), who based their continuous PBFW estimates on Stirnemann et al. (2013). For this estimation, we only considered 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.

We preregistered that we would estimate women's fertility status with a method that was state-of-the-art at the time of analysis. By following the aforementioned recommendations, we believe we have adhered to this goal. In our preregistration, we also mentioned a procedure for averaging forward and backward counting methods to obtain a corresponding predictor. This procedure was necessary in previous studies with few observations of next menstrual onsets in order to avoid losing too many data points. However, in this study, sufficient information on next menstrual onsets could be collected. Therefore, we decided to refrain from averaging and use only the backward-counted PBFW, as recommended by Gangestad et al. (2016). Among other robustness analyses below, all models were re-run using an averaged PBFW predictor, yielding almost identical results (see Figure 4 and Figures S1–S4 in the Supporting Information).

Since using a continuous estimator across the cycle meant including menstrual or premenstrual days that might affect outcomes in ways unrelated to ovulation, we specifically coded these cycle phases and added them as control variables. To assess menstrual days, we asked women to report on every diary day whether they had had menstruation-related pain. Together with the information on menstrual bleeding described above and the resulting cycle length, this information was used to

Table 1. Variables relevant to this study measured in the diary

Variable	Item (English translation)	Response format	Daily display probability (in%)
Onset of menstrual bleeding	'Today was the first day of my menstrual bleeding …'	Yes No (yesterday) No (day before yesterday) No (3 days ago) No (4 days ago) No (5 days ago) No (6 days ago) No (onset longer ago)[a]	Once women indicated having menstrual bleeding on that day
Desirability	'I felt sexually desirable'[b]	Five-point Likert scale: 0 ('less than usual') to 4 ('more than usual')	50
Attractiveness	'I was satisfied with my appearance' 'I liked looking at myself in the mirror' 'I liked looking at my body'	Five-point Likert scale: 0 ('less than usual') to 4 ('more than usual')	30 30 30
Grooming	'I was styled' 'I put effort into my outfit (clothes, make-up)'	Five-point Likert scale: 0 ('less than usual') to 4 ('more than usual')	30 30
Self-esteem	'I was satisfied with myself'	Five-point Likert scale: 0 ('less than usual') to 4 ('more than usual')	80
Positive mood	'My mood was good'	Five-point Likert scale: 0 ('less than usual') to 4 ('more than usual')	80

[a]Once women chose this option, a field appeared in which they could indicate the exact day of the onset of menstrual bleeding. [b]Only women in a relationship were asked that question (66% of total sample).

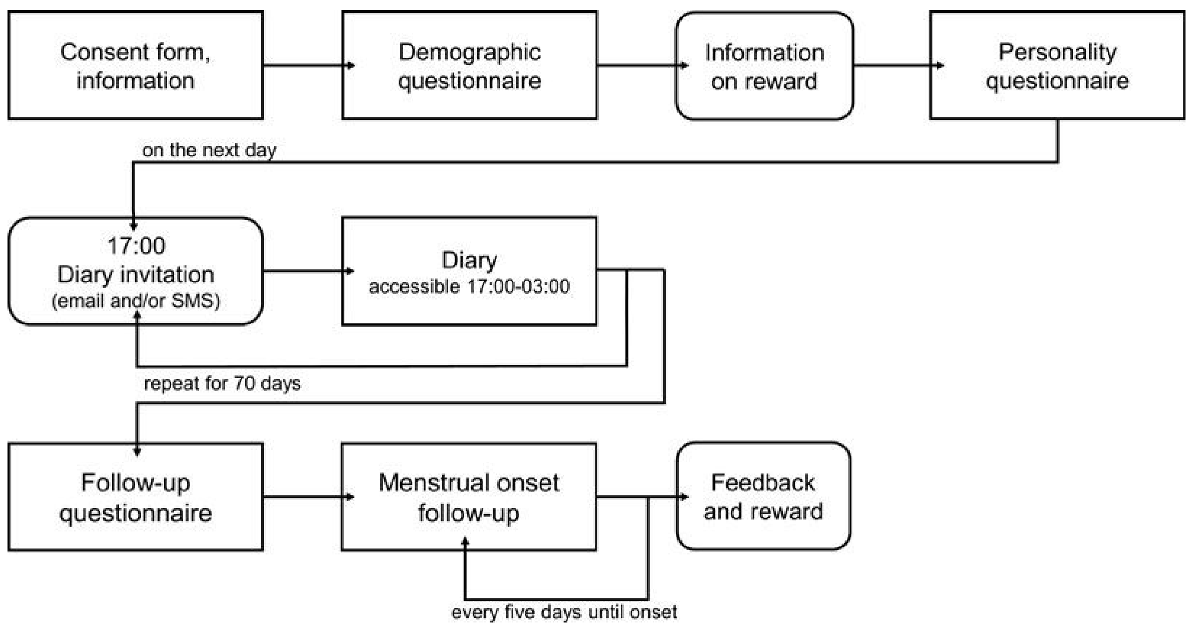

Figure 1. Overview of the study flow. The diary part spanned 70 consecutive days with one daily measurement.

impute the probability of menstrual bleeding on each day. Additionally, the 6 days preceding the onset of menstrual bleeding were dummy-coded as the premenstrual phase.

Exclusion criteria, participant flow and final sample

Out of the total $N = 1660$ women who started the study, $n = 1171$ women completed the diary part and the general follow-up survey. As preregistered, we excluded women who did not take part in the diary and who were probably not experiencing ovulation, because of pregnancy, breast-feeding or menopause. Additionally, we sought to increase internal validity by excluding women whose ovulatory cycles might have been affected by taking sex hormones other than for contraception purposes or age above 50, or whose ovulatory cycles were irregular (those women who stated not experiencing menstruation 'regularly (approximately monthly)' in the demographic survey). Moreover, since we were interested in ovulatory cycle shifts in mating-related self-perceptions that presumably evolved to serve reproductive functions, women had to consider themselves predominantly heterosexual to be eligible for analyses. We also excluded unfinished diary entries and those where participants appeared to have been inattentive or dishonest. A detailed participant flow with the relevant exclusion criteria is depicted in Figure 2. The results of further robustness analyses using different exclusion criteria are discussed below and shown in Figure 4 and Figures S1–S4.

Consequently, our final sample consisted of $n = 872$ women, out of whom $n = 580$ (66.5%) were naturally cycling. In total, these women filled out 38,254 analysable diary entries with on average 43.9 (median 48, standard deviation, *SD*, 19.6) diary entries per woman. Participants were between 18 and 49 years old (mean, *M*, 25.5, *SD* 5.6), mostly students (66%) or employed (22%), held mostly Christian beliefs (49%) or were not religious (43%), and had on average 15.25 years of education (*SD* 4.72). On average, women's first menstrual bleeding occurred at the age of 12.7 (*SD* 1.3), their first sexual intercourse at the age of 17.0 (*SD* 2.8) and they had had 7.78 (*SD* 10.25) sexual partners. While 34% of women were single and 6% of women were in a non-committed relationship, 50% were in a committed relationship, 2% were engaged, 7% were married and 1% reported an undefined relationship status such as a temporary break-up. Seven per cent of women were mothers.

For non-hormonal contraception methods, most women ($n = 258$) used condoms only, $n = 103$ used fertility-awareness-based methods (with varying combinations with other non-hormonal methods), $n = 53$ used non-hormonal intra-uterine devices and $n = 66$ used other methods such as coitus interruptus ($n = 12$) or refraining from penetrative sex when fertile ($n = 17$). The remaining $n = 100$ women in the NC group reported not using contraception regularly.

For hormonal contraception, most ($n = 153$) women used the hormonal pill only, $n = 96$ used the hormonal pill combined with condoms and $n = 29$ used other hormonal contraception methods such as the vaginal ring. The remaining 14 women in the HC group used varying combinations of contraception methods, for example, hormonal pill, condoms and coitus interruptus ($n = 2$). Across the diary, the mean number of observed cycles was 2.52 (*SD* 0.84). The mean observed cycle length in the diary of 28.77 days (*SD* 3.07) matched closely the mean cycle length that participants had reported for themselves in the demographic survey at the beginning (*M* 28.52, *SD* 2.95).

As depicted in Table 2, HC and NC women differed from each other in some demographic variables, with the most important one being that HC women were on average nearly 3 years younger than NC women. Additionally, HC women had had fewer sexual partners and were more satisfied in their relationships. Possibly owing to self-selection for choosing contraception methods, HC women were more conscientious and less open to experiences, as measured with the Big Five Inventory (John et al., 1991). Concerning cycle characteristics, HC women had more regular ovulatory cycles and these were on average one day shorter, which might be a consequence of hormonal contraceptive use. Conducting a probit regression including the demographic variables in Table 2 except for the cycle characteristics, only age and number of lifetime sexual partners remained significant predictors of hormonal contraceptive use ($p < .05$). Besides these aspects, HC and NC women did not differ in their living situations, self-reported health, weight, weekly sport or weekly alcohol consumption.

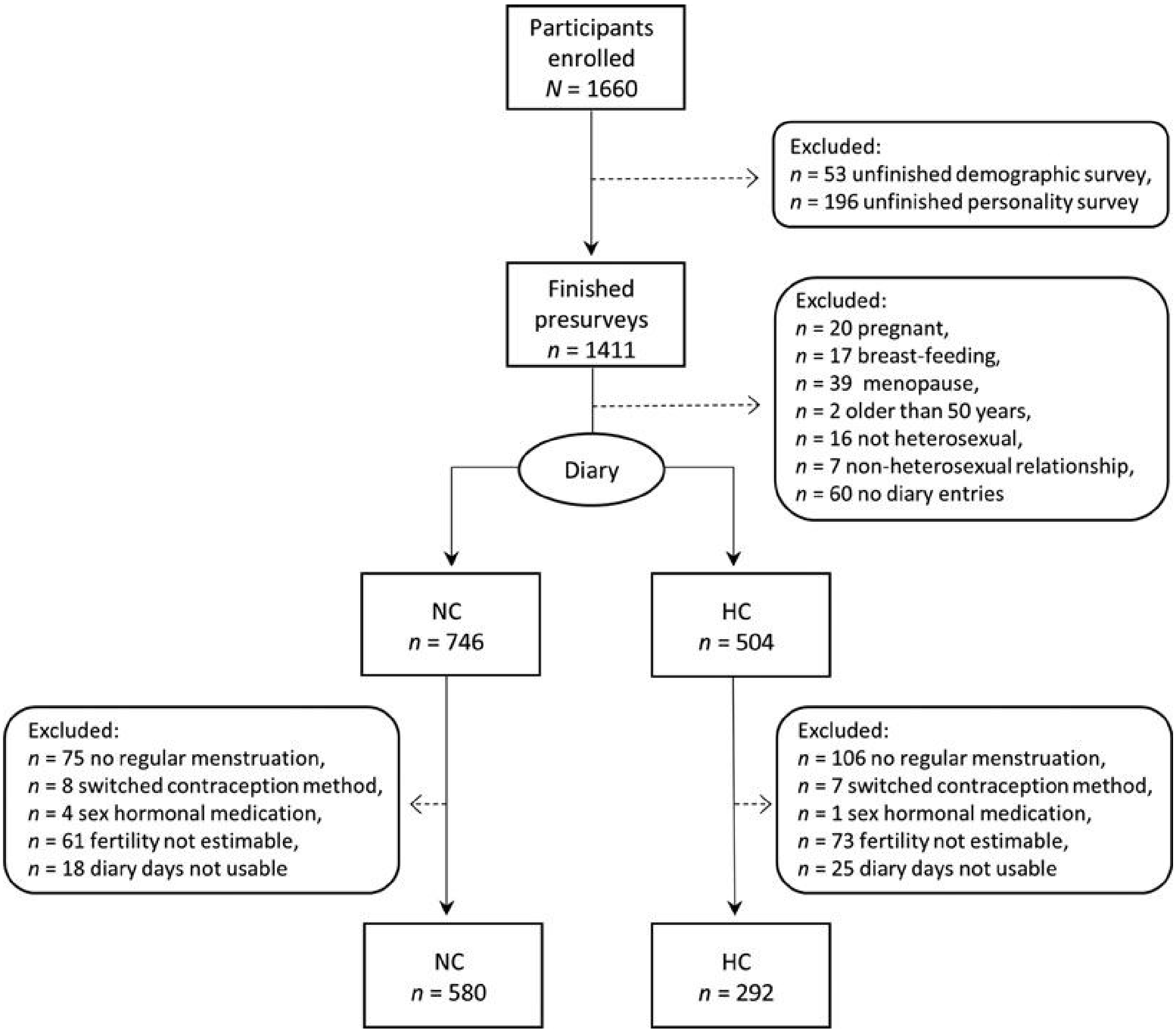

Figure 2. Participant flow and overview of exclusion criteria. If participants were affected by multiple exclusion criteria, only the first criterion is shown. NC, Naturally cycling women; HC, women using hormonal contraceptives.

Analyses

All analyses were performed using the statistical software R 4.0.2 (R Core Team, 2020) and the respective R packages lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017).

For all models, the main predictor was PBFW by backward counting from the next menstrual onset. As using PBFW as a continuous predictor across all days of the cycle meant including days of the premenstrual phase and menstruation too, we controlled for these variables by adding these phases as additional predictors to our models. Following Arslan, Schilling et al. (2018), we analysed the whole sample and used HC women as a quasi-control group to distinguish changes related to ovulation from other mid-cycle changes. Since most women taking hormonal contraceptives experience no ovulation but do have regular vaginal bleeding, comparing both groups helped ensure the ovulatory nature of these cycle shifts. Consequently, we included hormonal contraceptive use as a dummy variable (set to zero for NC women). To properly include interaction controls (Rohrer & Arslan, 2021), we amended our analysis plan in the preregistration with the interaction of hormonal contraceptive use with all predictors, not only PBFW. This decision was taken as the most appropriate modelling decision and not based on any result patterns. Among other robustness analyses such as using other exclusion criteria and fertility estimators as described below, we also ran models without interaction controls for premenstrual phase and menstruation. As can be seen in Figure 4 and Figures S1–S4, these analyses show no differences between the two modelling decisions. As preregistered, for all

Table 2. Descriptive statistics according to hormonal contraceptive use

	Mean (standard deviation)			
Variable	HC women	NC women	Hedges'*g*	*p*
Age	23.66 (4.43)	26.35 (5.86)	−0.46	<.001
Age at first sexual intercourse	16.79 (2.59)	17.09 (2.85)	−0.10	.133
Age at menarche	12.72 (1.26)	12.75 (1.38)	−0.02	.742
Relationship duration	3.4 (3.19)	4.16 (4.9)	−0.15	.025
Relationship satisfaction (0–5)	4.17 (0.76)	3.89 (0.9)	0.31	<.001
Number sexual partners	5.85 (8.65)	8.75 (10.88)	−0.27	<.001
Education years	14.89 (4.2)	15.43 (4.95)	−0.11	.089
Religiosity (0–5)	2.22 (1.36)	2.24 (1.35)	−0.01	.733
Cycle length	27.7 (2.34)	28.94 (3.14)	−0.39	<.001
BFI-Openness	3.72 (0.61)	3.82 (0.61)	−0.16	.015
BFI-Conscientiousness	3.63 (0.68)	3.48 (0.65)	0.23	.002
BFI-Extraversion	3.47 (0.82)	3.41 (0.76)	0.09	.195
BFI-Agreeableness	3.74 (0.62)	3.66 (0.59)	0.13	.059
BFI-Neuroticism	2.96 (0.78)	2.99 (0.77)	−0.04	.645

Note: NC, naturally cycling women; HC, women using hormonal contraceptives; BFI, Big Five Inventory. Variables are printed in bold if they remained significant after multivariate adjustment in a probit regression.

models we included random intercepts and random slopes for our main predictor variable PBFW. In Wilkinson's notation (Wilkinson & Rogers, 1973), our main models were specified as follows:

$$\text{outcome} \approx (\text{PBFW} + \text{premenstrual\_phase} + \text{menstruation}) \times \text{no\_hormonal\_contraception} \\ + (1 + \text{PBFW}|\text{woman})$$

Results

Adhering to our preregistration, we set the significance level to .01 to adjust for multiple comparisons. An extended overview of all linear mixed model results of our analyses is given in Table 3. We only report unstandardised effect sizes since all variables of interest were measured on commensurable scales and standardisation across different residual standard deviations might hinder comparability. Standardised effect sizes are shown in the robustness analyses in Figure 4 and Figures S4–S5, but differences from unstandardised effect sizes are small.

Attractiveness

We found ovulatory increases in self-perceived attractiveness for NC women. Analysing 25,187 observations, self-ratings of attractiveness rose significantly with increasing PBFW ($b = 0.25$, $t(1132.65) = 5.3$, $p < .001$, 99% CI [0.13, 0.36]). This increase was significantly diminished in the group of HC women ($b = -0.38$, $t(1320.92) = -4.42$, $p < .001$, 99% CI [−0.60, −0.16]).

Sexual desirability

We found ovulatory increases in self-perceived sexual desirability for NC women. Analysing 12,285 observations, self-ratings of sexual desirability rose significantly with increasing PBFW ($b = 0.38$, $t(810.07) = 4.64$, $p < .001$, 99% CI [0.17, 0.59]). This increase was descriptively diminished in the

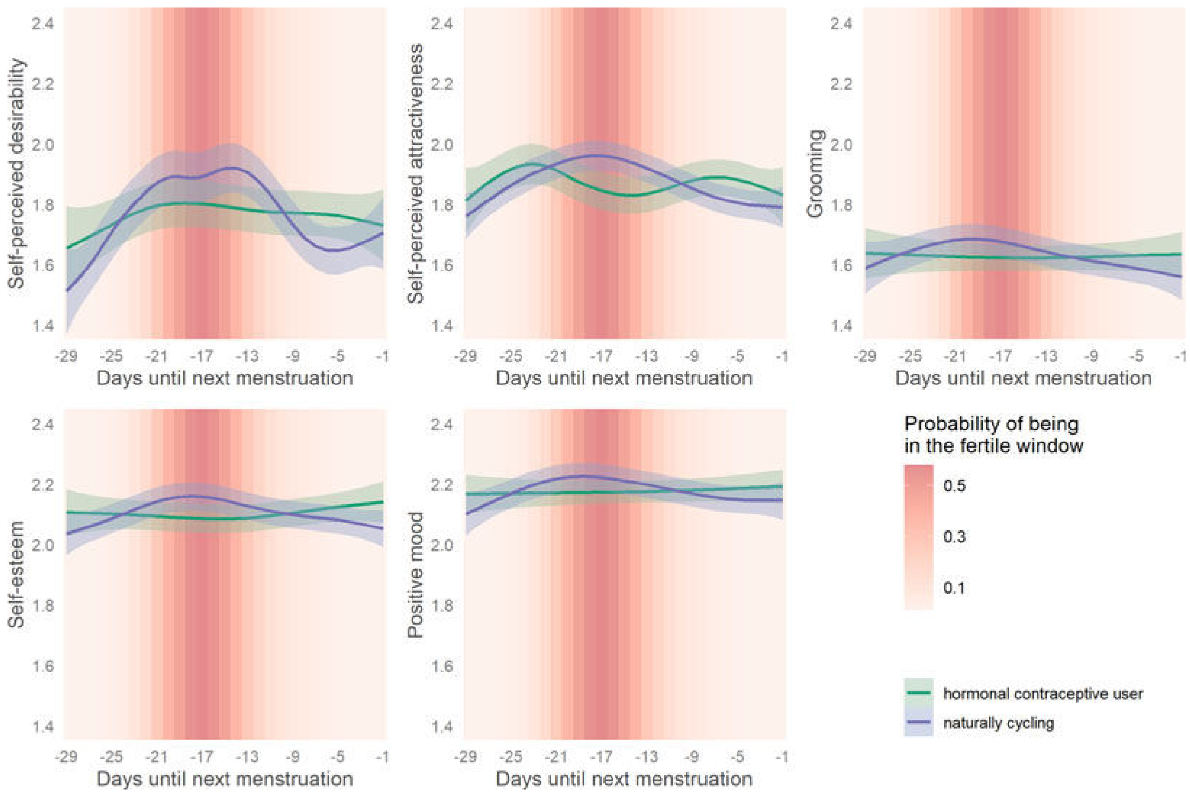

Figure 3. Changes in women's attractiveness-related self-perceptions across their ovulatory cycles. Smoothed curves calculated by generalised additive models using cyclic cubic splines. Days until next menstruation depict reverse cycle days backward counted from the next confirmed onset of menstrual bleeding. Bands represent 99% confidence intervals.

group of HC women ($b = -0.29$, $t(886.70) = -2.15$, $p = .031$, 99% CI [−0.65, 0.06]), but not significant according to our preregistered criterion. While not part of our predictions, we also found that sexual desirability significantly decreased with higher probability of menstrual bleeding in NC women ($b = -0.14$, $t(11930.57) = -3.45$, $p < .001$, 99% CI [−0.24, −0.03]). However, since we held no prior expectations regarding this finding, it should be interpreted with caution.

Grooming

We found no significant ovulatory changes in self-reported grooming for NC women. Analysing 19,483 observations, self-ratings of grooming descriptively rose with increasing PBFW ($b = 0.15$, $t(1357.87) = 2.52$, $p = .012$, 99% CI [−0.00, 0.30]). This increase was descriptively diminished in the group of HC ($b = -0.25$, $t(1506.40) = -2.29$, $p = .022$, 99% CI [−0.53, −0.03]). Neither change was significant according to our preregistered criterion, but the confidence intervals may still include previously reported estimates.

Self-esteem

We found ovulatory increases in self-esteem for NC women. Analysing 30,563 observations, self-esteem rose significantly with increasing PBFW ($b = 0.13$, $t(1162.24) = 2.97$, $p = .003$, 99% CI [0.02, 0.25]). This increase was significantly diminished in the group of HC women ($b = -0.21$, $t(1303.80) = -2.59$, $p = .01$, 99% CI [−0.43, −0.00]).

Positive mood

We found ovulatory increases in positive mood for NC women. Analysing 30,641 observations, self-reported positive mood rose significantly with increasing PBFW ($b = 0.13$, $t(1174.20) = 2.78$, $p = .005$,

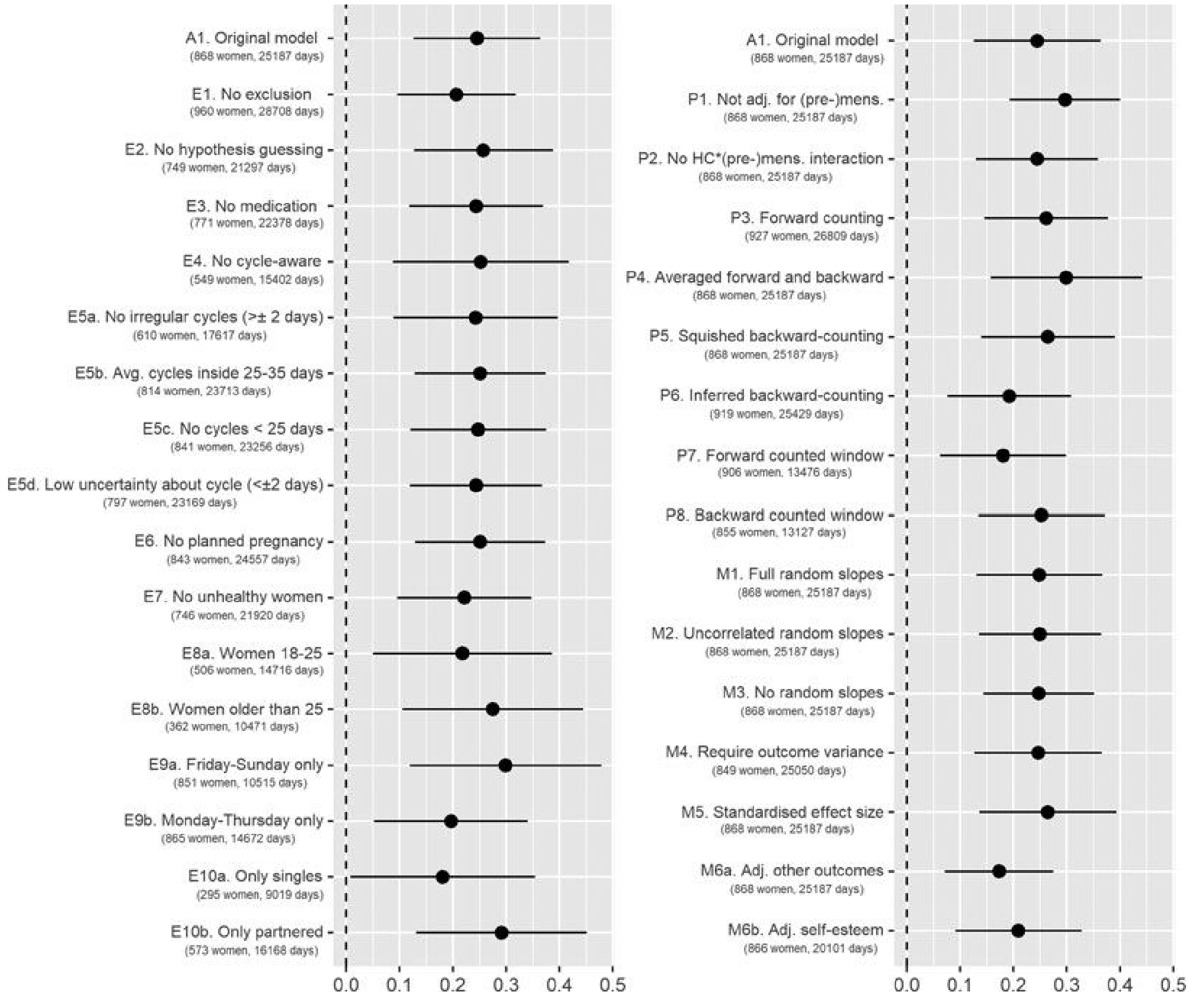

Figure 4. Effect of probability of being in the fertile window on self-perceived attractiveness with 99% confidence interval. A1 is the model described in the results section. Models starting with E are robustness analyses with different exclusion criteria. Models starting with P are robustness analyses with different specifications of the fertility predictor. Models starting with M are robustness analyses with different model specifications. Avg., Average; Adj., adjusted; HC, hormonal contraception; (pre-)mens, premenstrual and menstrual phase.

99% CI [0.01, 0.26]). This increase was descriptively diminished in the group of HC women ($b = -0.17$, $t(1279.09) = -2.05$, $p = .041$, 99% CI [−0.40, 0.05]), but not significant according to our criterion.

When plotting a smoothed spline over reverse cycle days, all outcomes showed small to moderate ovulatory increases as depicted in Figure 3.

Robustness analyses

We conducted preregistered robustness analyses and further supplementary analyses to gauge the robustness of our results. We tested how various exclusion criteria affected our outcomes, probed our results for different estimates of fertility and compared different model specifications.

Regarding alternative exclusion criteria, we tested (1) no exclusions besides those necessary for estimating PBFW, (2) additionally excluding women who guessed that the study investigated fertile window effects, (3) excluding women who used any psychopharmacological, hormonal or antibiotic medication, (4) excluding women who were cycle-aware, (5a) excluding women who reported cycles with more than 2 days' variability in length, (5b) excluding women who reported average cycle lengths shorter than 25 or longer than 35 days, (5c) excluding cycles shorter than 25 days in the diary, (5d) excluding women who were uncertain about the length and regularity of their ovulatory cycles, (6) excluding women who were

Table 3. Results of linear mixed effects models showing associations of cycle characteristics and women's self-perceptions

	Attractiveness		Sexual desirability		Grooming		Self-esteem		Positive mood	
Predictors	Estimate	99% CI	Estimate	99% CI	Estimate	99% CI	Estimate	99% CI	Estimate	99% CI
Intercept	1.84	1.79, 1.90	1.73	1.64, 1.81	1.62	1.56,1.68	2.10	2.04,2.15	2.16	2.10,2.21
PBFW	0.25	0.13, 0.36	0.38	0.17, 0.59	0.15	−0.00,0.30	0.13	0.02,0.25	0.13	0.01,0.26
Premenstruation	−0.04	−0.09, 0.00	−0.05	−0.14, 0.03	−0.04	−0.11,0.03	−0.03	−0.07,0.02	−0.02	−0.07,0.03
Menstruation	−0.02	−0.08, 0.03	−0.14	−0.24, −0.03	0.03	−0.05,0.10	−0.05	−0.10,0.00	−0.03	−0.08,0.03
HC (yes)	0.06	−0.04, 0.17	0.04	−0.11, 0.19	−0.00	−0.11,0.11	0.01	−0.09,0.11	0.04	−0.06,0.14
PBFW:HC	−0.38	−0.60, −0.16	−0.29	−0.65, 0.06	−0.25	−0.53,0.03	−0.21	−0.43,−0.00	−0.18	−0.40,0.05
Premens:HC	−0.00	−0.09, 0.09	0.05	−0.09, 0.20	0.04	−0.09,0.16	0.05	−0.04,0.13	0.04	−0.06,0.13
Mens:HC	−0.00	−0.11, 0.10	0.05	−0.12, 0.22	0.01	−0.14,0.15	0.06	−0.04,0.16	0.01	−0.10,0.12
Random effects										
σ^2	0.70		0.99		1.06		0.77		0.92	
τ_{00}	0.16_{woman}		0.19_{woman}		0.10_{woman}		0.16_{woman}		0.13_{woman}	
τ_{11}	$0.26_{woman.fertile}$		$0.40_{woman.fertile}$		$0.14_{woman.fertile}$		$0.28_{woman.fertile}$		$0.26_{woman.fertile}$	
ρ_{01}	-0.25_{woman}		-0.37_{woman}		-0.27_{woman}		-0.28_{woman}		-0.25_{woman}	
N	868_{woman}		568_{woman}		865_{woman}		870_{woman}		869_{woman}	
Observations	25,187		12,285		19,483		30,563		30,641	
Marginal R^2/ conditional R^2	0.003/0.192		0.006/0.161		0.001/0.089		0.001/0.172		0.001/0.124	

Notes: PBFW, probability of being in the fertile window; Premens(trual phase), dummy-coded whether women are within 6 days preceding their onset of menstrual bleeding (0 = false, 1 = true); Mens(truation), estimated probability of women having menstrual bleeding; HC, dummy-coded whether women use hormonal contraceptives or not (0 = false, 1 = true); CI, confidence interval. Estimates represent unstandardised regression coefficients. ICC, Intraclass correlation; σ^2, residual variance; τ_{00}, between-subject variance; τ_{11}, variance random slope; ρ_{01}, correlation random intercept and random slope.

trying to become pregnant, (7) excluding women who reported feeling unhealthy, (8a) including only women aged 18–25 years, (8b) including only women 26 years and older, (9a) including only Fridays to Sundays, (9b) including only Mondays to Thursdays, (10a) including only singles and (10b) including only partnered women. As an alternative method of estimating PBFW, we tested (1) not adjusting for (pre-)menstruation, (2) not adjusting for the interaction between hormonal contraception and (pre-) menstruation, (3) using forward-counting from the last menstrual onset, (4) averaging forward and backward counting estimates, (5) 'squishing' the follicular phase to a standard length before estimating PBFW, (6) counting backwards from the next menstrual onset inferred from the reported average cycle length, (7) using a discrete fertile window predictor when forward counting and (8) using a discrete predictor when backward counting. Regarding modelling choices, we (1) added varying slopes for the menstruation and premenstruation predictors, (2) added varying slopes but assumed them to be uncorrelated, (3) omitted varying slopes for PBFW, (4) required that the outcome have variance for each participant, (5) also report standardised effect sizes, (6a) adjusted outcomes for all other outcomes, (6b) adjusted for self-esteem, (6c) adjusted effects on self-esteem for mood and (6d) adjusted effects on desirability for grooming.

In the following, we seek to give a brief summary of these results. Importantly, for all models and robustness analyses, effects of PBFW differed in absolute size, but were rarely zero and never changed direction. A complete report of all these analyses including other visualisation methods and ordinal regressions showing the same result patterns can be found online (https://osf.io/2g4rc/). An overview of the conducted robustness analyses on attractiveness is given in Figure 4 and for the other outcomes in Figures S1–S4.

Regarding both attractiveness and sexual desirability, the results were largely robust. The significance of results was maintained in nearly all analyses and effect sizes varied only minimally. The sizes of PBFW effects on attractiveness peaked on weekends ($b = 0.30$, 99% CI [0.12, 0.48]) and in women in relationships ($b = 0.29$, 99% CI [0.13, 0.45]). The effect for sexual desirability peaked in women with low cycle irregularities (below 2 days, $b = 0.46$, 99% CI [0.19, 0.73]). Moreover, results were robust against adjusting for all other variables.

However, results for grooming, self-esteem and positive mood were less consistent. For grooming, most robustness analyses yielded non-significant cycle shifts, with some exceptions. A significant effect of PBFW emerged for example when only looking at women in relationships ($b = 0.24$, 99% CI [0.04, 0.44]) compared with single women, where the effect was the lowest ($b = 0.024$, 99% CI [−0.21, 0.26]). PBFW also became a significant predictor of grooming when using less valid methods for modelling the fertility estimate, such as forward counting to determine day of ovulation, ignoring possible influences of premenstrual and menstrual phases and ignoring the random effect structure of mixed models. Overall, effect sizes were small and the majority of analyses yielded non-significant results.

The effects of PBFW on self-esteem were robust for most fertility estimates and model specifications. Yet, the ovulatory increase in self-esteem varied according to several exclusion criteria. For example, when looking only at singles it was not significant ($b = 0.08$, 99% CI [−0.09, 0.26]), whereas when looking at women who were cycle unaware (not using awareness-based contraception or cycle tracking apps) the effect peaked ($b = 0.21$, 99% CI [0.05, 0.36]). The slight majority of robustness analyses supported significantly positive effects for PBFW.

The ovulatory increase in positive mood was the effect that showed the least robustness. The effect of PBFW held both in effect size and significance when dropping any exclusion criteria ($b = 0.12$, 99% CI [0.00, 0.23]) and it peaked in women who were cycle unaware ($b = 0.23$, 99% CI [0.07, 0.39]). However, many analyses of sample characteristics led to non-significant results, such as only using data of regularly cycling women ($b = 0.11$, 99% CI [−0.05, 0.26]) or women with good self-reported health ($b = 0.12$, 99% CI [−0.01, 0.26]). Additionally, decisions concerning fertility estimates and model specifications resulted in inconsistent results as well, with the effect becoming non-significant when using forward-counting methods to determine a fertile window ($b = 0.00$, 99% CI [−0.12, 0.12]). Whereas effect sizes varied only minimally, less than half of the conducted robustness analyses yielded significant results.

Discussion

The current study used a highly powered daily diary design to address the question whether and which attractiveness-related self-perceptions of women show ovulatory increases across their ovulatory cycles. In support of our hypotheses, by comparing NC with HC women and by conducting a variety of robustness analyses, we found statistically significant ovulatory increases in self-perceived attractiveness, sexual desirability, self-esteem and positive mood. The ovulatory increase in grooming was small and absent for HC women, but while confidence intervals might still include estimates of previous studies, it failed to reach our preregistered significance level of .01.

Attractiveness and sexual desirability

The finding of the existence of ovulatory increases in self-perceived attractiveness and sexual desirability is in line with previous research on ovulatory cycle shifts (Arslan, Schilling et al., 2018; Haselton & Gangestad, 2006). This study expands the previous, methodologically diverse literature by adding further robust evidence that women feel both more attractive and sexually desirable when fertile.

Although feelings of attractiveness and sexual desirability are similar and sometimes treated as equivalent, our analyses support previous findings that they are distinct constructs (Wade, 2000). Comparing effect sizes, it becomes apparent that sexual desirability descriptively shows a greater ovulatory increase ($b = 0.38$) than attractiveness ($b = 0.25$), and this general picture held across robustness analyses. Whereas more research is needed to disentangle these constructs, as was shown by Wade (2000), it is likely that they mostly differ in their sexual motivational component which in return could explain these different effect sizes. Looking at current literature on ovulatory changes in general, the predominant finding is that women show increased sexual motivation when they are fertile (Arslan, Schilling et al., 2018; Bullivant et al., 2004; Jones et al., 2019; Roney & Simmons, 2013, 2016; Shirazi et al., 2019). While the nature and function of these shifts remain a matter of debate (Arslan, Schilling et al., 2018; Gangestad et al., 2005; Havlíček et al., 2015; Pillsworth et al., 2004; Pillsworth & Haselton, 2006; Stern et al., 2019, 2020), one hypothesis that is gaining more attention and empirical support is the motivational priority shifts hypothesis (Roney, 2016; Roney & Simmons, 2013). According to this hypothesis, estradiol and progesterone act as a two-signal code that promotes mating effort during the fertile phase, when reproductive fitness benefits outweigh the costs (risking injury, sexually transmitted diseases and opportunity costs with regard to e.g. foraging and feeding). Thus, the main adaptive psychological effect of ovulatory hormonal changes might be a general increase in sexual motivation. It is possible that ovulatory increases in self-perceived sexual desirability and attractiveness follow this dominant change in sexual motivation in order to promote mating effort (Haselton & Gangestad, 2006) and adaptively affect strategic mating decisions and mate choice standards (Penke et al., 2008; Todd et al., 2007). As feeling sexually desirable has been predicted to be more specifically linked to sexual motivation than general self-perceived attractiveness (Wade, 2000), this might also explain why the increase in sexual desirability is higher descriptively.

Another explanation of our finding could be that the effect of sexual desirability is artificially higher because we accidentally only assessed it in partnered women. Yet, when comparing it with the effect size of attractiveness only in partnered women ($b = 0.29$), the cycle shift in sexual desirability is still more pronounced. Additionally, relationship status did not influence self-perceptions of attractiveness and sexual desirability in prior studies (Arslan, Schilling et al., 2018; Haselton & Gangestad, 2006; Schwarz & Hassebrauck, 2008). Therefore, we deem it unlikely that effect sizes of sexual desirability would deviate much for single women.

Considering comparisons of NC and HC women, the ovulatory increases in self-perceived attractiveness and sexual desirability were substantially diminished in HC women, which supports the hormonal basis and internal validity of these ovulatory cycle shifts. This difference only became statistically significant for attractiveness, not for sexual desirability, but power is presumably the best explanation. As sexual desirability was accidentally assessed only in partnered women, resulting in a 34% reduction of sample size, the subsequent cut in statistical power is the most plausible reason why the interaction effect failed to reach significance for sexual desirability.

Grooming

Unexpectedly, we did not replicate previous findings that women report increased grooming when they are fertile. While, descriptively, the effect was in the expected direction, it did not reach our strict criterion of significance and showed considerable variation in our robustness analyses. Together with the diary study of Arslan, Schilling et al. (2018), this study is the second highly powered longitudinal investigation to report a null finding for cycle shifts in self-reported grooming.

However, the sensitivity of our analyses for this outcome was smaller than that for the other outcomes, as the items were displayed more infrequently in our planned missingness design. Given the small estimated effect size, we may still have achieved insufficient statistical power. It is possible that an ovulatory increase in grooming does exist but that it is very small and consequently needs even higher statistical power to be detected. That an ovulatory increase in grooming, if it exists, is truly small could explain previous heterogeneous results. Another reason might be that previous research showing ovulatory increases in grooming mainly focused on clothing choices (but see Arslan, Schilling et al., 2018). In this study, we did not measure clothing choice specifically but operationalised grooming in a broader sense by asking the degree of styling in general and the extent of effort put into the participant's outfit. Moreover, our assessments were based on self-reports and not on external ratings of photographs or illustrations as was the case in Durante et al. (2008) and Haselton et al. (2007).

Finally, drawing from our robustness analyses, an ovulatory increase in grooming was present for a subsample of women who were in a relationship despite the subsequent reduced number of observations. Future research should consider relationship status as a moderating factor. Relationship dynamics might play an important role for the emergence of increased grooming when women are fertile. For example, it might be that grooming is enhanced only if another person serves as a romantic goal that these efforts are directed to. More research is needed to investigate whether only certain aspects of grooming change across the cycle and whether these differ according to relationship status or the availability of potential sexual partners in general.

Self-esteem

We found an unexpected ovulatory increase in self-esteem that was only present in NC women. This contradicts previous findings of no significant ovulatory changes (Arslan, Schilling et al., 2018) or even ovulatory decreases in self-esteem (Hill & Durante, 2009).

According to the sociometer theory (Leary & Baumeister, 2000), self-esteem is an affect-laden self-evaluation indicating one's relational worth. The related hierometer theory by Mahadevan et al. (2019) views self-esteem as an indicator of social status. Considering the importance of women's attractiveness in their intrasexual competition and intersexual selection (e.g. Buss, 1988, 1989), attractiveness is likely to be one such factor determining relational worth and social status. Supported by the contingency of self-esteem on self-perceived attractiveness and desirability in women (Bale & Archer, 2013; Brase & Guy, 2004; Connors & Casey, 2006; Penke & Denissen, 2008), it seems plausible that the ovulatory increases in self-perceived attractiveness and desirability in this sample coincide with an ovulatory increase in self-esteem. Although Hill and Durante (2009) also argue a positive relationship of self-esteem and self-perceived attractiveness, they did not assess ovulatory changes in self-perceived attractiveness. Thus, it remains unknown whether and how an ovulatory change in self-perceived attractiveness compared with the ovulatory decrease in self-esteem that they reported.

Besides clear methodological differences regarding higher sample size, longitudinal assessments and continuous fertility estimates in the present study, relationship status could also explain the discrepant results. Hill and Durante (2009) report that seeking long-term partners moderated the ovulatory cycle shift in self-esteem insofar as the ovulatory decrease in self-esteem was higher the more women were seeking long-term partners. While we did not measure women's wish for long-term partners, we found differences in the ovulatory cycle shift according to relationship status. For single women only, the ovulatory increase in self-esteem was not significant. Although relationship status showed no additional effect in Hill and Durante (2009), it might be that other, currently overlooked effects influence women's self-esteem across the cycle. It is possible that, assuming that women experience an increase in sexual motivation when fertile, mating effort and mate value become more salient. Consequently, it is a woman's evaluations of her mate value that affect her self-esteem, in line with the sociometer theory and hierometer theory. For example, a woman seeking a partner but not having one when her sexual motivation and salience of mate value increase might down-regulate her mating-related self-esteem, whereas a woman who wants to have sex and has the possibility to have it, might up-regulate her mating-related self-esteem. Given that Arslan, Schilling et al. (2018) investigated only women in relationships, the difference in results may be surprising. However, Arslan, Schilling et al. (2018) used a self-esteem item with more trait variation (an intraclass correclation (ICC) of approximately .42, compared with our ICC of .16). It is possible that their item was less sensitive to intra-individual changes than ours. The question of whether ovulatory changes in self-esteem are dependent on women's sexual motivation and self-perceived mate value poses a fruitful topic for future research.

Positive mood

Although we based our prediction on studies using daily assessments that indicated no ovulatory changes in positive mood, there are also studies using daily assessments that support our unexpected finding that positive mood increases when women are fertile. For example, Rossi and Rossi (1977) combined forward and backward counting methods to define the fertile phase of 67 women across 40 days and reported a clear ovulatory peak of positive mood that was only present in NC women. However, using the same counting methods as Rossi and Rossi (1977), McFarlane et al. (1988) compared daily data for 60–70 days of 27 women (12 using hormonal contraceptives). They found increased pleasant mood that was absent in the ovulatory phase but present in the menstrual and follicular phase only for NC women. Taken together, even studies that used similar study designs and methods reached opposing conclusions. The current study addresses the problem of low sample sizes that might have previously accounted for these inconsistencies. However, the ovulatory increase in positive mood showed low robustness across modelling decisions and different sample characteristics. Since we believe that our modelling decisions are appropriate, this highlights the importance of sample characteristics and interindividual differences in the effect of the ovulatory cycle on mood (Metcalf et al., 1989; Walker, 1994).

Unlike Rossi and Rossi (1977), we found that the ovulatory increase was descriptively but not statistically different between NC and HC women. This is in line with previous research that found no differences in the cyclical changes of mood between NC and HC women (Marriott & Faragher, 1986). Hence, we cannot rule out the possibility that other mid-cycle changes unrelated to ovulation drive the effect of PBFW on positive mood.

General discussion

Comparing the effect sizes and robustness analyses of the investigated ovulatory cycle shifts, we found the strongest ovulatory increase in women's self-perceived sexual desirability, followed by women's self-perceived attractiveness. Ovulatory increases in self-esteem and positive mood were smaller and less robust. Although the small effect size of ovulatory increases in grooming was comparable with those of self-esteem and mood, it did not reach our strict significance criterion.

However, we cannot confidently infer whether, for instance, self-esteem increased solely because women felt more sexually desirable. Although such questions are often hastily addressed by statistical control or mediation analyses, claiming causality for observational data depends on assumptions that we found difficult to justify (Rohrer, 2018; Rohrer et al., 2021). We added exploratory analyses to our robustness analyses, in which we adjusted for other measured outcomes. However, because outcomes were measured with varying amounts of error and covariates were often missing because of our planned missingness approach, these analyses should only be seen as a starting point for future research. To untangle the causal web of related ovulatory changes, we need different designs. Direct, physiological measures of women without make-up might help us find out whether ovulatory changes in, for instance, skin quality rather than grooming, explain the self-perceptions of desirability. Experience sampling might help us understand whether self-esteem changes follow self-perceptions of ovulatory increases in attractiveness.

Additionally, a theoretical approach is necessary that embeds these attractiveness-related ovulatory cycle shifts. It might be that the main function of cyclical hormonal fluctuations, especially of estradiol and progesterone, is calibrating the trade-off of mating and feeding efforts as suggested by the motivational priority shifts hypothesis. Consequently, it would be plausible to assume ovulatory increases in constructs that are associated with ovulatory increases in sexual motivation. Relative magnitudes of ovulatory cycle shifts in self-perceptions might reflect the strength of the association of these self-perceptions to sexual motivation. This is hinted at in our results, with the highest ovulatory increase being sexual desirability, followed by attractiveness and smaller increases in self-esteem and positive mood. Yet there are different theoretical approaches that try to account for the ovulatory increase in sexual motivation in women (Arslan, Schilling et al., 2018; Gangestad et al., 2005; Gildersleeve et al., 2014; Havliček et al., 2015; Pillsworth et al., 2004; Pillsworth & Haselton, 2006; Stern et al., 2019, 2020; Wood et al., 2014). In the face of these debates, there is a great need for methodologically sound studies, preferably using open science practices, before any final conclusions about the functions or associations of ovulatory cycle shifts can be drawn. Moreover, no current theoretical approach addresses the question whether and to what degree any ovulatory cycle shift might translate into biologically relevant outcomes, for example regarding women's mate choices or reproductive fitness. Besides more rigorous methods, a theoretical and empirical debate is called for that discusses the nature of the biological relevance of ovulatory cycle shifts (e.g. do increases in self-perceived attractiveness translate into a differential mate choice and affect relative number or viability of offspring?) and their smallest effect size of interest (e.g. which differences in mating decisions or partner mate value might be expected to have an impact on reproductive fitness?).

Another interesting topic for future research is whether other people also perceive any of these ovulatory cycle shifts in women. This could answer the question whether women's increased feelings of attractiveness follow internal states or are based on observable changes or even social feedback, for example from mating partners. In particular, many early studies reported that men perceive ovulatory changes in women's attractiveness as a possible cue to fertility (Bobst & Lobmaier, 2012; Cobey et al., 2013; Haselton & Gildersleeve, 2011; Roberts et al., 2004; Schwarz & Hassebrauck, 2008). However, more recent studies challenge this finding, for example by questioning whether postulated shifts in facial shape or colour exist or are even perceptible (Burriss et al., 2015; Catena et al., 2019). Whether shifts are perceptible has clear implications for theory. Shifts below a perceptible threshold could be more easily explained from the perspective that oestrus has been 'lost' or is even 'hidden' in humans. Future studies not only should try to answer these questions but should also expand them to see if ovulatory cycle shifts in self-perceived sexual desirability, self-esteem and positive mood are related to externally observable attractiveness changes across the cycle.

Limitations

Biases such as social desirability and recall bias might have affected our results. By using an online diary study that implemented features to ensure anonymity and by asking participants to never recall more than the last 24 h, these biases are probably attenuated but cannot be ruled out.

Another limitation is our assessment of ovulatory timing and the fertile phase. Backward counting from the next onset of menstrual bleeding is the best practice for counting methods, but it is still outperformed by ultrasound or hormonal measurements, especially luteinising hormone tests (Gangestad et al., 2016). However, using these methods was not feasible for an online diary study of this size. Well-validated proxy variables like ours still enhance the statistical power of a design because of the larger affordable and reachable sample. Future research that uses biological markers of ovulation and combines them with a large sample size would be desirable.

Additionally, because of the complexity of our diary study we mostly used single-item measures to lessen the time and effort for participants. This probably promoted a higher sample size and reduced non-response bias but came at the cost of using less-established measurements. The general discussion of the practical use of single-items is ongoing (Arslan, Brümmer et al., 2020; Fisher et al., 2018). However, future studies that ideally build on overarching theoretical assumptions of the nature of ovulatory cycle shifts could focus more on specific outcomes and validate our findings with more established scales.

Importantly, like the majority of studies in this field, our sample mostly consisted of young, educated participants from a developed Western country. Thus, our sample fulfils all aspects of a WEIRD sample (Henrich et al., 2010) and generalisability to other cultural backgrounds is limited. We expect the functional hormonal basis of ovulatory cycle shifts to be universal among humans, but cycle shifts can be conditional on age, parity, nutritional condition and health state. More research is needed to support the claim of the universality of ovulatory cycle shifts across different cultures and investigate how they change according to different hormonal levels.

Conclusion

In this large, preregistered online diary study across 70 consecutive days, we found ovulatory increases in women's self-perceived attractiveness, sexual desirability, self-esteem and positive mood. We did not confirm previous findings of increased self-reported grooming when women are fertile. Comparing NC with HC women, ovulatory increases were present only in NC women for attractiveness and self-esteem. Ovulatory increases in sexual desirability and positive mood differed descriptively but not significantly between NC and HC women. Thus, we cannot rule out that increases in sexual desirability and positive mood follow other, unrelated mid-cycle changes instead of being ovulatory. Previous studies largely were not preregistered, had low sample sizes, used discrete estimates of fertility instead of continuous ones and used between-subject designs to investigate within-subject effects. Together, these factors can inflate false positives and false negatives. Although this study addresses these shortcomings and provides more reliable results, it also shows heterogeneity in ovulatory changes according to sample characteristics and analytical decisions for grooming, self-esteem and positive mood. Not only is more research needed to account for these interindividual differences, but future studies should also address how the reported shifts are associated with each other and explain causal or directional influences between them. Most importantly, there is a need for a theoretical framework that embeds these attractiveness-related self-perceptions in a broader picture of the nature and function of ovulatory cycle shifts.

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Author contributions. RCA, TMG and LP designed the study. RCA and JCD collected and cleaned the data. LS analysed the data and wrote the manuscript. All authors read, edited and approved the manuscript.

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Declaration of interest. The authors declare no conflicts of interest.

Research transparency and reproducibility. All material of this study including survey files, data cleaning and codebooks are accessible at https://osf.io/d4avf/ and the respective analysis code for this study can be found at https://osf.io/2g4rc/. Owing to the intimate nature of data and because it cannot be fully anonymised, we will share data upon request.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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Supplemental Material for
"Women feel more attractive before ovulation: evidence from a large-scale online diary study"

Lara Schleifenbaum[1,2*], Julie C. Driebe[1], Tanja M. Gerlach[1,2], Lars Penke[1,2], Ruben C. Arslan[2,3,4]

[1]Georg August University Goettingen, Germany

[2]Leibniz ScienceCampus Primate Cognition, Goettingen, Germany

[3]University of Leipzig, Leipzig, Germany

[4]Max Planck Institute for Human Development, Berlin, Germany

*Correspondence regarding this article should be addressed to Lara Schleifenbaum,
Email: lara.schleifenbaum@uni-goettingen.de, Gosslerstrasse 14, 37073 Goettingen, Germany.

Supplementary Table S1.

Preregistration Planning and Deviation Documentation (PPDD) for our preregistration found at https://osf.io/d3avf/.

Preregistered Approach	Deviation	Explanation	Might deviations change the pattern of results?
We preregistered the following hypotheses: a) There are ovulatory increases in grooming b) There are ovulatory increases in attractiveness (named vanity) c) There are ovulatory increases in self-perceived desirability and these are over and above changes in grooming d) There are no ovulatory changes in self-esteem and if there are, this change is independent of variations in daily mood	We did not test hypotheses c) and d) as preregistered. For c), we omitted the last part and did not check whether the change in self-perceived desirability is above the change in grooming. For d), we omitted the last part and did not check whether the change in self-esteem is independent of variations in mood. Instead, we decided to independently test our expectation that there are no ovulatory changes in positive mood. These changes in tested hypotheses were decided upon before any analyses were conducted.	Hypotheses c) and d) were formulated that way as an attempt to uncover associative and possibly causal patterns. However, we subsequently started to doubt that mediational analyses in our observational data would speak to causal patterns. Instead, we formulated a simpler goal to give a general overview of ovulatory changes in women's attractiveness and related constructs. We hope future research can conduct more targeted probes to find which ovulatory shifts are rather primary and which rather secondary.	As can be seen in Figure S1 below, controlling ovulatory changes in self-perceived desirability for grooming did not change any results. Controlling ovulatory changes in self-esteem for positive mood (Figure S3) reduced effect sizes in both the fertility effect and the group comparison to hormonal contraceptive users. Moreover, *p*-values of both predictors lay above our preregistered significance level of .01. Ovulatory changes in self-esteem and positive mood do not seem to be independent, but it is not clear whether one causes the other.
In order to collect enough data of naturally cycling women we could analyse, we preregistered to pay women, who ● reported their gender as female (not "other"), ● were younger than 50, ● deemed themselves predominantly heteroexual,	We did not exclude women: ● who are actively trying to become pregnant ● who are using psychopharmacological medication ● who are using hormonal medication now or in the last three months	We did not preregister our exclusion criteria in sufficient detail (whether we would do so for main analyses or only in robustness checks). Thus, we used the set of exclusion criteria that seemed the most plausible to us but report robustness	As can be seen in our robustness analyses under "E3. No medication", additionally excluding women who used psychopharmacological, hormonal, or antibiotic medication did not change the results for the outcomes attractiveness, self-perceived desirability, grooming and self-

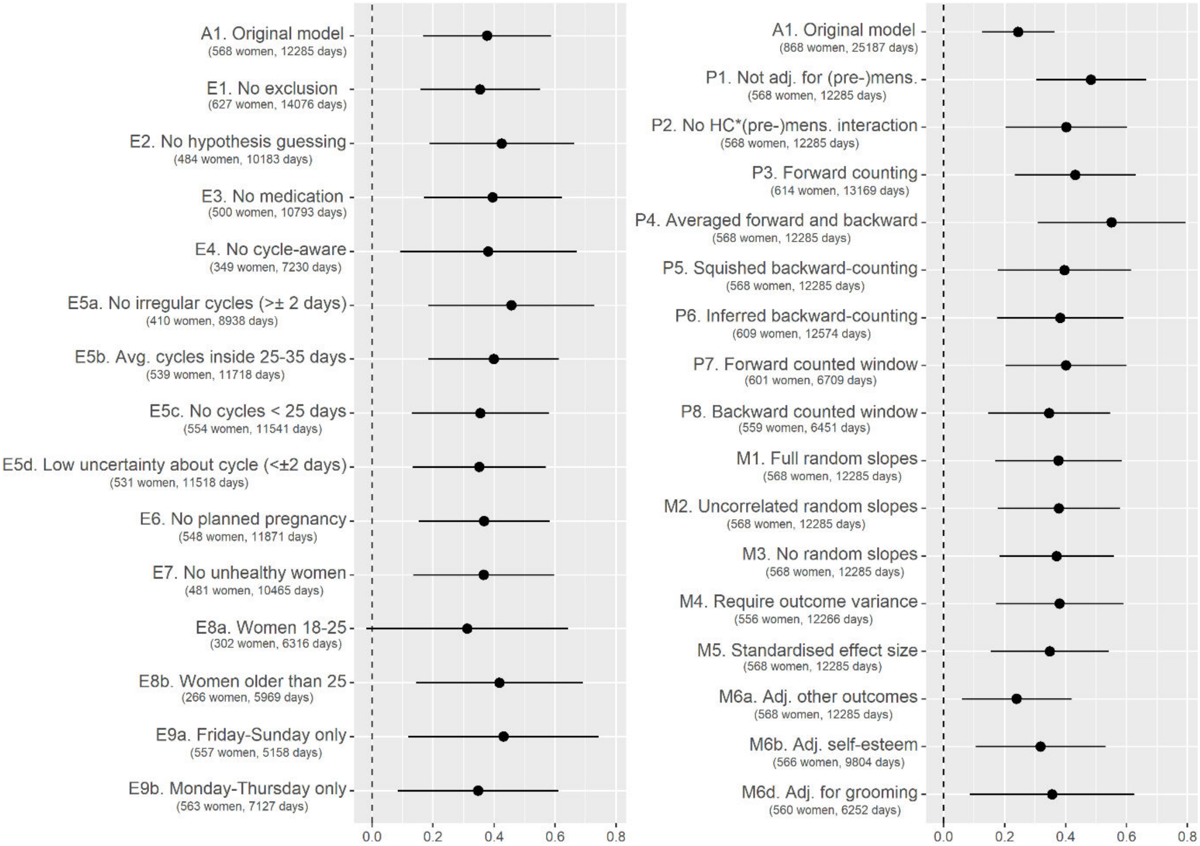
• were not pregnant or breastfeeding now or had been during the last three months, • were not actively trying to become pregnant, • were not using hormonal contraception or medication now or in the last three months, • were not using psychopharmacological medication • deemed themselves pre-menopausal • and who reported menstruating regularly at the moment The criterium of not using hormonal contraception was only included here as part of our incentive structure, not as an exclusion criteria since we would obviously need these women as our preregistered quasi-control group.		analyses with both stricter and less strict criteria. We did not exclude women who were trying to get pregnant, because we observed next menstrual onsets for all included women. We only excluded women taking sex hormones, and decided to exclude women using other hormonal medication (primarily, thyroxine) and psychopharmacological medication as a robustness check.	esteem. Applying this additional set of exclusion criteria to the outcome positive mood did affect the results. However, as discussed above, this outcome shows the least robustness for any decisions concerning inclusion and analytical choices.
We preregistered that we would use multiple imputation or a similar feasible method for our planned missingness design.	We did not impute any data and only analysed complete observed data.	We found that multiple imputation for a multilevel model like ours was computationally challenging (i.e., more complex procedures often did not work as advertised), required many assumptions that we could not endorse (such as the absence of variation in slopes), and were unlikely to improve estimates when it was the	We conducted an in-depth investigation on one item (risk taking) to determine whether multiple imputation would affect standard errors and found no appreciable differences with the models we were able to compute (not shown).

		outcome that was unobserved.	
We preregistered that we would use the package brms (Bürkner, 2017) for analyses using Bayesian inferences.	We used lme4 (Bates *et al.*, 2015) and lmerTest (Kuznetsova *et al.*, 2017) for general linear mixed models for all our analyses.	We changed the respective analytical method because of the expertise of the first author for frequentist statistical approaches.	Given that we did not preregister informative priors, the results can be expected to largely converge between Frequentist and Bayesian estimation. The last author confirmed this through several reanalyses (not shown).
Our preregistered analytical models included main effects for fertility, premenstrual phase and menstruation, an interaction of fertility*hormonal contraception and a random intercept and random slope of fertility per woman.	We added the interaction of premenstrual phase and menstruation with hormonal contraception to our preregistered models.	As we learned after writing our preregistration, applying these interaction controls is the most appropriate way of modelling our control variables (Rohrer and Arslan, 2020).	As depicted in our robustness checks under "P2. No HC*(pre)mens. interaction", this deviation did not change any results.
We preregistered robustness analyses to check: a. whether the results differ by contraceptive method, specifically by whether women are fertility -aware (i.e. using a counting or temperature method or using a cycle tracking app) b. whether results are specific to the outcome of interest or driven by more general changes (e.g. whether sexual desire increases go above and beyond any increases in self -esteem) c. whether the outcome visually peaks at the estimated day of	We modelled g) with separate models instead of moderation analyses and we interpret the results of b) more cautiously because we do not think the causal inference can necessarily be made.	Similar to our preregistered hypotheses (see first row of this table), we now deem mediational analyses largely uninformative for the causal question of whether one effect "drives" another. For the moderator robustness checks in g), group sizes for some subgroups were very small. That is why we decided to report analyses with these groups excluded (rather than including a group variable as a moderator).	We do not expect any of these deviations to have an effect on our reported results. Instead, by using analyses with exclusion rather than moderation for g), we could more properly estimate the effects of sample characteristics for partly small subgroups.

ovulation when using a generalized additive model or a simpler model across days on the X axis d. whether excluding various participants who are potentially less likely to ovulate affects the effect size estimate e. whether the specification of the predictor matters (we will at least compare forward- vs. backward-counting, continuous predictor versus window estimation) f. whether not adjusting for menstruation matters (we predict that it does for some outcomes, e.g. in-pair sexual desire and sexual activity, self -perceived desirability) g. whether effect sizes are moderated by i. age ii. weekday iii. self -reported average cycle length iv. self -reported cycle regularity v. self- reported certainty about the details of own menstrual cycle vi. self-reported health			

Supplementary Figure S1

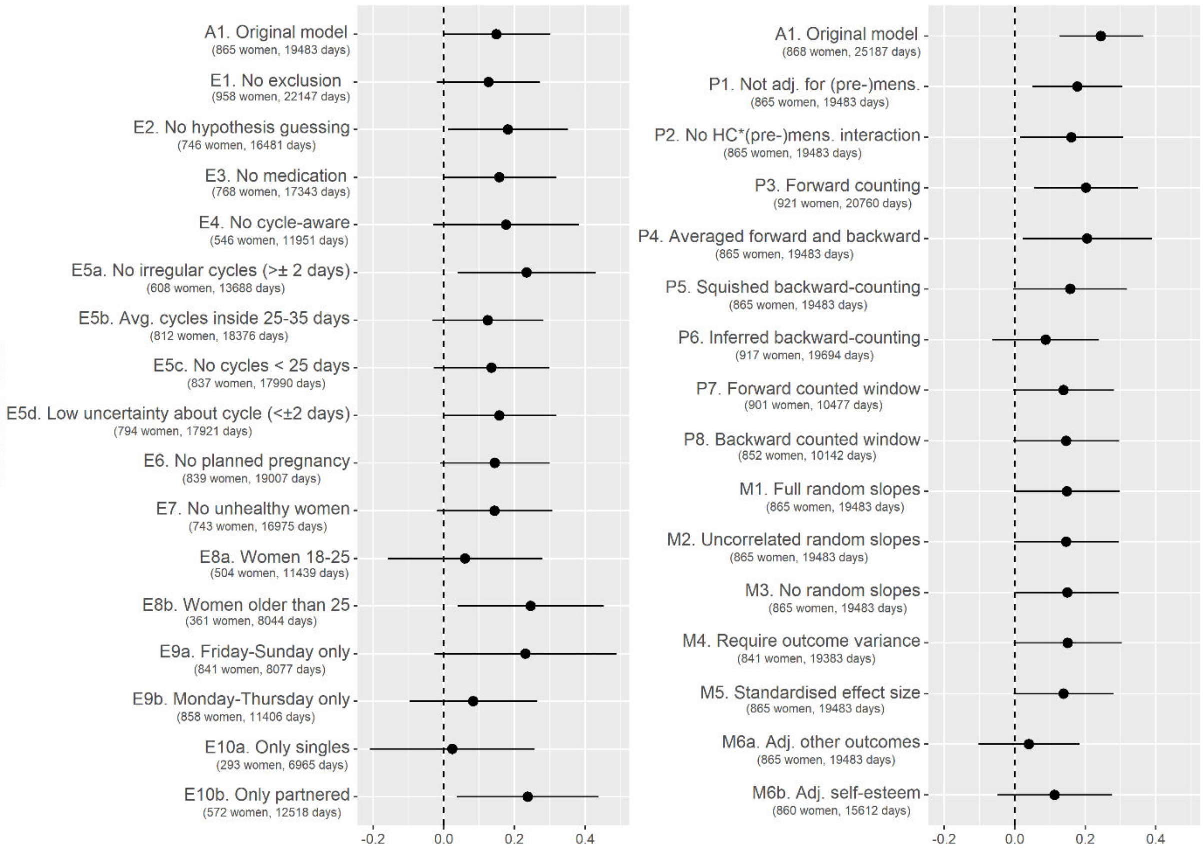
Effect of probability of being in the fertile window on sexual desirability with 99 % confidence interval



Note. A1 is the model described 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, Adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Figure S2

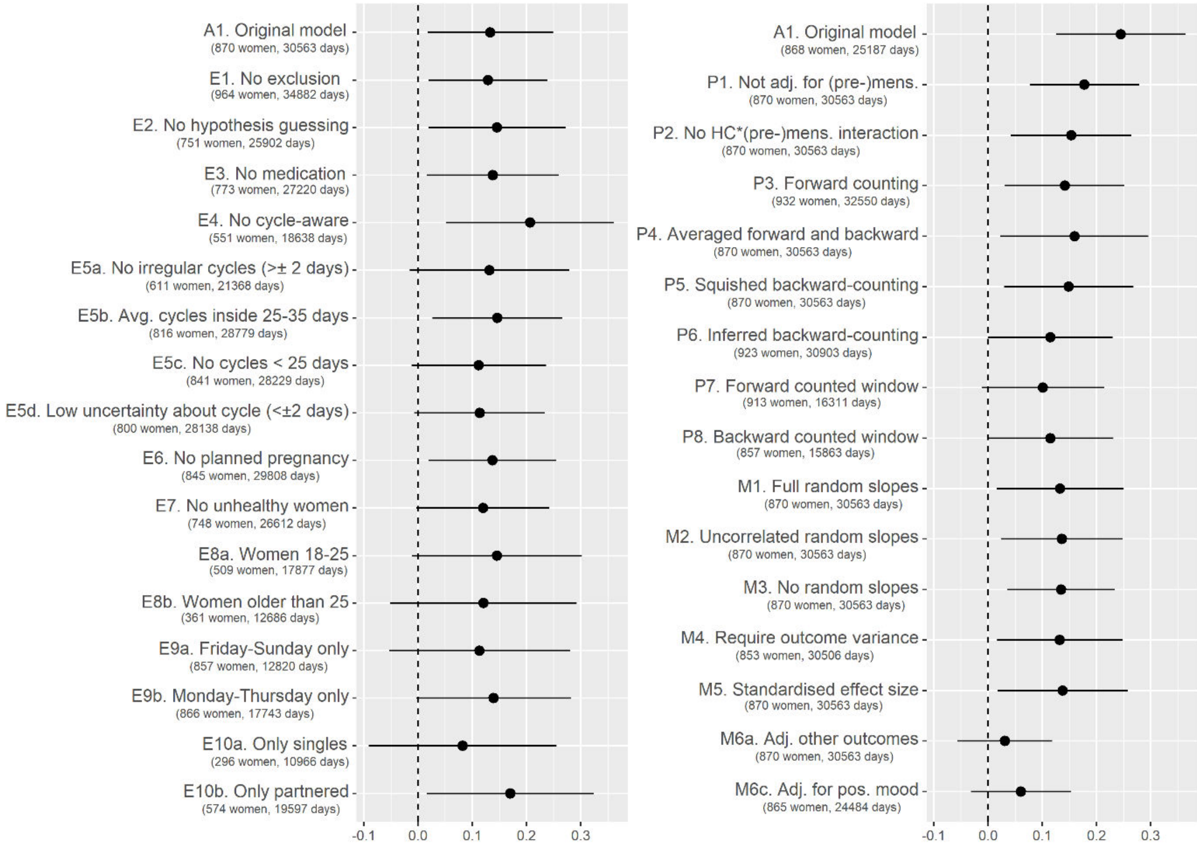
Effect of probability of being in the fertile window on self-perceived grooming with 99 % confidence interval



Note. A1 is the model described 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, Adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Figure S3

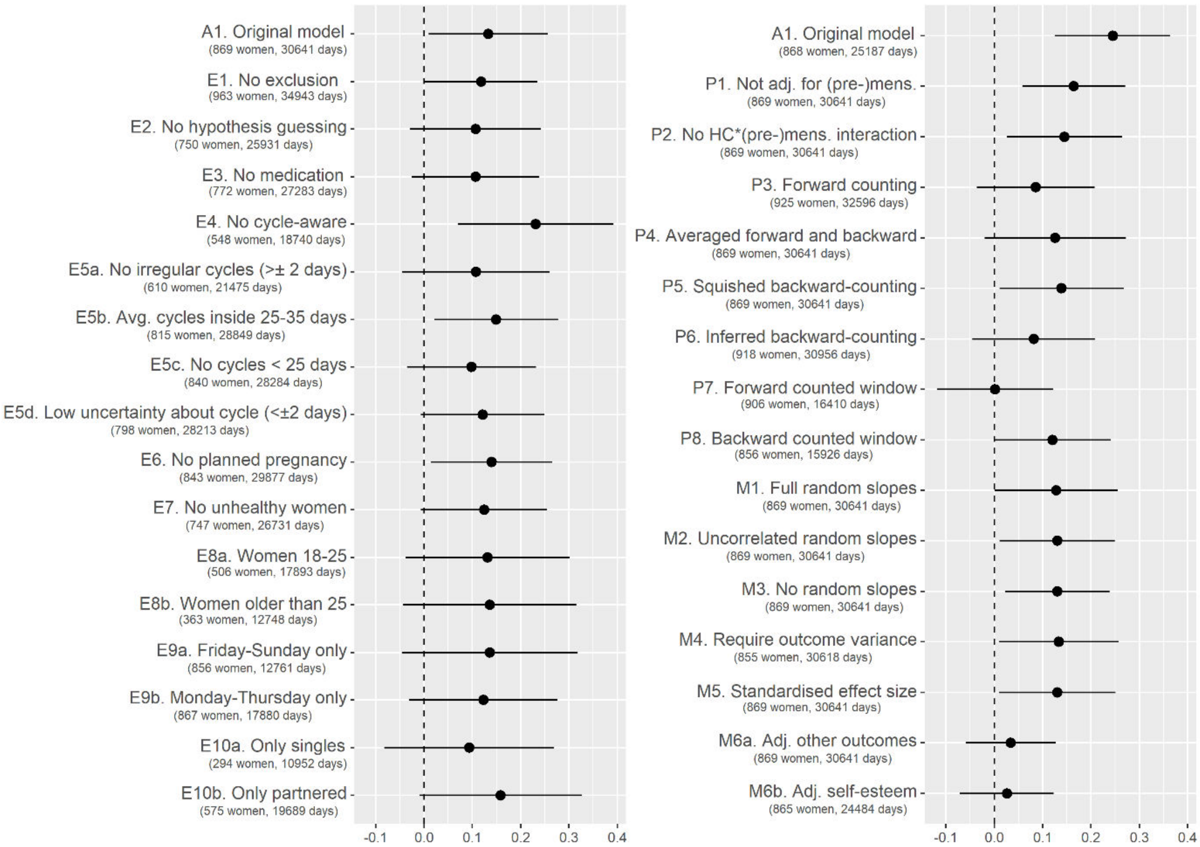
Effect of probability of being in the fertile window on self-esteem with 99 % confidence interval



Note. A1 is the model described 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, Adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Figure S4

Effect of probability of being in the fertile window on positive mood with 99 % confidence interval



Note. A1 is the model described 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, Adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

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Appendix B

Manuscript 2

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“Ovulatory cycle shifts in motivational prioritisation of sex and food”

Lara Schleifenbaum[1,2], Julia Stern[1,2,3], Julie C. Driebe[1], Larissa L. Wieczorek[4], Tanja M. Gerlach[1,2], Ruben C. Arslan[2,5,6], Lars Penke[1,2]

[1]University of Goettingen, Goettingen, Germany

[2]Leibniz ScienceCampus Primate Cognition, Goettingen, Germany

[3]University of Bremen, Bremen, Germany

[4]University of Hamburg, Hamburg, Germany

[5]University of Leipzig, Leipzig, Germany

[6]Max Planck Institute for Human Development, Berlin, Germany

Author Note

Corresponding author:

Lara Schleifenbaum, M.Sc.

Gosslerstrasse 14, 37073 Goettingen, Germany

Email: lara.schleifenbaum@uni-goettingen.de,

Phone: +49551/39-20706

ORCID iD corresponding author

Lara Schleifenbaum https://orcid.org/0000-0002-8608-1483

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Transparency and Openness

All materials including preregistration (of study design, hypotheses, data collection process and sample size, data analyses), survey files, data cleaning, analysis scripts, codebook as well as code used for data anonymisation are accessible on the Open Science Framework (not blinded link): https://osf.io/v98t2/

Due to the highly sensitive nature of our data, sharing them entails additional precautions that we are currently working on with the ZPID in Trier, Germany. We expect to have uploaded anonymised data by the beginning of October but we are glad to share data upon request of the reviewers.

Declaration of Interest

The authors declare that they have no conflicts of interest.

Ethical Standards

The authors assert that all procedures contributing to this work comply with the APA Ethical Principles.

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CRediT Author Statement

Lara Schleifenbaum: Conceptualization, Methodology, Investigation, Software, Formal Analysis, Writing – Original Draft, Visualization, Project administration **Julia Stern:** Conceptualization, Investigation, Writing – Review & Editing, **Julie C. Driebe:** Conceptualization, Validation, Writing – Review & Editing, **Larissa L. Wieczorek:** Software, Writing – Review & Editing, **Tanja M. Gerlach:** Conceptualization, Writing – Review & Editing, **Ruben C. Arslan:** Conceptualization, Methodology, Software, Validation, Writing- Review & Editing **Lars Penke:** Conceptualization, Writing – Review & Editing, Resources

Abstract

Although previous work has shown endogenous effects of ovarian hormones on motivational states in women, most research has focused on their effects on sexual motivation. A broader theoretical approach, the Motivational Priority Shifts Hypothesis, predicts that, when fertile, women exhibit increased sexual motivation that serves to facilitate reproduction but results in depleted resources for eating motivation. In a highly powered, preregistered, online diary study across 40 days, we tested whether 390 women report such an ovulatory shift in sexual and eating motivation and corresponding sexual and eating behaviour. We compared 209 naturally cycling women to 181 women taking hormonal contraceptives (HC) to infer the hormonal basis of these shifts. We found robust ovulatory decreases in food intake and increases in general sexual desire, in-pair sexual desire and initiation of dyadic sexual behaviour. While extra-pair sexual desire increased mid-cycle, the effect did not differ significantly in HC women, restricting inference of an ovulatory effect. Descriptively, solitary sexual desire and behaviour, dyadic sexual behaviour, appetite, and satiety showed expected mid-cycle changes that were diminished in HC women, but these failed to reach our strict preregistered significance level. Our results provide insight into current theoretical debates about ovulatory cycle shifts while calling for future research to determine motivational mechanisms behind ovulatory changes in food intake and considering romantic partners' motivational states to explain the occurrence of dyadic sexual behaviour.

keywords: ovulatory cycle shifts, sexual motivation, eating motivation, hormonal contraception, diary study

Introduction

Motivational states energise goal-directed behaviours (Kennedy & Shapiro, 2009; Kleinginna & Kleinginna, 1981) and consequently do not only shape, for example, our social interactions, interpersonal relationships or health (Marteau et al., 2006), but also our mating efforts and ultimately our reproductive fitness. Differences in motivational states are often thought of as a consequence of interindividual differences (motive dispositions; McClelland, 1987) or situational contexts (Rauthmann, 2016). Yet, there also exist endogenous, hormone-regulated mechanisms that affect intraindividual personality processes of motivational states and motivated behaviour. One such mechanism is the endogenous endocrine regulation of motivational states across women's ovulatory cycles (Fessler, 2003; Roney, 2016). Previous research has shown that women exhibit increased sexual motivation during the fertile phase of the ovulatory cycle (Arslan et al., 2018; Bullivant et al., 2004; Gangestad et al., 2002; Grebe et al., 2016; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016). These findings have given rise to a number of theories on so-called ovulatory cycle shifts in women's sexual motivation. Whereas most theories agree that ovulatory cycle shifts serve a reproductive function, there is an ongoing debate about the exact nature of these shifts (e.g. Gangestad et al., 2019; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Jünger, Kordsmeyer, et al., 2018; Marcinkowska, Kaminski, et al., 2018; Roney, 2019; Stern et al., 2019; Stern et al., 2020). The Motivational Priority Shifts Hypothesis (MPSH; Roney, 2016; Roney & Simmons, 2013, 2016, 2017) extends this debate by combining findings of ovulatory cycle increases in sexual motivation with decreases in eating motivation. The hypothesis states that women evolved a motivational priority of mating over somatic efforts when conception is possible. As only few studies have investigated the MPSH so far, in this study, we sought to advance the current debate by directly testing the predictions of ovulatory cycle shifts in sexual and eating motivation and corresponding behaviour.

The Influence of the Ovulatory Cycle on Women's Motivational States

Women's ovulatory cycles can be divided into the follicular phase (between menstrual onset and ovulation) and the luteal phase (after ovulation and before the next menstrual onset). As part of a complex interplay of various hormones, the transition from one phase to the other is characterised by intraindividual changes of women's levels of the steroid hormones estradiol and progesterone. Across the ovulatory cycle, women can only conceive during the so-called fertile window that marks the late part of the follicular phase and spans approximately five days before ovulation and the day of ovulation itself (Wilcox et al., 1998).

Unlike human's closest relative, the chimpanzee (Deschner et al., 2004), women do not show obvious cues that indicate their fertile window (e.g. anogenital swellings). Additionally, many other non-human primate species only engage in mating and sexual behaviour during oestrus, a phase of fertility that is typically characterised by heightened sexual proceptivity, receptivity and attractiveness (Beach, 1976). Yet, human women exhibit extended sexuality, meaning that they show sexual motivation and engage in sexual behaviour outside their fertile window across the whole ovulatory cycle (Gangestad & Thornhill, 2008; Grebe et al., 2013). These distinct features of women's sexuality led researchers to believe that women have phylogenetically lost their oestrus (e.g. Burley, 1979; Symons, 1979). However, empirical evidence is growing that women show changes during their fertile window that indicate heightened sexual proceptivity (i.e. women show increased sexual motivation and initiate more sexual behaviour; Bullivant et al., 2004), sexual receptivity (women rate male bodies as more attractive; Jünger, Kordsmeyer, et al., 2018; Stern et al., 2021) and increased attractiveness (men rate female faces as more attractive; Roberts et al., 2004). Such findings of distinct sexuality when women are fertile made researchers question the notion of a lost oestrus. Instead, Gangestad and Thornhill (2008) proposed a "dual sexuality" in women, whereby sexuality during the fertile window serves reproduction, whereas extended sexuality outside of the fertile window serves to obtain reources from the male partner and promotes pair-bond formation. Although many researchers currently agree that women's sexuality differs between fertile and non-fertile phases, the debate about the nature and function of ovulatory cycle shifts in sexual motivation is ongoing.

Debate about the Nature of Ovulatory Cycle Shifts in Sexual Motivation

Among multiple theoretical perspectives, the most prominent representatives of the current debate are the Good Genes Ovulatory Shift Hypothesis (GGOSH, Gangestad & Thornhill, 2008) that became very popular in cycle research and the more recent MPSH (Roney, 2016; Roney & Simmons, 2013, 2016, 2017). In the following, we describe both of these theories in more detail and summarise the current state of empirical evidence.

Good Genes Ovulatory Shift Hypothesis

The GGOSH (Gangestad & Thornhill, 2008) represents one of the most influential theoretical approaches towards ovulatory cycle shifts. From an evolutionary perspective, women should be motivated to seek male partners who are able and willing to invest in them and their offspring but also provide high genetic quality to increase their reproductive fitness (Buss, 1989; Buss & Schmitt, 2019; Gangestad & Simpson, 2000). Since men high in genetic quality are expected to have many mating opportunities and thus might be less willing to invest in partners, these two benefits might need to be traded off when in search of a partner. The GGOSH describes possible evolved adaptations in women to secure both high investment and genetic quality from partners. Based on the dual sexuality concept, the GGOSH proposes that varying fertility status across women's ovulatory cycles enables shifting mate preferences to serve goals related to securing either genetic benefits or resources. Accordingly, women can maximise their reproductive fitness by mating with men with good genes when fertile while securing support from a long-term mate with possibly lower genetic quality but higher resource investment when outside the fertile window. Consequently, during the fertile window, women should prefer men with features that indicate genetic quality. Suggested indicators for genetic quality are, for example, masculine faces and bodies, dominant behaviour and facial and bodily symmetry, often summarised in short-term partner attractiveness (Gangestad & Thornhill, 2008). According to the GGOSH, this ovulatory mate preference shift should be most pronounced in short-term mating contexts and largely translate into increased sexual motivation for men other than women's primary partner (extra-pair sexual desire) as opposed to sexual motivation for her primary partner (in-pair sexual desire).

Evidence for the Good Genes Ovulatory Shift Hypothesis

A wide range of studies has provided empirical support for ovulatory mate preference shifts in the past (for a meta-analytic review, see Gildersleeve et al., 2014) and some report ovulatory increases in target-specific extra-pair sexual desire (Gangestad et al., 2002; Grebe et al., 2016). However, there exist both theoretical and empirical considerations that cast doubt on the validity of the GGOSH. Regarding theoretical considerations, there are alternative hypotheses that might explain the proclaimed shifts in mate preferences and target-specific sexual motivation. For example, the mate switching hypothesis (Buss et al., 2017) states that ovulatory changes in extra-pair sexual desire function to ensure a back-up mate and to possibly attain a more desirable partner. Other researchers have proposed that hormonal effects on women's mate preferences are rather a by-product of between-women differences without a specific function (Havliček et al., 2015). Such reported between-women effects on mate preferences might explain previous findings in favour of the GGOSH that could in fact follow a false attribution of between-women to ovulatory within-women effects. Other theoretical considerations further doubt the existence of mate preference shifts since the supposed indicators of genetic quality are questionable (Arslan & Penke, 2015; Buss & Schmitt, 2019; Lee et al., 2014; Lidborg et al., 2021; Nowak et al., 2018) and rates of cuckoldry in human populations are mostly low at around 1% (Anderson, 2006; Wolf et al., 2012). Moreover, a mating strategy partly built upon extra-pair mating runs the risk of triggering male sexual jealousy that threatens a woman's own health and both her survival and that of her offspring (Buss & Duntley, 2011; Daly et al., 1982). Regarding empirical evidence, a growing body of research fails to support the predictions of the GGOSH. Contradicting the meta-analysis by Gildersleeve et al. (2014), a meta-analysis by Wood et al. (2014) using mostly overlapping studies found no compelling evidence for shifting mate preferences across the cycle. In line with this finding, multiple recent studies that investigated preference shifts for masculine faces, bodies, voices or dominant behaviours failed to detect ovulatory shifts in women's mate preferences (Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Jones, Hahn, Fisher, Wang, Kandrik, Han, et al., 2018; Jünger, Kordsmeyer, et al., 2018; Jünger, Motta-Mena, et al., 2018; Marcinkowska, Galbarczyk, & Jasieńska, 2018; Marcinkowska, Kaminski, et al., 2018; Stern et al., 2020; Stern et al., 2021; van Stein et al., 2019).

One likely explanation for these incongruities is that many early studies suffered from methodological shortcomings that reduced their informational value. Early research often used small samples, between-subject designs, investigated many outcomes, lacked a gold standard for fertility estimation, and took no measures to constrain researcher degrees of freedom, such as preregistration or cross-validation (Arslan et al., 2018; Harris et al., 2014). These practices can inflate false positive findings and artificially increase effect sizes (Harris et al., 2014). This problem is aggravated by studies that apply between-subject designs to the within-subject effects of ovulatory changes since these designs have especially low statistical power. Moreover, there are various methods of estimating women's fertility that differ in their validity. Based on simulation studies, Gangestad et al. (2016) recommended abandoning operationalising fertility as a discrete window that yielded unreliable estimates and instead use a continuous probability of being in the fertile window. In addition, Harris et al. (2014) recommended that new studies be preregistered.

Recent studies that address some of these methodological shortcomings provide less empirical evidence for ovulatory mate preference shifts or ovulatory increases in sexual motivation for specific men. Instead, they report ovulatory shifts in women's general attraction to men and their general sexual motivation (Arslan et al., 2018; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016; Shirazi, Jones, et al., 2019; Stern et al., 2020). For example, Arslan et al. (2018) carried out a preregistered and highly powered online diary study across 40 days analysing over 26,000 diary entries from 1,054 women. Since women who take hormonal contraceptives do not experience hormonal fluctuations that lead to a fertile window (Fleischman et al., 2010), Arslan et al. (2018) employed a quasi-control group design that compared women taking hormonal contraceptives (625 women) to naturally cycling women (429 women). They found ovulatory increases in sexual motivation for naturally cycling women which were diminished in women taking hormonal contraceptives. Contrary to the predictions of GGOSH, women showed both increased in-pair sexual desire as well as increased extra-pair sexual desire. These results were supported by multiple robustness analyses, for example, by comparing different estimates to gauge women's fertility. The finding that women taking hormonal contraceptives did not show ovulatory increases in sexual motivation strengthens the claim that these shifts are related to changes in ovarian hormones across the natural ovulatory cycle. Yet, while these findings of ovulatory increases in general sexual motivation receive growing support as cited above, they cannot be fully explained by the GGOSH. In addition, a recent correction concluded that the data of Arslan et al. (2018) can neither support nor rule out moderation effects of partner attractiveness for women's sexual motivation as predicted by the GGOSH, yielding rather mixed and uncertain evidence (Arslan et al., 2021; Gangestad & Dinh, 2021).

The Motivational Priority Shifts Hypothesis

One alternative hypothesis that can explain recent findings is the MPSH. The MPSH combines ovulatory shifts in sexual motivation with a corresponding trade-off in eating motivation. These motivational trade-offs are informed by life history theory (e.g. Hill, 1993). Hormone-regulated prioritisations of mating and somatic efforts exist in a multitude of species (e.g. reptiles, birds and mammals, see Schneider et al., 2013 for a review). The MPSH extends these findings to humans and states that in a world with limited resources, ovarian hormones facilitate an adaptive motivational trade-off of mating and somatic efforts that depends on their respective cost-benefit-ratios.

According to the MPSH, while mating effort (e.g. seeking and courting a partner, sexual behaviour) can yield a direct reproductive fitness benefit, it also carries certain costs (e.g. spent resources, risk of injury, risk of infection and opportunity costs with regard to other activities e.g. foraging and feeding). Consequently, women should show endogenous increases in sexual motivation during the fertile window when conception is possible and potential fitness benefits of sexual behaviour outweigh its costs. Concurrently, somatic efforts (incl. foraging and eating motivation and behaviour) should be decreased during the fertile window, as they incur opportunity costs. After ovulation, when women can no longer conceive, resources are expected to be re-prioritised and re-allocated towards somatic investment during the non-fertile luteal phase. Thus, women can invest into foraging and food intake, thereby securing their survival and enabling future reproductive opportunities. Importantly, the MPSH does not claim that sexual motivation and behaviour occur only when women are fertile. Similar to the concept of dual sexuality introduced by Gangestad and Thornhill (2008), the MPSH acknowledges external factors such as social and relationship aspects that enable extended sexuality to promote formation and maintenance of long-term bonds in humans. Instead, the MPSH assumes that besides external factors, hormonal regulations of women's sexual motivation are particularly relevant during the fertile window. As outlined in the following, there are multiple studies that provide support for the predictions of the MPSH on ovulatory changes in sexual and eating motivation and corresponding behaviour.

Evidence for the Motivational Priority Shifts Hypothesis

The aforementioned studies showing a robust ovulatory increase in general sexual motivation in women provide strong support for the MPSH (Arslan et al., 2018; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2013, 2016; Shirazi, Jones, et al., 2019; Stern et al., 2020). Moreover, several studies report ovulatory increases in dyadic (Bullivant et al., 2004; Caruso et al., 2014; Harvey, 1987; van Goozen et al., 1997; Wilcox et al., 2004), female-initiated (Adams et al., 1978; Bullivant et al., 2004; Gangestad et al., 2002; Harvey, 1987), and solitary sexual behaviour (Brown et al., 2011; Burleson et al., 2002; van Goozen et al., 1997). Yet, other studies failed to detect ovulatory changes in sexual behaviour (Brewis & Meyer, 2005; Elaut et al., 2016; Roney & Simmons, 2013). Reasons behind these mixed results are likely methodological differences between studies such as assessment of ovulation (Brown et al., 2011) and statistical power. However, these studies could also point to the relevance of external factors that affect sexual behaviour. Dyadic sexual motivation and behaviour, in particular, are not only influenced by hormones but are affected by relationship dynamics (Caruso et al., 2014; Roney & Simmons, 2016) such as emotional intimacy (Basson, 2001), and are limited by partner availability (Arslan et al., 2018) and free time (e.g. increased self-reported sexual motivation and behaviour on weekends compared to weekdays; Roney & Simmons, 2013).

Studies that focus on changes in women's eating motivation and behaviour provide support for a second prediction of the MPSH. In a review, Fessler (2003) summed up empirical evidence that women show an ovulatory nadir in food intake. Based on animal models, he suggests that this nadir follows a hormone-regulated decrease in satiation thresholds. He further relates this ovulatory nadir in food intake to increased investment in mating activities seen in other non-human primates such as increased locomotion as part of mate-seeking in chimpanzees, baboons, and macaques. Importantly, Fessler argues that a decrease in food intake is unrelated to energy expenditure because it occurs at a time of increased energy demands of the growing endometrium. In line with the notion that other factors than energy expenditure affect women's cyclical eating motivation, the ovulatory decrease in food intake is even more pronounced in sexually active compared to sexually inactive women (Fleischman & Fessler, 2007). Supporting a post-ovulatory shift towards somatic investment as proclaimed by the MPSH, women report increased food intake, appetite and food cravings in their luteal phases, especially of highly caloric, protein-rich and sweet food (Asarian & Geary, 2006; Barr et al., 1995; Gorczyca et al., 2016; Pliner & Fleming, 1983). These changes might follow heightened food cue reactivity in the brain (Strahler et al., 2020) and also translate into corresponding weight gain of women during the luteal phase (Kammoun et al., 2017; Pliner & Fleming, 1983). Thus, there is empirical evidence of both sexual and eating related changes across the ovulatory cycle from different lines of research that only the MPSH connects into a more holistic understanding of the nature of ovulatory cycle shifts.

Although previous research provides empirical evidence for the MPSH, most previous studies have investigated ovulatory cycle shifts in either sexual or eating motivation and corresponding behaviour individually. As the MPSH proclaims a trade-off of both motivations, however, it is crucial to test the existence of these ovulatory changes concurrently in the same sample. To our knowledge, this trade-off has only been tested in the same sample using 43 women so far (Roney & Simmons, 2013, 2017). In addition, the methodological shortcomings described above hold in this literature too. Hence, it remains unclear whether the expected patterns can be found in a larger sample, with a preregistered analysis plan, and whether results are robust across different analytical decisions.

Aims of the Current Study

In this study, we tested the predictions of the MPSH of ovulatory changes in sexual and eating motivation and thereby sought to advance the current debate about ovulatory cycle shifts in five important ways: First, in order to investigate the possibility of a trade-off between both motivational states, we assessed sexual and eating motivation simultaneously. Second, to address previous methodological shortcomings, we conducted a highly powered, within-subject diary study for which we preregistered our hypotheses, study materials, variable transformations and statistical analyses. Third, 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, and different model specifications. Fourth, we implemented exploratory analyses on the separate components of in-pair and extra-pair sexual desire to uncover which components might account most for respective ovulatory changes. Finally, we implemented a smallest effect size of interest (SESOI, Lakens, 2014) to gauge the practical relevance of ovulatory cycle shifts. In order to enable a high sample size, we used backward counting from the next observed onset of menstrual bleedings to determine the day of ovulation as a valid method to assess women's probability of being fertile (Gangestad et al., 2016). Additionally, we compared naturally cycling women (NC women) to the quasi-control group of women taking hormonal contraceptives (HC women) to infer the hormonal basis of ovulatory cycle shifts.

Assuming that endogenous signals lead to increases in broad motivational states as proclaimed by the MPSH, we expected ovulatory increases in general sexual desire (H1), solitary sexual desire

(desire to masturbate, H2), and ovulatory increases in both in-pair sexual desire (H3) and extra-pair sexual desire (H4) as opposed to effects only for extra-pair sexual desire expected according to the GGOSH[1]. Following the functional properties of motivational states (Zygar et al., 2018), we expected concurrent behavioural changes of ovulatory increases in dyadic sexual behaviour (H5), solitary sexual behaviour (masturbation frequency, H6), and female initiation of dyadic sexual behaviour (H7). Addressing the adaptive trade-off with eating motivation, we extended previous constructs of eating motivation and predicted ovulatory decreases in appetite (H8), corresponding to an ovulatory increase in satiety (H9), and an ovulatory decrease in self-reported food intake[2] (H10). We expected these to be higher in NC women compared to baseline changes in our quasi-control group HC women.

Methods

We conducted a large-scale, preregistered online diary study to properly account for the within-subject effects of ovulatory cycle shifts (Schmalenberger et al., 2021). This observational study was implemented using the online survey framework formr.org (Arslan, Walther, & Tata, 2020) that 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). For this study, we analysed data of women who took part in the [name blinded for peer review] that assessed romantic couples in heterosexual relationships. All material including preregistration, survey files, data cleaning and processing, codebooks and analysis codes are accessible in the respective files of our online supplement (https://osf.io/v98t2/?view_only=0476215ef6c44a46bd4a3212e517143f). All necessary data were anonymised and can be accessed online [link will be inserted during review process] after consenting to restrictive scientific use due to the sensitive nature of these data.

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[1] In order to sharpen the focus of the paper, we omitted one preregistered hypothesis concerning ovulatory increases in self-perceived desirability, but for transparency, we conducted and report preregistered analyses in our online supplement.

[2] Due to an unfortunate copy-paste error, one of our central hypotheses that food intake decreases for naturally cycling women when they are fertile, is missing in the final version of our preregistration. As can be seen by reading the short theoretical introduction in the respective preregistration, we clearly phrased our goal of investigating ovulatory changes in direct food intake as one central outcome. Thus, we hope it becomes clear and believable that food intake was meant to be included among the preregistered outcomes.

Sample Size Rationale and Recruitment

We based our targeted sample size on a-priori power simulations (https://rubenarslan.github.io/ovulatory_shifts/1_power_analysis.html). These showed that for an unstandardised effect size of .2 reported before (Arslan et al., 2018), a statistical power of 99% can be achieved with 150 naturally cycling women across 30 diary days and an alpha rate of .01. However, because these power analyses did not include random slopes or behavioural outcomes, we used this 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 (the latter are unrelated to the current study).

We recruited romantic couples from October 2019 until April 2020 via different strategies, such as distributing posters and flyers locally, using digital media (contacting mailing lists of German university students, posting advertisements on Facebook and on the study platform psytests.de), inviting participants who had taken part in similar studies before, and by referring to the study in other media. 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.

Exclusion Criteria and Participants

Since we were interested in ovulatory 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. Of the total of $N = 615$ women who started the study, following our preregistration, we excluded those who were likely not experiencing ovulation, i.e. because of pregnancy, breast-feeding, or menopause ($n = 29$). Additionally, we excluded women who reported that they or their partners were infertile or sterilised ($n = 11$). We excluded women who switched to or from hormonal contraceptives during the study ($n = 11$) and who reported other irregular contraception such as morning-after pill use ($n = 14$). We also excluded women without any diary entries ($n = 39$), without data on menstrual bleedings (women who declined having a menstrual bleeding “sometimes or regularly”, $n = 62$), and women for which data were not sufficient to estimate fertility ($n = 47$). 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. Women without any such usable diary entry were excluded completely (n

= 9). Adding to our preregistered exclusion criteria but in line with our research plan, we excluded women whose ovulatory cycle might have been affected by taking steroid hormones besides hormonal contraceptives (*n* = 3). A detailed participant flow showing the first of possibly multiple exclusion criteria is provided in the online supplement (file 3_desciptive analyses, Figure S4). Robustness analyses including different exclusion criteria are described below.

Our final sample consisted of *n* = 390 women (54% naturally cycling) who filled out 12,996 analysable diary entries with on average *M* = 33.17 (*SD* = 9.47) diary entries per person. Women were on average, *M* = 23.7 years old (*SD* = 4.2, range 18-47), they first had sexual intercourse at the age of *M* = 16.9 (*SD* = 2.7), and they had *M* = 5.09 (*SD* = 6.90) lifetime sexual partners. Most women were students (80%) with on average *M* = 14.5 years of education (*SD* = 4.2). The vast majority of women were in a committed relationship with one partner (94.36%), had no children (96%) and had been, on average, in a relationship for *M* = 3.1 (*SD* =3.0) years. Spanning the time from the menstrual onset reported in the demographic survey until the menstruation follow-up, we collected data of menstrual bleedings of on average *M* = 2.26 (*SD* = 0.58) number of cycles. The mean observed cycle length across the study was *M* = 29.04 days (*SD* = 2.86). Details on the different contraception methods of HC and NC women can be accessed in the online supplement (file 3_descriptive_analyses).

Comparing demographic data of HC and NC women, on average, HC women were significantly younger ($t(375.18) = 4.59$, $p < .001$), had a shorter relationship duration ($t(386.1) = 3.03$, $p = .003$), and had fewer lifetime sexual partners ($t(373.64) = 2.15$, $p = .032$). HC women also had shorter cycle lengths ($t(341.92) = 5.66$, $p < .001$) which might be a consequence of hormonal contraceptive use. As a possible self-selection factor, HC women were more conscientious ($t(385.26) = -3.09$, $p = .002$) as measured with the Big Five Inventory (Rammstedt & John, 2005). When predicting hormonal contraceptive use by including the demographic variables depicted in Table 1 (except for average cycle length) in a probit regression, age and conscientiousness emerged as significant predictors ($p <.05$). These results resemble those of a detailed investigation of selection effects on hormonal contraceptive use (Botzet et al., 2021).

Table 1

Descriptive statistics according to hormonal contraceptive use

	Mean (Standard deviation)			
Variable	**HC women**	**NC women**	**Hedges'g**	***p***
Age	22.71 (3.35)	24.59 (4.69)	-.40	< .001
Age at first time	16.97 (2.82)	16.79 (2.68)	.07	.524
Years of education	14.15 (3.95)	14.83 (4.47)	-.15	.113
Religiosity (0-5)	2.17 (1.27)	2.25 (1.33)	-.07	.506
Relationship duration (years)	2.61 (2.61)	3.51 (3.24)	-.28	.003
Relationship satisfaction	4.75 (0.59)	4.73 (0.63)	.04	.715
Average cycle length (days)	27.82 (2.17)	29.55 (3.73)	-.46	< .001
Number sexual partners	4.30 (5.54)	5.77 (7.84)	-.19	.032
BFI-Openness (0-5)	4.06 (0.68)	4.17 (0.64)	-.16	.121
BFI-Conscientiousness (0-5)	3.90 (0.68)	3.68 (0.73)	.30	.002
BFI-Extraversion (0-5)	3.74 (0.82)	3.61 (0.81)	.16	.107
BFI-Agreeableness (0-5)	3.20 (0.87)	3.07 (0.83)	.16	.124
BFI-Neuroticism (0-5)	3.34 (0.89)	3.41 (0.87)	-.08	.449

Note. NC = naturally cycling women, HC = women using hormonal contraceptives, BFI = Big Five Inventory. Variables are printed in bold if they remained significant after multivariate adjustment in a probit regression.

Procedure

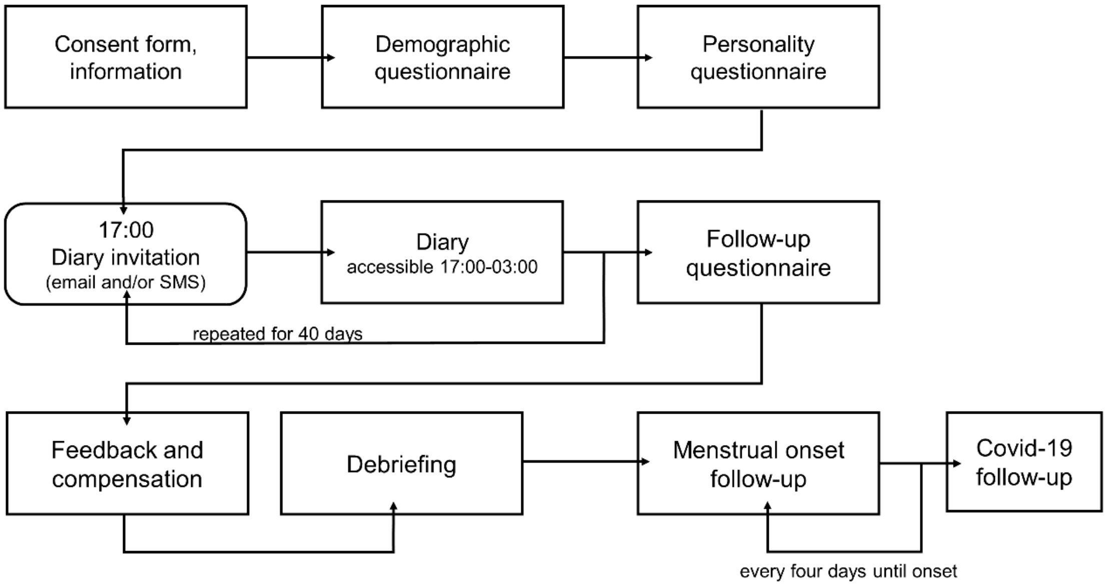
Following the study link, participants received detailed information about the study entitled "[name blinded for peer review] Couple's Study". The study was introduced as a dyadic quiz investigating emotions and needs in romantic relationships and how well romantic partners perceived these in everyday life. After having provided their informed consent, participants answered a demographic presurvey where we assessed general information such as age, gender and educational status. Women also provided information about their menstrual cycles and contraception methods and completed the Big Five Inventory (Rammstedt & John, 2005). All personal and identifying data such as email addresses and mobile phone numbers were collected and stored separately using formr features to further guarantee anonymity.

After the presurvey, the diary part of the study began on the next day. The diary encompassed 40 consecutive days and assessed women's sexual and eating motivation and behaviour, information about women's menstrual bleedings as well as daily self- and partner-ratings of well-being, health, stress and relaxation 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 women to answer diary entries by referring to 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 women to answer the diary referring to the time spanning the previous 24 hours. That way we sought to cover the period of the diary continuously for women 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 to address possible measurement reactivity biases (Arslan, Reitz, et al., 2020).

After the diary, women took part in three consecutive follow-up surveys. First, one day after the last diary entry, we asked them to answer a general follow-up survey assessing, for example, illness and (hormonal) medication use, changes in contraceptive methods, and whether they guessed the study's focus on the ovulatory cycle. Afterwards, women 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. Women were fully debriefed once both partners had answered the follow-up surveys. Second, women who had not indicated an onset of menstrual bleedings within the last five days of the diary were then directed to a menstruation follow-up. Every four days, we asked women to report the date of their next onset of menstrual bleedings until they indicated a new onset. Third, due to the COVID-19 pandemic, we launched an additional COVID-19 follow-up survey in April 2020. As the final survey, we asked women 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 is given in Figure 1.

Figure 1

Overview of the study design of the [name blinded for peer review]



Note. The diary spanned 40 consecutive days with one daily measurement.

Measurements and Variable Transformations

Measurements

Due to the high number of daily questions, we sought to ease the strain of participation in order to achieve a high participation rate. That is why we mostly used single-item measures, preferably those of [name blinded for peer review] to increase comparability where possible. Yet, as the comparison of in-pair and extra-pair sexual desire is one focus of the ongoing debate in ovulatory cycle research, we sought to use multiple items with different desire components for both outcomes. Consequently, based on Haselton and Gangestad (2006) and Arslan, Driebe, et al. (2020), we used four items of extra-pair sexual desire regarding sexual fantasies, sexual attraction and interest in sexual behaviour that could be easily parallelised for in-pair sexual desire as well. We computed the generalisability of within-subject change aggregated across items (Shrout & Lane, 2012) using the psych (Revelle, 2021) and codebook (Arslan, 2019) packages. The main outcome measurements of the diary part of this study and their reliabilities are documented in Table 2.

Estimating Women's Fertile window

Following the recommendations of Gangestad et al. (2016), we operationalised the fertile window as a continuous estimator of fertility, i.e. the probability of being in the fertile window (PBFW). As the basis for PBFW, we estimated women's day of ovulation by backward counting 15 days from the next observed onset of menstrual bleedings. Such a combination of backward counting of known cycle lengths with a continuous estimator of fertility displays high accuracy with a validity of estimating fertility as high as ~.70 (Gangestad et al., 2016).

We collected information on menstrual bleedings continuously throughout all study parts. In the demographic presurvey and during the diary, we asked women to enter the exact dates of onsets and offsets of their menstrual bleedings. Thus, information on menstrual bleedings could be collected even if women skipped diary entries in-between. At the end of the diary, those women who had not reported menstrual bleedings 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 bleedings after the diary and could use backward counting to assess the day of ovulation for all diary days.

Adhering to the procedure of Gangestad et al. (2016), we applied the continuous estimates reported by Stirnemann et al. (2013) to compute PBFW. Unlike Gangestad et al. (2016), however, we did not standardise women's observed cycle length to a 29-day cycle for our main analyses. Since ovulatory cycles naturally show considerable inter- and intraindividual variation (Bull et al., 2019), we found no compelling reason for such a standardisation. Yet, we included such a squished estimator in our robustness analyses described below where we gauged the impact of different researcher degrees of freedom on result patterns. Parallel to the study conducted by Arslan, Schilling, et al. (2018), however, we controlled for grave cycle irregularities by only considering cycles that were between 20 and 40 days long. Additionally, we did not count further back than 40 days from the next onset of menstrual bleedings. Yet, using a continuous fertility estimator results in including days of the premenstrual phase and menstruation as well that 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.

Table 2

Main measurements in the diary part of the study

Construct	Item (English Translation)	Response Format	Rcn
Onset of menstrual bleedings	After having indicated to have had menstrual bleedings since the last diary entry: "The first day of menstruation was on... "	Date entered	-
General sexual desire	"I was interested in sexual behaviour."	5-point Likert scale "not at all" – "very much"	.86
Solitary sexual desire	"I was interested in masturbating."	5-point Likert scale "not at all" – "very much"	.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"	.76
Extra-pair sexual desire	"I had fantasies about sex with another man." "I had fantasies about being intimate with another man." "I felt sexually attracted to another man". "I was interested in being sexually active with another man."	5-point Likert scale "not at all" – "very much"	.78
Dyadic sexual behaviour	After having indicated to have been sexually active: "I was sexually active with my partner (e.g. petting, oral, anal, sexual intercourse, ...) this many times:"	Number entered	-
Solitary sexual behaviour	After having indicated to have been sexually active: "I masturbated this many times:"	Number entered	-
Initiation of dyadic sexual behaviour	"I initiated sexual activity with my partner."	5-point Likert scale "not at all" – "very much"	.87
Appetite	"I felt like eating."	5-point Likert scale "not at all" – "very much"	.86
Satiety	"I quickly felt full whilst eating."	5-point Likert scale "not at all" – "very much"	.86
Food intake	"I ate a lot."	5-point Likert scale "not at all" – "very much"	.87

Note. Rcn = Reliability of change or generalisability of within person variations averaged over items. Since we assessed count data for dyadic and solitary sexual behaviour, we did not compute a reliability of change for these outcomes. Instead, we provide details on respective frequencies in the online supplement (file 3_descriptive_analyses).

Analyses

We preregistered general mixed effects models using a Gaussian error distribution for all of our outcomes. We adhered to this preregistered analysis protocol with one minor exception: For the count variables dyadic and solitary sexual behaviour, data indicated that the most appropriate analysis method is applying generalised mixed effects models using a Poisson error distribution (Coxe et al., 2009).

Consequently, for both outcomes, we chose the most appropriate way of analysis instead of our preregistered one, but report the preregistered analyses in our robustness checks (results were virtually identical).

For all models, the main predictor was PBFW by backward counting from the next observed menstrual onset. In order to control for the premenstrual phase and menstruation that might affect our outcomes independently, we added these as predictors to our models. We implemented hormonal contraceptive users as quasi-control group to distinguish changes related to ovulation from other mid-cycle changes. We added hormonal contraceptive use as a dummy variable (set to zero for NC women) interacting with all predictors to properly apply interaction controls (Rohrer & Arslan, 2021). We included random intercepts, random slopes and their correlation for PBFW, premenstrual phase and menstruation to account for interindividual variation between women and the repeated measurement of our outcome variables. In Wilkinson notation (Wilkinson & Rogers, 1973), our main models were specified as follows:

*outcome ~ (PBFW + premenstrual_phase + menstruation) * no_hormonal_contraception + (1 + PBFW + premenstrual_phase + menstruation| woman)*

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 .01 with two-tailed statistical testing. Additionally, we sought to extend the current debate about ovulatory cycle shifts 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 effects of PBFW for Likert-scaled outcomes. Since neither theoretical approach to ovulatory cycle shifts we based this study on makes any predictions about effect sizes, we adopted the conventional SESOI of .10 and an established 90% confidence interval as 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 .1, but its confidence interval includes the SESOI, the respective hypothesis can neither be accepted nor discarded. Consequently, we are only confident in the existence of a relevant ovulatory cycle shift if the following three conditions are fulfilled 1) PBFW shows a significant influence of fertility on our preregistered alpha rate of .01 and a corresponding 99% confidence interval, 2) the interaction of PBFW and hormonal contraception is significantly in the opposite direction (effect of PBFW not present for HC women), and 3) the 90% confidence interval lower-bound on the effect size of PBFW is at least .1. 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) and lmerTest (Kuznetsova et al., 2017). All analysis code is documented and can be downloaded from our online supplement (file 4_main_analyses).

Results

To facilitate comprehensibility, we summarise the main results for all hypotheses in the relevant sections but provide full tables in our online supplement (file 4_main_analyses). Since we preregistered comparing unstandardised estimates to the SESOI, we report and base our conclusions on unstandardised estimates. We provide standardised estimates in parentheses and in the online supplement except for dyadic and solitary sexual behaviour, where standardisation would disrupt the non-negative integer nature of these data. As explained in the 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.

Ovulatory Shifts in Sexual Motivation

In order to investigate possible ovulatory shifts in sexual motivation, we ran general mixed effects models predicting our different sexual motivation outcomes from women's PBFW. The main results are shown in Table 3. Regarding associations of our main predictor PBFW, we found small to medium significant ovulatory increases in general sexual desire, in-pair sexual desire and extra-pair sexual desire. Although PBFW was positively associated with solitary sexual desire and was below a classical significance threshold of .05, the effect did not reach our preregistered alpha rate of .01. Considering the interaction of PBFW with hormonal contraceptive use that compares the effect of PBFW between NC and HC women, descriptively, HC women showed effect sizes that were in the opposite direction to NC women for all outcomes. However, this difference in the effect of PBFW between NC and HC women only became significant for general sexual desire and in-pair sexual desire.

Comparing the effect size of PBFW to the SESOI, all effect sizes were above .10 in absolute value. Yet, considering their 90% confidence intervals, lower limits of extra-pair sexual desire (90% CI [.04, .19]) fell below the SESOI. Only confidence intervals of PBFW for general sexual desire (90% CI [.30, .71]) and in-pair sexual desire (90% CI [.23, .53]) met or exceeded the SESOI. Accordingly, naturally cycling women who were more likely to be in their fertile window reported higher general and in-pair sexual desire. Higher PBFW was also related to intraindividual increases in extra-pair sexual desire, but these associations were less clear. When plotting a smoothed spline across backward counted cycle days, all outcomes showed small to moderate mid-cycle increases as depicted in Figure 2.

Additionally, in a set of exploratory analyses, we investigated the effect of PBFW on single items of in-pair and extra-pair sexual desire individually (see Table 2 for the single items). All models and results described below can be accessed in the online supplement (file 4_main_analyses) under the header "Exploratory Analyses". For in-pair sexual desire, the effect of PBFW was highest for women's interest in sexual behaviour (b = .51, 99% CI [.20, .82], p < .001, β = .35) and her fantasies about sexual behaviour with her own partner (b = .43, 99% CI [.15, .71], p < .001, β = .30). Effects of PBFW were smaller for women's sexual attraction to her partner (b = .25, 99% CI [-.01, .52], p = .015, β = .19) and her fantasies about being intimate with him (b = .29, 99% CI [.01, .57], p = .009, β = .19). For extra-pair sexual desire, effect sizes were overall smaller than for in-pair sexual desire. Additionally, cycle shifts in women's interest in sexual behaviour (b = .09, 99% CI [-.03, .21], p = .053, β = .15) and her fantasies about sexual behaviour with another man (other than her partner) (b = .08, 99% CI [-.07, .23], p = .158, β = .12) were comparably lower than her sexual attraction to other men (b = .14, 99% CI [.00, .27], p = .008, β = .20) and her fantasies about being intimate with another man (b = .14, 99% CI [-.01, .30], p = .019, β = .19). Thus, descriptively, ovulatory increases in women's in-pair sexual desire are best characterised by interest in sexual behaviour with their partners, whereas changes in extra-pair sexual desire, which are generally smaller than in-pair sexual desire changes, are descriptively best characterised by an attraction to other men.

Table 3

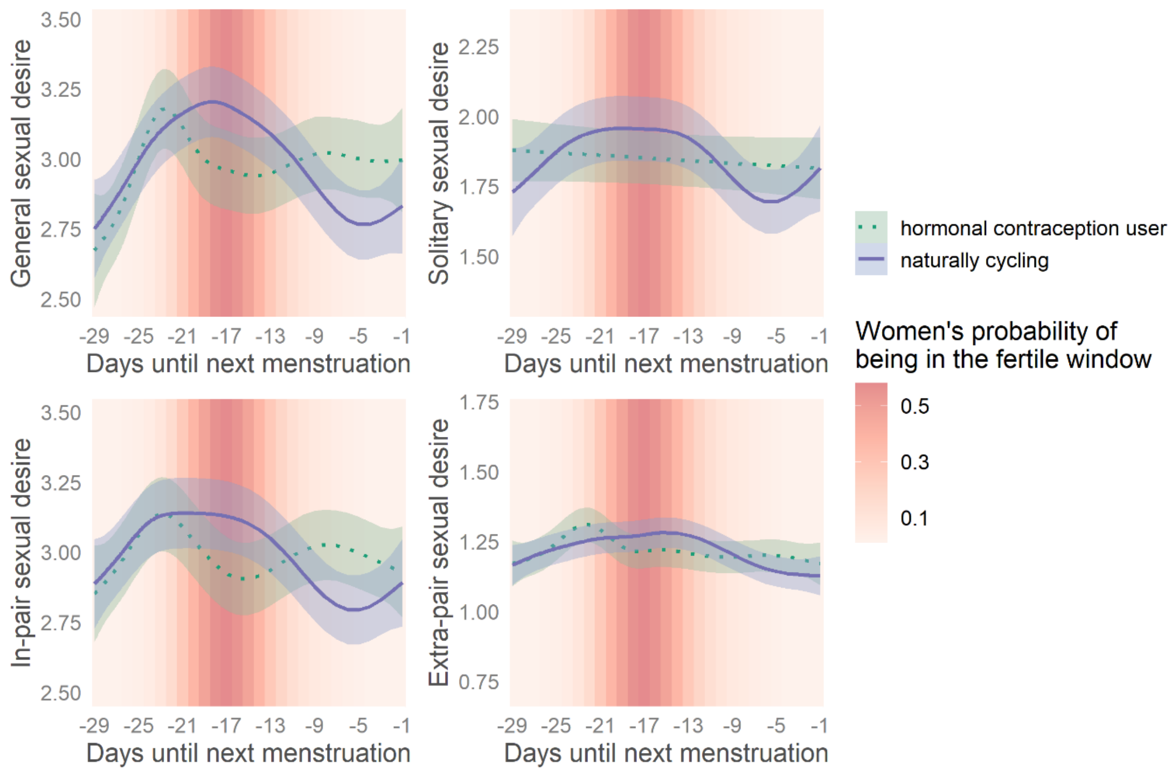
Overview of preregistered analyses of women's self-reported sexual motivation

	PBFW			HC			PBFW*HC		
Outcomes	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.),*	*99% CI*	*p*
General sexual desire	.51 (.36)	.19, .82	<.001	.41 (.30)	.18, .64	<.001	-.73 (-.52)	-1.2, -.26	<.001
Solitary sexual desire	.26 (.21)	-.02, .53	.017	-.01 (-.01)	-.23, .21	.885	-.37 (-.30)	-.78, .04	.019
In-pair sexual desire	.38 (.31)	.14, .62	<.001	.41 (.34)	.18, .64	<.001	-.62 (-.51)	-.98, -.27	<.001
Extra-pair sexual desire	.12 (.20)	.001, .23	.009	-.05 (-.08)	-.16, -.07	.292	-.11 (-.20)	-.28, .06	.094

Note. PBFW = probability of being in the fertile window, HC= dummy-coded whether women use hormonal contraceptives or not (0 = false, 1 = true), Unstd. Est. = unstandardised regression coefficient, Std. Est. = standardised regression coefficient, CI = confidence interval. Outcomes are printed in bold if an ovulatory change was significant, its 90% confidence interval above .10 and if it was significantly diminished in women using hormonal contraceptives. For better readability, we do not report results of control variables here but they can be obtained in the online supplement (file 4_main_analyses).

Figure 2

Women's self-ratings of sexual motivation across the ovulatory cycle



Note. Smoothed curves were calculated by generalised additive models. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleedings. Bands represent a 99% confidence interval. As outcomes had different means, we always displayed a y-axis range of one standard deviation around respective means.

Ovulatory Shifts in Sexual Behaviour

In order to investigate possible ovulatory shifts in sexual behaviour, we ran general and generalised mixed effects models predicting our different sexual behaviour outcomes from women's PBFW. The main results are shown in Table 4. Regarding associations of our main predictor PBFW, we found a significant, medium-sized ovulatory increase in women's initiation of dyadic sexual behaviour with her male romantic partners. Although PBFW was positively associated with dyadic and solitary sexual behaviour, both effects were not statistically significant. Considering the interaction of PBFW with hormonal contraceptive use that compares the effect of PBFW between NC and HC women, descriptively, HC women showed effect sizes that were in opposite direction to NC women for all outcomes. However, this difference in the effect of PBFW between NC and HC women only became significant for dyadic sexual behaviour and initiation of dyadic sexual behaviour. We did not preregister a SESOI for count data. Hence, only comparing the effect size of PBFW to the SESOI for initiation of dyadic sexual behaviour, both absolute value and 90% confidence intervals (90 % CI [.13, .53]) met or exceeded the SESOI. Accordingly, naturally cycling women who were more likely to be in their fertile window reported to initiate sexual behaviour more with their romantic partners but reported no significant mid-cycle increases in the occurrence of dyadic or solitary sexual behaviour. When plotting a smoothed spline across backward counted cycle days, all outcomes showed small to moderate mid-cycle increases as depicted in Figure 3.

Table 4

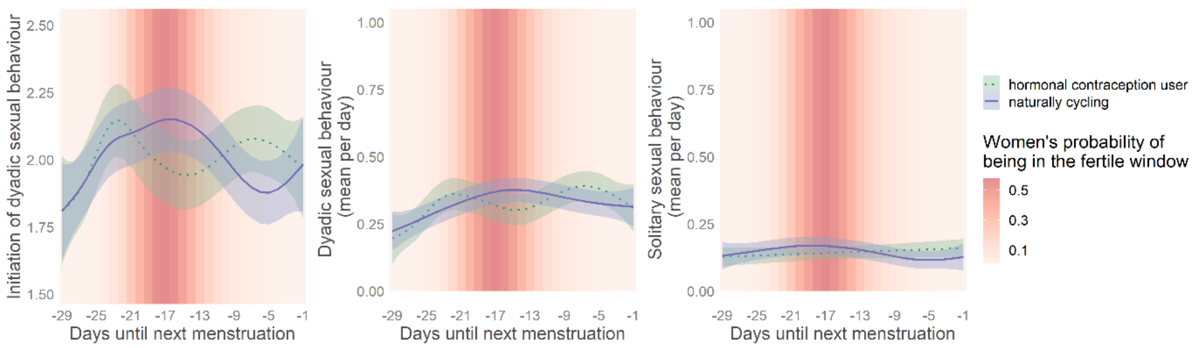
Overview of preregistered analyses of women's self-reported sexual behaviour

	PBFW			HC			PBFW*HC		
Outcomes	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.),*	*99% CI*	*p*
Dyadic sexual behaviour[a]	.24 (-)	-.21, .68	.172	.38 (-)	.12, .64	<.001	-.71 (-)	-1.30, -.11	.002
Solitary sexual behaviour[a]	.20 (-)	-.65, 1.05	.543	-.37 (-)	-.88, .13	.059	-.28 (-)	-1.30, .74	.476
Initiation of dyadic sexual behaviour	.33 (.23)	.02, .64	.006	.26 (.18)	.05, .46	.001	-.59 (-.41)	-1.05, -.13	.001

Note. PBFW = probability of being in the fertile window, HC= dummy-coded whether women use hormonal contraceptives or not (0 = false, 1 = true), Unstd. Est. = unstandardised regression coefficient, Std. Est. = standardised regression coefficient, CI = confidence interval. [a]Count variables were modelled using a Poisson error distribution with a corresponding log link; no comparison with a smallest effect size of interest was preregistered. Outcomes are printed in bold if an ovulatory change was significant, its 90% confidence interval above .10 and if it was significantly diminished in women using hormonal contraceptives. For better readability, we do not report results of control variables here but they can be obtained in the online supplement (file 4_main_analyses).

Figure 3

Women's self-ratings of sexual behaviour across the ovulatory cycle



Note. Smoothed curves were calculated by generalised additive models. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleedings. Bands represent a 99% confidence interval. For initiation of dyadic sexual behaviour, we displayed a y-axis range of one standard deviation around its mean but for the count variables of dyadic and solitary sexual desire where such a range would go below zero, we displayed a range from zero to one.

Ovulatory Shifts in Eating Motivation and Food Intake

In order to investigate possible ovulatory shifts in eating motivation and food intake, we ran general mixed effects models predicting these outcomes from women's PBFW. The main results are shown in Table 5. Regarding associations of our main predictor, we found a medium-sized significant ovulatory decrease in women's food intake. Although PBFW was negatively associated with appetite and positively associated with satiety and both effects were below a classical significance threshold of .05, they did not reach our preregistered alpha rate of .01. Considering the interaction of PBFW with hormonal contraceptive use that compares the effect of PBFW between NC and HC women, descriptively, HC women showed effect sizes that were in opposite direction to NC women for all outcomes. However, this difference in the effect of PBFW between NC and HC women only became significant for food intake. Comparing the effect size of PBFW to the SESOI, all effect sizes were above .10 in absolute value. Yet, considering their 90% confidence intervals, lower limits of appetite (90 % CI [-.36, -.08]) and satiety (90 % CI [.05, .31]) fell below the SESOI. Only confidence intervals of PBFW for food intake (90 % CI [-.43, -.13]) exceeded the SESOI in absolute value. Accordingly, naturally cycling women who were more likely to be in their fertile window reported lower food intake but no significant changes in appetite or satiety. When plotting a smoothed spline across backward counted cycle days, appetite and food intake showed small ovulatory decreases and a pronounced luteal increase, whereas satiety showed a small ovulatory increase and a small luteal decrease as depicted in Figure 4.

Table 5

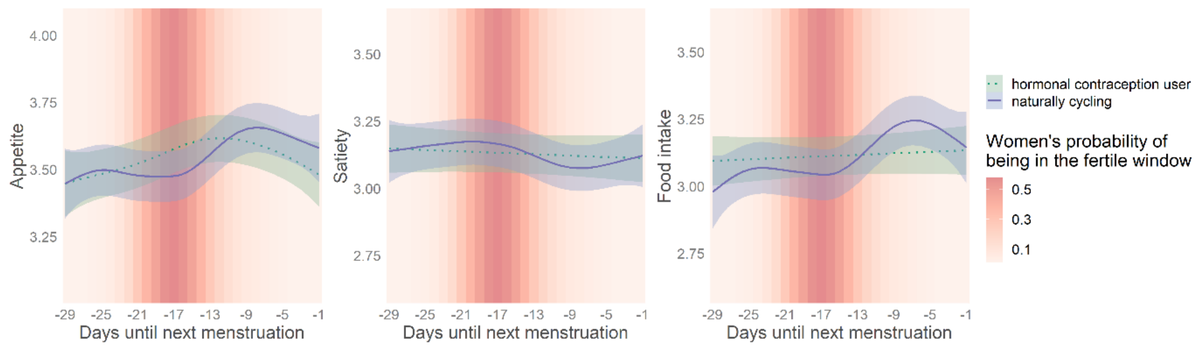
Overview of preregistered analyses of women's self-reported eating motivation and food intake

	PBFW			**HC**			**PBFW*HC**		
Outcomes	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.)*	*99% CI*	*p*	*Unstd. Est. (Std. Est.),*	*99% CI*	*p*
Appetite	-.22 (-.21)	-.45, .00	.011	.15 (.15)	-.02, .33	.020	.25 (.24)	-.08, .59	.050
Satiety	.18 (.17)	-.02, .39	.023	-.00 (-.00)	-.17, .17	.986	-.15 (-.14)	-.45, .16	.208
Food intake	-.28 (-.25)	-.52, -.04	.003	.05 (.05)	-.12, .22	.442	.38 (.34)	.03, .73	.006

Note. PBFW = probability of being in the fertile window, HC= dummy-coded whether women use hormonal contraceptives or not (0 = false, 1 = true), Unstd. Est. = unstandardised regression coefficient, Std. Est. = standardised regression coefficient, CI = confidence interval. Outcomes are printed in bold if an ovulatory change was significant, its 90% confidence interval above .10 and if it was significantly diminished in women using hormonal contraceptives. For better readability, we do not report results of control variables here but they can be obtained in the online supplement (file 4_main_analyses).

Figure 4

Women's self-ratings of eating motivation and food intake across the ovulatory cycle



Note. Smoothed curves were calculated by generalised additive models. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleedings. Bands represent a 99% confidence interval. As outcomes had different means, we always display a y-axis range of one standard deviation around respective means.

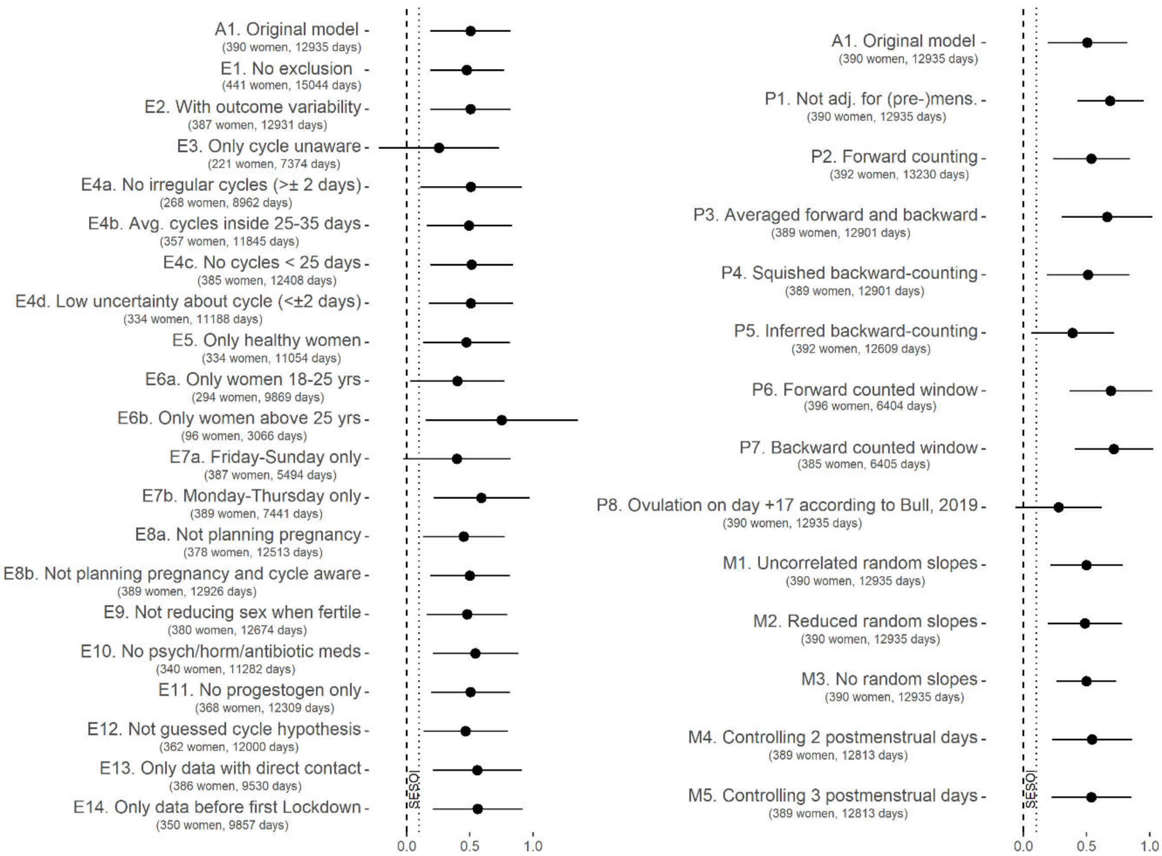
Robustness Analyses

We conducted several preregistered and supplementary analyses to gauge the robustness of the reported ovulatory cycle shifts. First, we investigated how results of PBFW varied depending on analytical decisions that might be considered arbitrary. For that, we applied different exclusion criteria (e.g. women who were cycle-aware, had average cycle lengths below 25 or above 35 days or guessed study goals), different estimators of fertility (e.g. forward counting, backward counting 13 instead of the established 15 days to estimate the day of ovulation as reported by Bull et al. (2019) or using discrete fertile windows), and different model specifications (e.g. omitting random effects for (pre)-menstruation, using ordinal models for all Likert-scale outcomes and Gaussian models for solitary and dyadic sexual behaviour). Second, we sought to investigate whether ovulatory cycle shifts are robust against a possible menstrual abstinence effect (e.g. Adams et al., 1978), that is that women might experience diminished sexual motivation and behaviour during menstruation that they catch-up on after the end of menstrual bleedings. Such behaviour could alternatively explain post-menstrual, peri-ovulatory changes. For that, we added a dummy-coded variable for days after menstruation to our models (set to 1 for days after end of menstruation and set to zero for all other days). Since there is little research about the duration of such a possible catch-up effect after menstruation, we coded two dummy variables, spanning two days and three days after the end of menstruation, and compared these models to our preregistered analyses. Third, 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 lockdown in [blinded for peer review] on March 16, 2020, we had collected 76.22% of women's diary entries. Consequently, we added further robustness analyses where we compared our main analyses using all data to those only using data before the first lockdown.

In the following, we seek to give a brief summary of these results. We provide a graphical overview of the conducted robustness analyses for general sexual motivation in Figure 5. A complete overview of all robustness analyses including further robustness analyses of the comparison of HC and NC women can be found in our online supplement (file 5_robustness_analyses). Importantly, for all models in our robustness analyses, effects of PBFW differed from our main analyses in absolute size, particularly between different fertility estimators, but were rarely zero and rarely changed direction.

Figure 5

Overview robustness analyses for ovulatory increase in women's general sexual motivation



Note. 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, Adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase, SESOI = smallest effect size of interest preregistered at .10.

First, concerning robustness analyses of researcher degrees of freedom, our results for general and in-pair sexual desire were vastly robust across all models, both regarding statistical significance and effect sizes. For extra-pair sexual desire and solitary desire, while significance of results varied across alternative analytical approaches, effect sizes remained relatively constant. Regarding dyadic sexual behaviour, effects of PBFW mostly remained non-significant but showed a clear descriptive peak when analysing only women above 25 years (b = .70, 99% CI [-.17, 1.58], p = .039) and between Mondays and Thursdays (b = .73, 99% CI [.04, 1.41], p = .006). The same pattern applied to solitary sexual behaviour but here effects of PBFW peaked in women above 25 years (b = .68, 99% CI [-.93, 2.29], p = .275) and between Fridays and Sundays (b = 1.00, 99% CI [-.30, 2.29], p = .047. For initiation of dyadic sexual behaviour, the effect of PBFW became significant for most modelling decisions but significance of effects varied across different exclusion criteria and fertility estimators. Yet, effect sizes remained relatively unaffected. Regarding outcomes of eating motivation, significance of effects of PBFW for both appetite and satiety varied across modelling decisions, but effect sizes remained relatively constant. Regarding food intake, effects of PBFW became non-significant for some modelling decisions and for about half of the alternative fertility estimators, but effect sizes only varied minimally.

Second, concerning a possible menstrual abstinence effect, only general sexual desire and in-pair sexual desire were significantly, positively associated with post-menstrual days (effect of coded two post-menstrual days on general sexual desire b = .22, 99% CI [.04, .40], p = .002, and on in-pair sexual desire b = .17, 99% CI [.03, .31], p = .002), indicating a possible menstrual catch-up effect for these two outcomes for all women. Supporting distinct ovulatory effects, however, for all models, unstandardised effect sizes of PBFW increased when additionally controlling for post-menstrual days. For example, when controlling for two days after the end of menstruation, unstandardised effect sizes of PBFW for general sexual desire increased descriptively from b = .51, 99% CI [.19, .82] to b = .54, 99% CI [.23, .86] and for in-pair sexual desire from b = .38, 99% CI [.14, .62] to b = .42, 99% CI [.18, .67]. Third, the influence of COVID-19 on our data collection seems negligible since effect sizes were nearly identical when comparing all data to only those collected before the first lockdown in Germany. Taken together, robustness analyses indicate that effect sizes of PBFW were largely robust against different exclusion criteria, menstrual abstinence effects or influences of COVID-19 measures. Regarding statistical significance, results varied considerably when choosing other, presumably less valid methods of estimating women’s fertility, although effects of PBFW for general and in-pair sexual desire held across nearly all researcher degrees of freedom.

Discussion

Using almost 13,000 diary entries of NC and HC women, the aim of this preregistered diary study was to investigate adaptive trade-offs in sexual and eating motivation and corresponding behaviours across women's ovulatory cycles. In general, our findings were in line with the MPSH: We found evidence for ovulatory increases in general sexual desire, in-pair sexual desire and initiation of dyadic sexual behaviour with women's male romantic partners. Additionally, we found evidence for concurrent ovulatory decreases in food intake. These motivational and behavioural shifts possibly reflect an endogeneous, hormone-regulated trade-off in sexual and eating motivation. Findings for the remaining motivational (i.e. extra-pair sexual desire, solitary sexual desire, appetite, and satiety) and behavioural (i.e. number of dyadic and solitary sexual behaviour) outcomes, however, remain less conclusive. Below, we discuss our findings in detail and consider their theoretical implications.

Ovulatory Changes in Sexual Motivation

In line with studies showing increases in broader sexual motivation (Arslan et al., 2018; Bullivant et al., 2004; Jones, Hahn, Fisher, Wang, Kandrik, & DeBruine, 2018; Roney & Simmons, 2016; Shirazi, Self, et al., 2019), we found ovulatory increases in general sexual desire and in-pair sexual desire for naturally cycling women. Importantly, we found no corresponding effects in HC women who do not experience ovarian hormonal fluctuations. These medium-sized effects clearly exceeded our preregistered SESOI and were robust to multiple researcher degrees of freedom in analytical decisions. Hence, our results support the MPSH by providing clear evidence for the existence of ovulatory increases in general sexual desire and in-pair sexual desire. With regards to the other components of sexual motivation, findings require a more detailed discussion.

As expected, extra-pair sexual desire of NC women showed a mid-cycle increase, yet the overall pattern and the theoretical implications of this finding are less clear: Although effects run in opposing directions for HC women descriptively, NC and HC women did not differ in their extra-pair sexual desire across their ovulatory cycle at a statistically significant level (neither for a classical significance threshold nor for our stricter one). Thus, we cannot rule out that observed increases in extra-pair sexual desire follow other mid-cycle changes unrelated to approaching ovulation, such as an absence of pre-, peri- and/or post-menstrual symptoms. Yet, since comparing NC and HC women by testing interaction effects takes even higher statistical power than testing main effects (Rohrer & Arslan, 2021), it is possible that the interaction effect exists but was still too small to be detected, despite the high sample size of this study.

Although we found no significant associations of PBFW with solitary sexual desire, considering the high robustness of its effect size, we still expect solitary desire to be affected by PBFW. Yet, it might be that solitary sexual desire rather follows other ovulatory increases such as those in general sexual desire. For example, it might be that women resort to solitary sexual desire if no sexual partner is available. In support for this idea, effect sizes on days where women had contact with their romantic partners were lower than effect sizes on all days. Unfortunately, the number of diary days without direct contact of the couple was too low (~3000 days) to yield any reliable results. In order to explain the current heterogeneity in studies, more research is needed to investigate whether partner contact or partner availability might be a possible moderator of ovulatory increases in solitary sexual desire.

Comparing In-Pair and Extra-Pair Sexual Desire

Regarding our results of in-pair and extra-pair sexual desire, it was striking that standardised and unstandardised effect sizes of the association of women's PBFW with their extra-pair sexual desire were descriptively lower than with their intra-pair sexual desire. We identified three reasons that might explain this difference. First of all, in a study with women in romantic relationships, it makes sense that ovulatory increases in general sexual motivation as predicted by the MPSH largely translated into increased in-pair sexual desire. Second, ovulatory shifts in in-pair sexual desire might have further increased by self-selection of couples: Since the cover story was framed as a couple's quiz to investigate needs and emotions of one's romantic partner, it is possible that couples participated who were highly satisfied and committed to each other (Park et al., 2021). This might explain the lower variance we find in extra-pair sexual desire compared to in-pair sexual desire, which in turn might have resulted in lower effect sizes. Supporting this explanation, as one of few dyadic diary studies that analysed data of possibly highly committed couples as well, Righetti et al. (2020) reported no associations of estradiol (the steroid hormone that dominates the follicular and fertile window) with extra-pair sexual desire. However, they also found negative associations of estradiol with in-pair sexual desire that contradict our findings. As Righetti et al. (2020) discuss themselves, their results are likely limited by low statistical power since they only investigated 33 women across 15 diary days, thereby making comparisons to our findings difficult. Third, it is also possible that effects of extra-pair sexual desire were small because women who participate in a study together with their romantic partners are reluctant to report on their extra-pair sexual desire. Yet, this effect is likely mitigated by the high anonymity we ensured in this online study and by excluding participants who reported to have answered dishonestly.

Implications for the Theoretical Debate on Ovulatory Cycle Shifts

Although the reported increase in extra-pair desire was small, we do not refute the possible existence of ovulatory cycle shifts in extra-pair sexual desire. Nonetheless, our findings of robust and medium-sized ovulatory increases in both general and in-pair sexual desire but inconclusive evidence for extra-pair sexual desire contradict previous studies reporting no ovulatory increases in in-pair sexual desire but only a target-specific ovulatory increase in extra-pair sexual desire (Gangestad et al., 2002; Grebe et al., 2016). As exploratory analyses revealed that extra-pair sexual desire was mostly characterised by attraction to, as opposed to wanting sexual contact with, other men, it seems unlikely that ovulatory shifts in extra-pair sexual desire in this sample function to obtain high sire genetic quality from men other than women's primary partners as predicted by the GGOSH. Instead, as women's in-pair sexual desire was mostly characterised by seeking sexual contact with their primary partners, any resulting offspring would carry genes of women's primary partners. Rather than considering in-pair sexual desire and extra-pair sexual desire as opposing effects, it is possible to conceptualise them as different facets of the same ovulatory increase in general sexual motivation that translate into target-specifity depending on women's pre-existing preferences or situational factors.

Ovulatory Changes in Sexual Behaviour

The reported ovulatory changes in sexual motivation are largely reflected in the ovulatory changes in sexual behaviour. Providing further support for the MPSH, naturally cycling women initiated more sexual behaviour with their romantic partners when fertile. The effect exceeded the SESOI and was significantly diminished in HC, thereby fully supporting the existence of ovulatory increases in sexual initiation, as also demonstrated in previous research (Adams et al., 1978; Bullivant et al., 2004; Harvey, 1987). Despite this increase in sexual initiation, or proceptivity in evolutionary terminology, women did neither report more frequent sexual behaviour with their romantic partners, nor more frequent solitary sexual activity. In the case of dyadic sexual behaviour, this lack of findings might be explained by the fact that partnered sexual behaviour is not only influenced by sexual initiation of one partner. Instead, it is also strongly affected by the other person's motivational states, their possibly biased perceptions of these sexual advances (Dobson et al., 2018) as well as external factors such as time constraints, relationship dynamics and partner availability (Arslan et al., 2018). In support for the relevance of such external factors, effect sizes for dyadic sexual behaviour increased when only analysing days with direct contact of the romantic couple. Hence, ovulatory increases in sexual initiation might more strongly reflect endogenous shifts in sexual motivation, as proposed by the MPSH, that does not necessarily lead to dyadic sexual behaviour but rather increases its possibility (Caruso et al., 2014; Roney, 2016). Future research is needed to better understand the interplay of sexual initiation and dyadic sexual behaviour, particularly by considering the perceptions and motivational states of both romantic partners.

In the case of solitary sexual behaviour, it might be that – as with solitary sexual desire – women resort to solitary sexual behaviour when they experience ovulatory increases in sexual motivation but have no sexual partner available (Burleson et al., 2002; Caruso et al., 2014). Unfortunately, the number of observed diary days where romantic couples had no direct contact were too few to analyse such moderating effects of partner availability.

Ovulatory Changes in Eating Motivation and Food Intake

In line with the MPSH, concurrent to ovulatory increases in sexual motivation and sexual initiation, women showed an ovulatory decrease in food intake that fully met all our criteria of evidential support. Thus, this study adds convincing evidence, based on self-reported food intake, to previous studies reporting an ovulatory nadir in both self-reported and weighed food intake (Fessler, 2003; Fleischman & Fessler, 2007; Roney & Simmons, 2017). However, we could not convincingly support ovulatory changes in appetite and satiety as possible motivational mechanisms behind the reduction in food intake. To our knowledge, this is the first study that sought to expand our understanding of ovulatory changes in eating motivation by assessing self-reported appetite and satiety. As appetite in particular showed the expected result pattern on a classical, liberal level of significance and there is neuroscientific evidence that appetite is modulated by estradiol in rats (Asarian & Geary, 2006), we hope to encourage future empirical studies and theoretical debates about which motivational and physiological processes translate into the observed reduction in food intake. However, as Fessler (2003) argued that women might simply lack the time to eat because of their prioritisation of mating efforts when fertile, it is also possible that ovulatory decreases in eating motivation are not needed to explain the observed reduction in food intake. Ideally, future studies should directly investigate a trade-off in time spent on different behaviours. Additionally, replications of our study are needed that assess further aspects of eating motivation such as food craving (Gorczyca et al., 2016) or cost-intensive foraging, and address current incongruities in the types of food consumed across the ovulatory cycle (Fleischman & Fessler, 2007; Gorczyca et al., 2016).

Limitations and Future Directions

Despite having multiple strengths, this study has some limitations. To begin with limitations regarding our design, a number of measures could be improved in future studies. First, we based our results only on women's self-reports. Therefore, biases such as measurement reactivity, desirability bias and recall error might affect our findings. Although these biases cannot be ruled out, we expect they are diminished by using an anonymous online diary design, randomising the item order and by restricting daily recall to the previous 24 hours.

Second, we used backward counting from the next onset of menstrual bleedings to determine the day of ovulation. Unlike forward counting, backward counting is less affected by the higher variability in length of the follicular phase (Fehring et al., 2006). Additionally, many women use forward counting methods as a form of contraception method and cycle-awareness. Hence, fertile days based on backward counting might be less affected by demand characteristics on days when women expect to be fertile based on their own forward counting. Yet, while backward counting is the best practice for counting methods, it is still outperformed by ultrasound or luteinising hormone tests (Gangestad et al., 2016). However, high costs, low feasibility and reduced anonymity of these measurements often result in low sample sizes that in turn restrict informational value of studies. Moreover, using direct measurements of ovulation often reveal a study's focus on ovulation which might introduce response biases. Thus, backward counting of observed menstrual onsets balanced the need of high statistical power and high validity of measurements. Future research might benefit from studies that combine biological markers of ovulation and large sample sizes.

Third, the complexity of our diary study as well as the high number of daily items did not allow for multi-item assessments of most variables. Although multilevel reliabilities were satisfying and using mostly single-items probably resulted in a higher sample size and reduced nonresponse bias, we had to use less established measurements. While the discussion of the practical use of single-items is ongoing (Arslan, Brümmer, et al., 2020; Fisher et al., 2018), we hope future research validates our findings with more established scales.

Fourth, our study was not able to capture all constructs that might be relevant to ovulatory cycle shifts in sexual behaviour. Specifically, as a limitation caused by the dyadic diary design we did not assess extra-dyadic copulations, in order not to cause adverse effects on women's relationships or put them at risk of partner violence. As a result, we cannot compare ovulatory effects on the target of dyadic sexual behaviour that might have informed theoretical debates. However, in previous research (Arslan et al., 2018) rates of extra-pair copulations were too low for proper statistical analyses. In addition, as a limitation of our research focus, we did not assess pre-existing preferences in targets of sexual motivation in women that might have advanced a discussion of how increases in general sexual motivation might translate differently into sexual motivation aimed at primary partners or other men. Future studies might directly assess pre-existing preferences and investigate their influences. Such studies should preferably implement Open Science practices, use cover stories to reduce self-selection bias, and aim to achieve diverse samples. As another limitation of our research focus, we only investigated ovulatory changes. Since the MPSH predicts an alternating pattern of sexual and eating motivation across the whole cycle, we would also expect decreased sexual but increased eating motivation in the luteal phase. Only few studies have reported such a mid-luteal increase in food intake, appetite and food cravings so far (Gorczyca et al., 2016; McNeil et al., 2013). Graphically, the effects we find are consistent with a luteal increase in appetite and food intake, but since this preregistered study aimed at uncovering ovulatory changes, we restricted our statistical analyses to the preregistered examination of the fertile window. To inform future research, we added exploratory analyses of luteal changes in appetite, satiety and food intake that descriptively support luteal increases in eating motivation and behaviour to our online supplement (file 4_main_analyses). As these exploratory analyses were not preregistered and hence impede statistical inference, more research is needed that asserts wether the motivational trade-off we observed is restricted to the fertile window or is inversed after ovulation as the MPSH predicts.

Finally, regarding external validity of our findings, to investigate possible reproductive functions, we only assessed heterosexual couples. Moreover, our sample, although more diverse than an undergraduate student sample, predominantly consisted of young, educated participants from a developed Western country that fulfils all aspects of a WEIRD sample (Henrich et al., 2010). Consequently, the generalisability of our results may be limited although we expect functional hormonal mechanisms to be universal among humans. Particularly because of the relevance of nutritional status and food availability on possible motivational trade-offs in sexual and eating motivation (Fessler, 2003; Loucks & Thuma, 2003; Roney & Simmons, 2017), more research with higher diversity in sample characteristics, cultural backgrounds and health state is called for.

Conclusion

In this preregistered and highly powered online diary study, we observed ovulatory increases in partnered, naturally cycling women for general sexual desire, in-pair sexual desire and initiation of dyadic sexual behaviour as well as ovulatory decreases in food intake. Extra-pair sexual desire showed a significant mid-cycle increase, but we cannot draw final conclusions about the ovulatory nature of this within-women change. We found no significant ovulatory changes for solitary sexual desire, solitary and dyadic sexual behaviour, appetite and satiety. Since all outcomes showed expected changes descriptively, we encourage replication of our results. Although previous theoretical approaches can possibly account for specific ovulatory changes in sexual motivation, the overall result pattern favours an adaptive motivational trade-off of sexual and eating motivation in women.

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Appendix C

Manuscript 3

Schleifenbaum, L., Stern, J., Driebe, J. C., Wieczorek, L. L., Gerlach, T. M., Arslan, R. C. Penke, L. (2021). *Men are not aware of and do not respond to their female partner's fertility status: evidence from a dyadic diary of 384 couples.* [Manuscript submitted for publication]. Department of Biological Personality Psychology, University of Goettingen.

Submitted supplementary material is provided here, further supplementary material is available at https://osf.io/w43gq/. Open data are available at https://doi.org/10.7802/2330 as scientific use files.

"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"

Lara Schleifenbaum*[1,2], Julia Stern[1,3], Julie C. Driebe[1], Larissa L. Wieczorek[4], Tanja M. Gerlach[1,2], Ruben C. Arslan[5,6], Lars Penke[1,2]

[1]University of Goettingen, Goettingen, Germany

[2]Leibniz ScienceCampus Primate Cognition, Goettingen, Germany

[3]University of Bremen, Bremen, Germany

[4]University of Hamburg, Hamburg, Germany

[5]University of Leipzig, Leipzig, Germany

[6]Max Planck Institute for Human Development, Berlin, Germany

***Corresponding author:**

Lara Schleifenbaum, M.Sc.

Gosslerstrasse 14, 37073 Goettingen, Germany

Email: lara.schleifenbaum@uni-goettingen.de,

Phone: +49551/39-28205

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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 behaviour. 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 ovulatory 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.

In humans, there is a short, recurring time span during which their sexual decisions have critical reproductive consequences: women's fertile window. Spanning approximately five days before ovulation and the day of ovulation itself[1], 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 behaviour during the fertile window is assumed to have been strongly shaped by selection[2]. According to Parental Investment Theory[3], women and men face different pressures of sexual selection. Women's minimal parental investment including larger gamete production, 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*[4]). Following these divergent selection pressures, men and women have different strategies to optimise their reproductive success[5]. 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)[6]. 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[7], and b) react in a specific manner to secure access to their fertile partners via so called mate retention tactics[8,9].

Cues to fertility should consist of differences in either physical appearance or manifest behaviour[10] 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[11–14]. 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)[15]. However, this notion has been challenged by recent findings showing increases in women's attractiveness[7,16–18] and sexual motivation[19–24] 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[16,25] and might perceive ovulatory changes in women's facial shape and texture[18,26], vocal attractiveness[27], body scent[28–33] and grooming behaviour[16,34]. 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[35]. This problem is exacerbated by employing between-subject designs to estimate within-subject changes[30], or comparing only high- to low-fertility days, and using estimation methods for women's fertility with low validity[35]. Importantly, recent replications fail to find predicted shifts in men's ratings of women's facial[36,37] and bodily attractiveness[37], women's body scent[38], and women's voice pitch[39]. Moreover, other findings question whether postulated shifts in facial shape or colour exist or are even perceptible[40,41].

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[9,42,43]. Moreover, women reported more interest in going out to social gatherings to meet men on fertile days compared to nonfertile days[42]. 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[19,44–49], more recent studies employing large sample sizes have shown that women exhibit ovulatory increases in their general sexual motivation[19,23,24,44]. 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[23,24].

Accordingly, ovulatory changes in women's sexual motivation might be observable, for example, through flirtatious behaviour or reported increases in women's initiation of sexual activity[21]. However, to our knowledge, no study has investigated whether men do indeed perceive women's ovulatory 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[8,9,50], reacting even to weakly valid cues and fending off potential competitors is assumed to be highly adaptive[6]. Consequently, men are expected to increase their mate retention tactics when women are fertile[51]. 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[52]. According to error management theory[53], 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[8]), 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 ovulatory 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) behaviour of their male partners on high fertile days[9]. Similarly, in a daily diary design, 23 women reported higher jealousy and possessiveness of their male partners when they were fertile[42], with a large effect of .7 Cohen's *d* for women's reports of male jealousy[7]. 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 ovulatory changes in reported mate retention[24]. 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[24]. In addition, as these studies were only based on women's reports of men's behaviour, 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 ovulatory 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 behaviour of men on women's high fertile days[8]. 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[54]. 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[55], male sexual motivation likely plays a considerable role in the occurrence of dyadic sexual behaviour 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[24,56]. 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[57]. 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)[58]. 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[35]. Seventh, we implemented a smallest effect size of interest (SESOI[59]) with a threshold of .10 to gauge the practical relevance of ovulatory 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[60], 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, and different model specifications.

Following our preregistered hypotheses, we expected possible male perceptions of women's cues to fertility to manifest in ovulatory 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 ovulatory increases in male jealousy reported by men (H4.1) and women (H4.2). We also expected ovulatory 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 men to show ovulatory increases in their in-pair sexual desire towards their romantic female partners (H7). Although we preregistered an additional hypothesis concerning ovulatory 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 https://doi.org/10.7802/2330.

Results

For all models, we followed our preregistered analysis plan. We conducted linear mixed effects models to account for the hierarchical data structure of diary entries nested in participants. 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 ovulatory changes in men's mate retention tactics. Our 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. We added women's premenstrual and menstrual days, and amount of direct and indirect contact the couples had 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).

We ran all models separately for men and women, comparing NC men to HC men and NC women to HC women. 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. We included random intercepts, random slopes and their correlation for PBFW, premenstrual phase and menstruation. As preregistered, we set our significance level to .01 and defined three conditions that needed to be fulfilled in order to infer an ovulatory increase in all outcomes: 1) PBFW shows a significant influence of fertility according to our preregistered alpha rate of .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 .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 (Table S3-S11). 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.

Men's awareness of cues to fertility

Analysing data of all 384 men, we found no significant ovulatory 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 1, more details on random effects can be found in the supplementary material (Table S12). Descriptively, men's ratings of women's attractiveness and women's wish for contact with others were negatively associated with PBFW, showing non-significant ovulatory decreases as opposed to the expected ovulatory 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 [-.23, -.01]) nor women's wish for contact with other people (90% CI [-.25, .05]) included the SESOI of .10. Thus, while we cannot distinguish the effect of PBFW from zero, we can confidently rule out an effect size of .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 .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 [.04, .38]) fell below the SESOI of .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 ovulatory increases. All findings are illustrated in Fig.1.

Men's mate retention tactics

Analysing only data of the 364 men and 364 women in monogamous relationships, we found no significant ovulatory increases in men's jealousy (neither male nor female reports), men's attention paid to their 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 2, more details on random effects can be found in the supplementary material (Table S13). 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 [-.03, .14]), women's ratings of male jealousy (90% CI [-.00, .13]), men's ratings of male attention to women (90% CI [-.00, .23]), women's ratings of male attention to them (90% CI [-.12, .14]), men's wish for contact with their female partners (90% CI [-.13, .14]), and men's ratings of their in-pair sexual desire (90% CI [-.07, .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 ovulatory increases. All findings are illustrated in Fig.2.

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 8,881 days at which couples had any direct contact (b = .36, 99% CI [.06, .66]), or only considering couples where women self-reported highly regular cycles within a two-day range (b = .39, 99% CI [.01, .76]). For the former effect, the confidence interval exceeded the SESOI (90% CI [.17, .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. S1-S8). In Fig. 3, 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. S1-S8, Table S14-S22).

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 ovulatory 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 ovulatory 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[7]. 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 couple's everyday lives. Hence, our results question the extent to which ovulatory changes in women's attractiveness are of biological relevance in real life.

Although women of the same sample self-reported robust ovulatory increases in their sexual desire[23], 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 ovulatory 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[61,62] and hence men might miss women's ovulatory increases. Third, as suggested by our robustness analyses, men might require direct contact to their partners to detect ovulatory changes (e.g. for noticing not only explicit but also implicit motives that are hard to verbalise[63]). 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[64] 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 ovulatory 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[9,42], 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[23]. 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 ovulatory 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[65]. While these findings contradict earlier research[8,9,42], they are in line with other recent null-findings on ovulatory changes in mate retention[24,54]. Previous research has shown that jealousy in particular is linked to a perceived infidelity risk of one's partner[52,66,67] and associated with an anxious attachment style[67]. Given the small and inconclusive mid-cycle increases in extra-pair sexual desire reported by the women in this sample[23], 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[9,53], women in this sample primarily displayed increases in their in-pair sexual desire and initiation of dyadic sexual behaviour[23], 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[68], 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 behaviour 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 ovulatory 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 behaviour 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[69]. Moreover, men exhibit a higher sexual desire than women in general, with more frequent and spontaneous sexual thoughts, fantasies and arousal[70], which is less affected by contextual or relationship dynamics than women's[71,72]. 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 behaviour throughout the whole cycle, thereby increasing the likelihood of sexual behaviour during women's fertile window as well.

Taken together, our results question the notion that women display perceptible cues to fertility across their ovulatory 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[73,74]. 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[75,76] which guides their mating choices[10,77], 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[50,55]. Third, we relied on couples' self-reports that might be affected by measurement reactivity, desirability bias, or recall error. 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[78] sample, generalisability to other cultures and norms may be limited as well. 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 still outperformed by ultrasound or hormonal tests[35].

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[11], male[11] and female[79] intrasexual competition, or by increasing long-term bonds[80] and paternal investment[12]. Importantly, although concealed ovulation has traditionally been equated with a lost oestrus in women, both are not necessarily equivalent[14]. 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[19,20,24,44,81,82] and their self-perceived attractiveness and desirability[24,42,83] which might nudge women towards sexual behaviour when the possibility of conception maximises the benefit-cost ratio[84] and thus may constitute an oestrus-like phase. By applying high methodological rigour, this work advances our understanding of how ovulatory 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.

Methods

We conducted a large-scale, preregistered online dyadic diary study which was implemented in the open source survey framework formr.org[85]. 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. (2021)[23].

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 .26 that has been previously reported for women's ovulatory increases in sexual motivation[24], a statistical power of 99% can be achieved with an alpha rate of .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[24], 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.

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.

Exclusion criteria and participant flow

Since we were interested in ovulatory 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 ovulatory 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 negated having a menstrual bleeding "sometimes or regularly"), 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 ovulatory 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. 4, 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).

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 female participants have been previously analysed for ovulatory changes in motivational priorities[23]. 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. S9) and comparisons between naturally cycling and quasi control groups for both men and women in the supplementary material (Table S23).

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 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 hours. 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[86].

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 ovulatory 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. S10).

Measures

While a dyadic diary design is best suited to test within-cycle changes[57], 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 behaviour, 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 behaviour that have been used in previous studies[24,42]. 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[42], 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[87] across all participants using the statistical software R 4.1.0[88] and the psych[89] and codebook[90] packages. We provide results of generalisability estimates that are virtually identical when analysing female and male data separately in our supplementary material (Table S24). The main outcome measures of the diary part of this study and their reliabilities are documented in Table 3.

Estimating women's fertile window

Following current recommendations[35], we operationalised women's fertile window as a continuous estimator of fertility, i.e. the probability of being in the fertile window (PBFW). As the basis for PBFW, we estimated women's day of ovulation by backward counting 15 days from the next observed onset of menstrual bleeding. Such a combination of backward counting of known cycle lengths with a continuous estimator of fertility achieves high accuracy with a validity of estimating fertility as high as ~.70[35].

We collected information on menstrual bleeding continuously throughout all study parts. In the presurvey and during the diary, we asked women to enter the exact dates of onsets and offsets of their menstrual bleeding. Thus, information on menstrual bleeding could be collected even if women skipped diary entries in-between. At the end of the diary, those 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 and could use backward counting to assess the day of ovulation for all diary days. In order to compute women's PBFW as predictor 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 on whether couples had entered diary entries on the same day.

Adhering to previously reported procedures[23,24,35,83], we applied continuous estimates[91] to compute PBFW. Since ovulatory cycles naturally show considerable inter- and intraindividual variation[92], 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[93]. 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.

Data analysis

We preregistered general mixed effects models using a Gaussian error distribution for all of our outcomes. For all models, the main predictor was PBFW by backward counting from the next observed menstrual onset of women. As explained above, we added premenstrual and menstrual phases as additional predictors to control for their influences. We employed hormonal contraceptive users and their male romantic partners (i.e. HC women and HC men) 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 hormonal contraceptive use as a dummy variable (set to zero for NC women and men) interacting with all predictors to properly apply interaction controls[94]. 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. Controlling for the kind and amount of contact couples had, we further added the amount of direct and indirect contact on a specific day. In Wilkinson notation[95], 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 .01 with two-tailed statistical testing. Additionally, we sought to extend the current debate about ovulatory 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[59]), for unstandardised effects. Since no theoretical approach of ovulatory cycle shifts makes any predictions about minimal effect sizes that are needed to have biological relevance so far, we adopted the conventional SESOI of .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 .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[88] and the respective R packages lme4[96] and sjPlot[97].

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Author Contributions

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.

Competing Interests Statement

The authors declare no competing interests.

Figures & Figure Legends

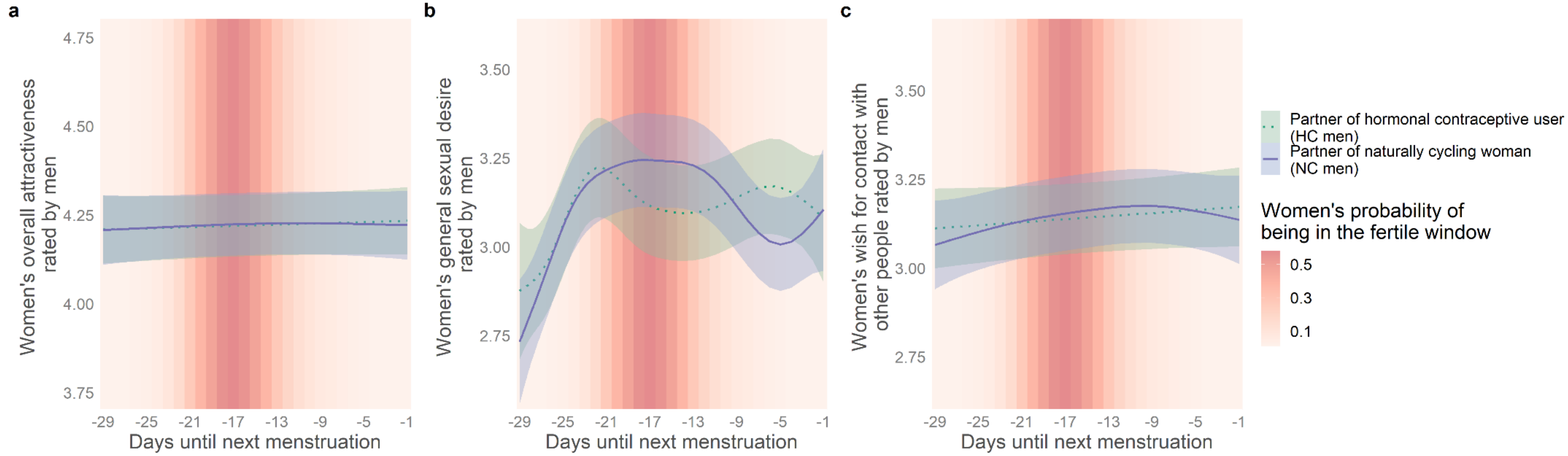

Fig.1 | Men's ratings of women's cues to fertility across the ovulatory cycle. a,b,c Smoothed curves were calculated by generalised additive models, no control variables are included here. Days until next menstruation are reverse cycle days backward counted from the next observed onset of menstrual bleeding 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.

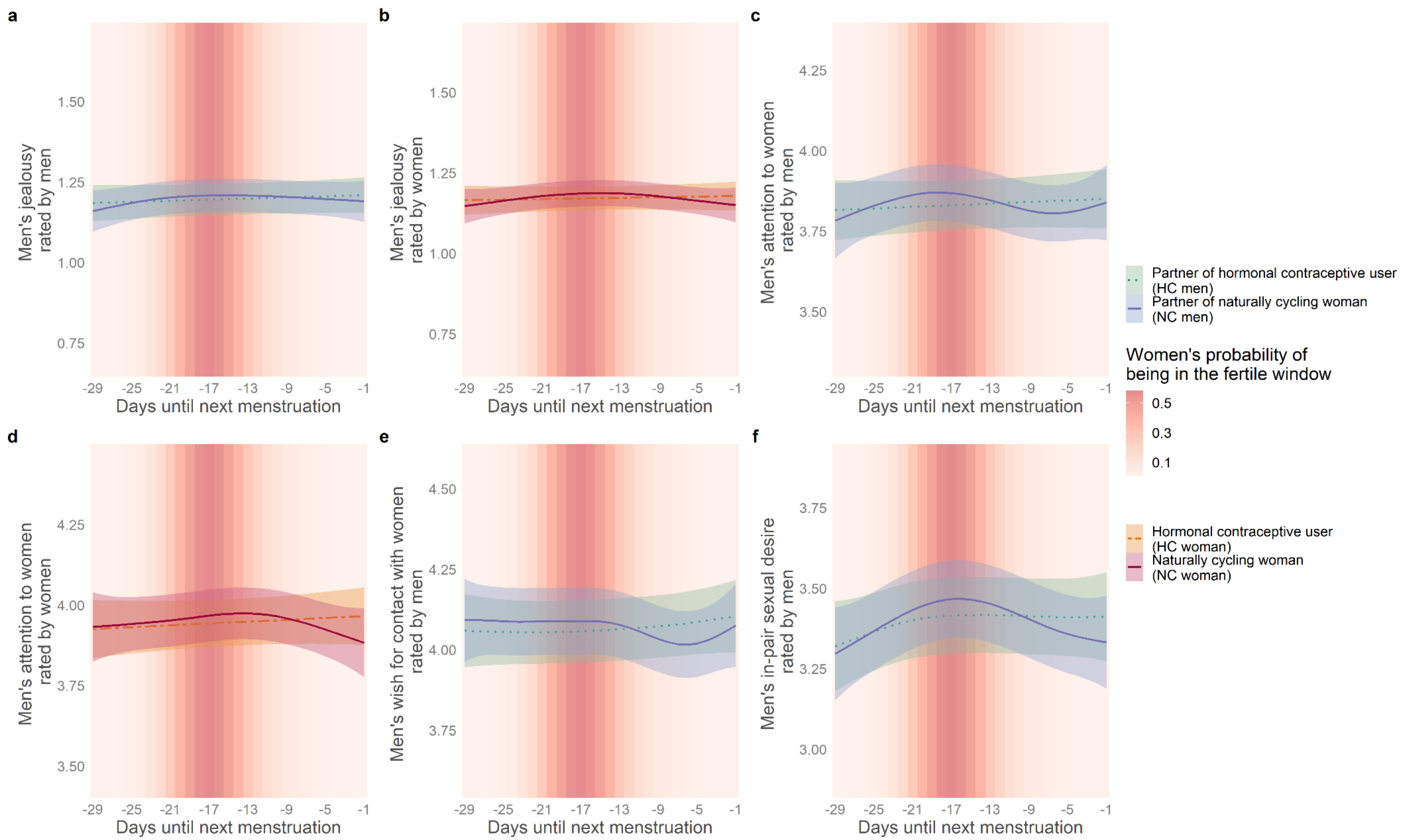

Fig.2 | Men's and women's ratings of men's mate retention tactics across the ovulatory cycle. a,b,c,d,e,f Smoothed curves were calculated by generalised additive models, no control variables are included here. Days until next menstruation are reverse cycle days backward counted from the next observed 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.

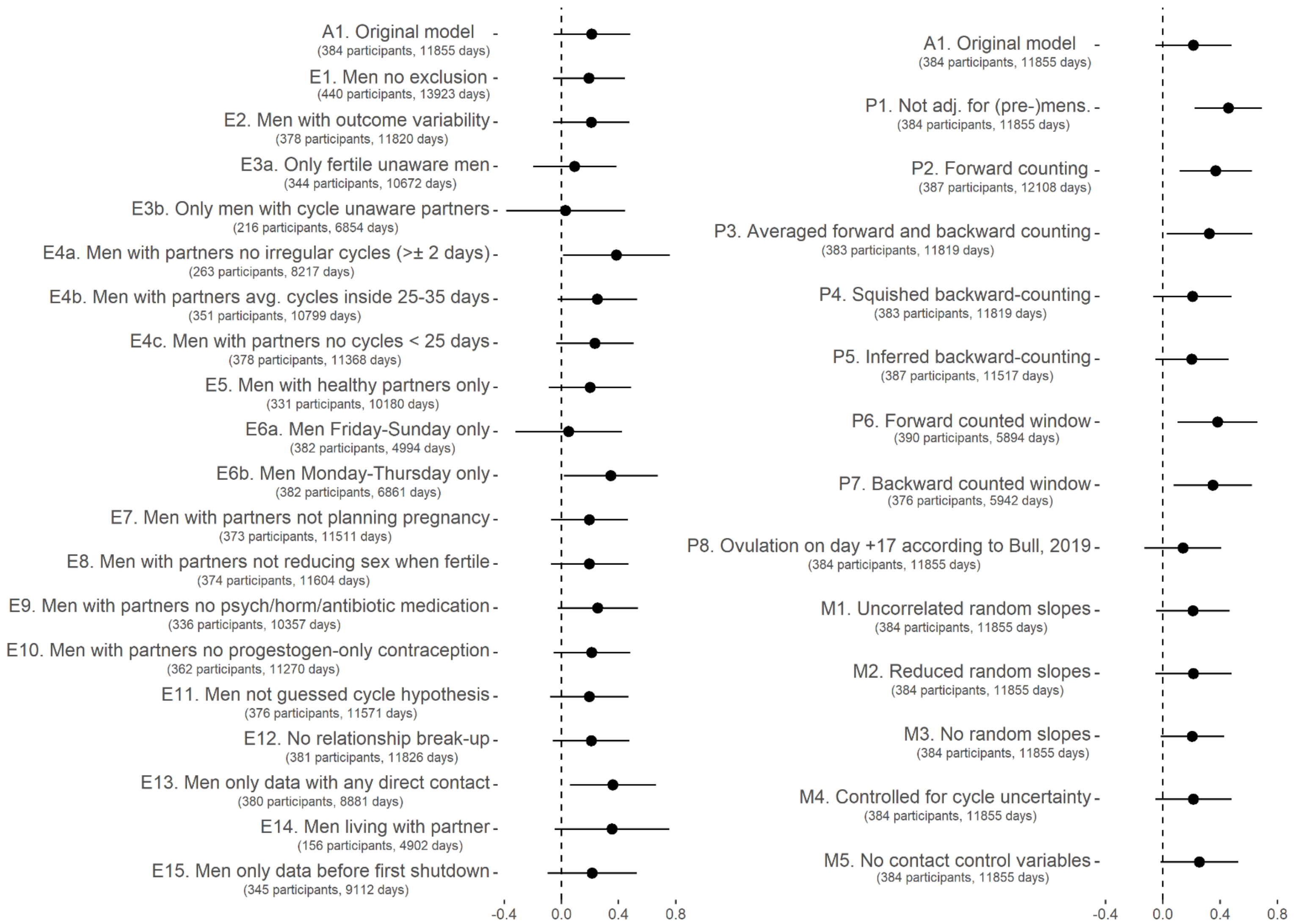

Fig.3 | Robustness analyses for men's ratings of women's sexual desire across the ovulatory cycle. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with 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.

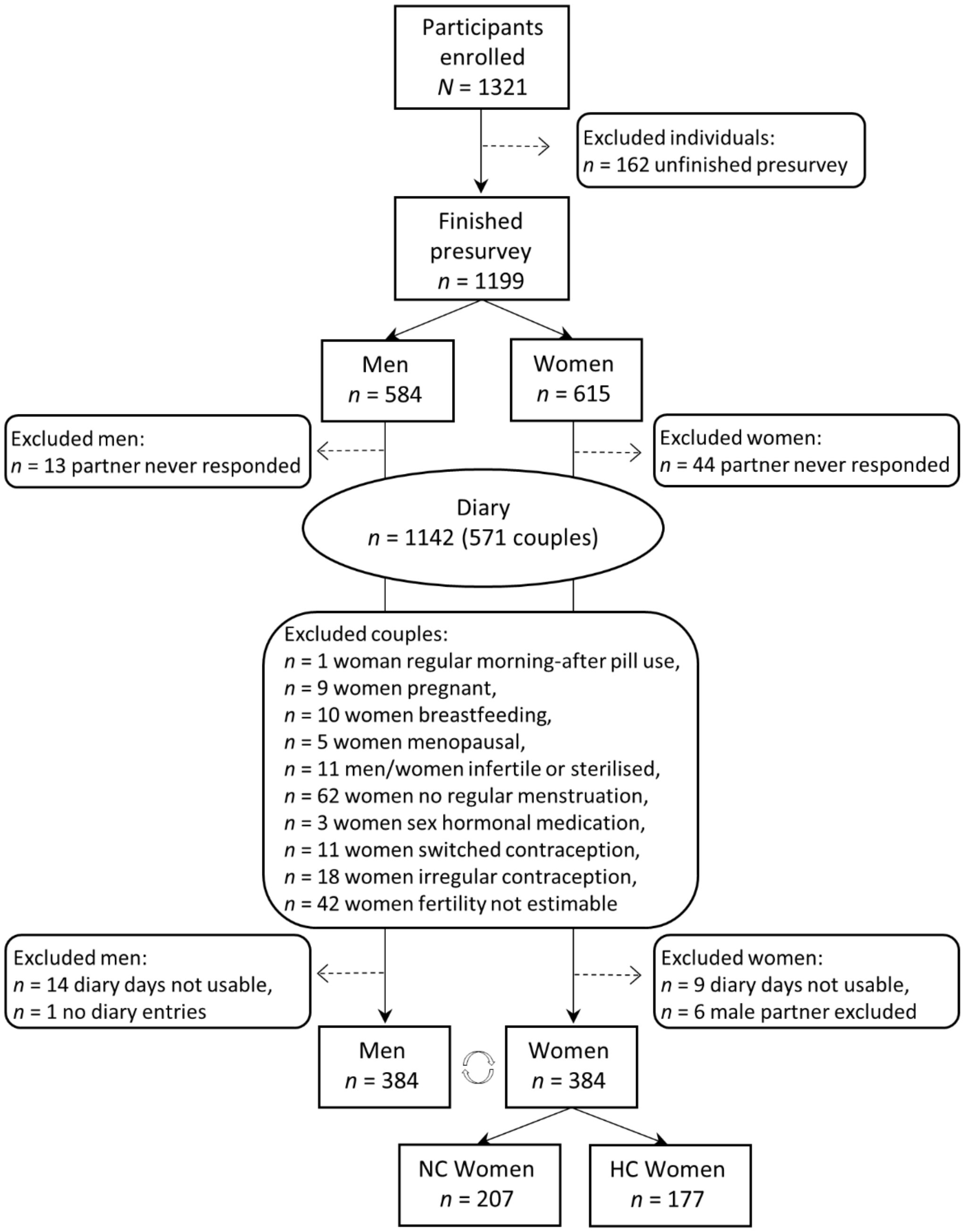

Fig.4 | Participant flow of the dyadic diary study. If participants were affected by multiple exclusion criteria, only the first criterion is shown. NC = naturally cycling women, HC = women using hormonal contraceptives.

Tables

Table 1 | Overview of male ratings of women's cues to fertility across the ovulatory 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	.081	0.21	0.10	-0.05, 0.48	.039	-0.10	0.09	-0.33, 0.13	.280
Premenstrual phase (yes)	-0.06	0.03	-0.14, 0.01	.032	-0.12	0.04	-0.24, -0.01	.005	-0.06	0.04	-0.16, 0.03	.097
Menstruation day (yes)	-0.09	0.03	-0.17, -0.01	.004	-0.23	0.05	-0.36, -0.11	<.001	-0.12	0.04	-0.22, -0.01	.004
Direct partner contact	0.03	0.00	0.02, 0.03	<.001	0.05	0.00	0.04, 0.05	<.001	-0.01	0.00	-0.02, -0.01	<.001
Indirect partner contact	0.02	0.01	0.01, 0.03	<.001	0.03	0.01	0.01, 0.05	.001	-0.00	0.01	-0.02, 0.01	.457
Level 2												
Hormonal contraception (yes)	0.05	0.07	-0.14, 0.23	.512	0.31	0.09	0.06, 0.55	.001	0.09	0.08	-0.12, 0.30	.275
Cross-level interaction												
PBFW:Hormonal contraception	0.06	0.10	-0.19, 0.32	.518	-0.28	0.15	-0.67, 0.12	.072	0.25	0.13	-0.09, 0.59	.060
Premens:Hormonal contraception	0.04	0.04	-0.07, 0.15	.351	0.10	0.06	-0.07, 0.26	.134	0.14	0.05	0.00, 0.28	.009
Mens:Hormonal contraception	0.05	0.05	-0.07, 0.17	.273	0.08	0.07	-0.11, 0.27	.272	0.15	0.06	-0.00, 0.30	.012
ICC	0.51				0.38				0.43			
N	384 $_{\text{men}}$				384 $_{\text{men}}$				384 $_{\text{men}}$			
Observations	11855				11855				11855			
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. 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).

Table 2 | Overview of male and female ratings of men's mate retention tactics across the ovulatory 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	.278	0.06	0.04	-0.04, 0.17	.126	0.12	0.07	-0.07, 0.30	.106
Premenstrual phase (yes)	0.01	0.02	-0.05, 0.06	.761	-0.01	0.02	-0.06, 0.04	.639	0.01	0.04	-0.08, 0.10	.728
Menstruation day (yes)	-0.01	0.02	-0.06, 0.05	.816	-0.02	0.02	-0.06, 0.03	.336	-0.01	0.04	-0.11, 0.08	.730
Direct partner contact	0.00	0.00	-0.00, 0.00	.275	-0.00	0.00	-0.00, 0.00	.750	0.08	0.00	0.07, 0.08	<.001
Indirect partner contact	-0.00	0.00	-0.01, 0.01	.757	0.00	0.00	-0.00, 0.01	.196	0.07	0.01	0.05, 0.08	<.001
Level 2												
Hormonal contraception (yes)	0.05	0.04	-0.06, 0.17	.231	0.01	0.03	-0.08, 0.09	.871	0.08	0.06	-0.08, 0.25	.179
Cross-level interaction												
PBFW:Hormonal contraception	-0.06	0.08	-0.25, 0.14	.438	-0.06	0.06	-0.21, 0.10	.345	-0.10	0.10	-0.37, 0.17	.342
Premens:Hormonal contraception	0.00	0.03	-0.08, 0.09	.957	0.01	0.03	-0.06, 0.09	.620	0.03	0.05	-0.11, 0.16	.627
Mens:Hormonal contraception	0.00	0.03	-0.09, 0.09	.968	0.01	0.03	-0.06, 0.08	.618	0.05	0.06	-0.09, 0.20	.338
ICC	0.36				0.26				0.32			
N	364_{men}				364_{women}				364_{men}			
Observations	11433				11945				11433			
Marginal R^2 / Conditional R^2	0.002 / 0.362				0.001 / 0.258				0.157 / 0.428			

Table 2 | continued

	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	.923	0.00	0.08	-0.21, 0.22	.966	0.07	0.09	-0.16, 0.30	.403
Premenstrual phase (yes)	-0.06	0.04	-0.16, 0.04	.131	-0.04	0.04	-0.14, 0.06	.301	-0.08	0.04	-0.18, 0.03	.053
Menstruation day (yes)	-0.05	0.04	-0.15, 0.05	.170	0.00	0.04	-0.10, 0.10	.929	-0.12	0.04	-0.24, -0.01	.004
Direct partner contact	0.07	0.00	0.06, 0.07	<.001	-0.01	0.00	-0.01, -0.00	<.001	0.04	0.00	0.04, 0.05	<.001
Indirect partner contact	0.06	0.01	0.05, 0.08	<.001	0.03	0.01	0.01, 0.04	<.001	0.05	0.01	0.03, 0.07	<.001
Level 2												
Hormonal contraception (yes)	0.13	0.06	-0.03, 0.29	.031	0.10	0.08	-0.10, 0.31	.199	0.22	0.09	-0.01, 0.46	.015
Cross-level interaction												
PBFW:Hormonal contraception	-0.09	0.12	-0.39, 0.21	.452	0.01	0.12	-0.30, 0.32	.929	-0.20	0.13	-0.54, 0.14	.128
Premens:Hormonal contraception	0.06	0.06	-0.09, 0.20	.301	0.08	0.06	-0.07, 0.22	.175	0.01	0.06	-0.14, 0.16	.846
Mens:Hormonal contraception	0.03	0.06	-0.12, 0.18	.578	0.00	0.06	-0.14, 0.15	.944	-0.01	0.06	-0.17, 0.15	.863
ICC	0.31				0.44				0.51			
N	364 $_{women}$				364 $_{men}$				364 $_{men}$			
Observations	11945				11433				11307			
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. 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).

Table 3 | 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	.85
Women’s general sexual desire	“My partner was interested in sexual activity.”	5-point Likert scale “not at all” – “very much”	Men	.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	.85
Men’s jealousy	“I was jealous.”	5-point Likert scale “not at all” – “very much”	Men	.86
Men’s jealousy	“My partner was jealous.”	5-point Likert scale “not at all” – “very much”	Women	.86
Men’s attention to their partners	“I paid attention to my partner.”	5-point Likert scale “not at all” – “very much”	Men	.86
Men’s attention to their partners	“My partner paid attention to me.”	5-point Likert scale “not at all” – “very much”	Women	.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	.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	.74

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

Supplemental Material for

"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"

Lara Schleifenbaum*[1,2], Julia Stern[1,2,3], Julie C. Driebe[1], Larissa L. Wieczorek[4], Tanja M. Gerlach[1,2], Ruben C. Arslan[2,5,6], Lars Penke[1,2]

[1]University of Goettingen, Goettingen, Germany

[2]Leibniz ScienceCampus Primate Cognition, Goettingen, Germany

[3]University of Bremen, Bremen, Germany

[4]University of Hamburg, Hamburg, Germany

[5]University of Leipzig, Leipzig, Germany

[6]Max Planck Institute for Human Development, Berlin, Germany

***Corresponding author:**

Lara Schleifenbaum, M.Sc.
Gosslerstrasse 14, 37073 Goettingen, Germany
Email: lara.schleifenbaum@uni-goettingen.de,
Phone: +49551/39-28205

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1. Omitted hypotheses of ovulatory increases in jealousy-related conflict

We sought to test whether men and women would report more jealousy-related conflict as a consequence of women's assumed ovulatory increases in extra-pair sexual desire and corresponding increases in men's jealousy. Based on previous literature, we expected ovulatory increases in both men's and women's ratings of jealousy-related conflict. However, we overestimated the frequency of conflict that would occur compared to the low frequency of conflict present in our sample: Men reported no conflicts on 10,994 diary entries and of the remaining 1,075 diary entries with reported conflict, 80.6% were rated as not at all related to jealousy; of 384 couples, 279 men never reported any jealousy-related conflict at all across the whole diary and the mean of jealousy-related conflict was M =.0173 (SD = .13). This low amount of data provided very little information for any of our planned analyses. Consequently, we omitted this variable in our main text but conducted several exploratory analyses and provide these for transparency.

We assessed jealousy-related conflict by asking participants every day whether they had a conflict with their partner and if so, to indicate the degree to which jealousy was related to this conflict (5-point Likert scale, 1 = "not at all", 5 = "very much"). In an attempt to analyse the low amount of data, first, we coded every day without conflict as 1 and treated it the same as a day with conflict that was not at all related to jealousy but left other values untouched (no conflict and no jealousy-related conflict = 1, "not at all"; jealousy-related conflict = 2 until 5, "very much") and analysed these according to our preregistered analysis plan using linear mixed effects models (Model 1). Importantly, this recoding violates the necessary assumption of an interval scale for this outcome. Hence, these models are only reported for transparency reasons, but we advise against uncautiously interpreting them. Second, since binary models might best reflect the highly left-skewed data structure (mostly observations with 1 and some few observations between 2 and 5), we conducted logistic mixed effects models (days with reported jealousy-related conflict coded as 1, all other days coded as 0) to predict the probability of jealousy-related conflict with women's fertility (Model 2). However, because data with jealousy-related conflict are so few and these are purely exploratory analyses, even these binary models should be interpreted with caution. We advise future research to consider assessing jealousy-related conflict as a count variable.

Supplementary Table S1 | Exploratory analyses of men's ratings of jealousy-related conflict across the ovulatory cycle

	Model 1		Model 2	
	Estimates	*99% CI*	*Odds Ratios*	*99% CI*
Level 1				
PBFW	.01	-.06, .08	.84	.03, 23.34
Premenstrual phase (yes)	.01	.-.02, .04	.95	..41, 2.23
Menstruation day (yes)	-.00	-.03, .03	.87	.38, 2.00
Direct partner contact	.00	-.00, .00	1.04	1.00, 1.08
Indirect partner contact	.00	-.01, .01	1.02	.88, 1.18
Level 2				
Hormonal contraception (yes)	.03	-.01, .08	1.52	.52, 4.45
Cross-level interaction				
PBFW:Hormonal contraception	-.04	-.15, .06	.53	.03, 9.12
Premens:Hormonal contraception	-.02	-.07, .03	.85	.27, 2.68
Mens:Hormonal contraception	-.03	-.08, .02	.69	.21, 2.34
ICC		.06		.52
N		364		364
Observations		11433		11433
Marginal R^2 / Conditional R^2		.002/.061		.010/.528

Outcomes of mixed effects models with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men in monogamous relationships were analysed. All estimates are unstandardised. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation. Models display mixed effects models using an identity (Model 1) or a logit link (Model 2). Both models should be interpreted with caution.

Supplementary Table S2 | Exploratory analyses of women's ratings of jealousy-related conflict across the ovulatory cycle

	Model 1		Model 2	
	Estimates	***99% CI***	***Odds Ratios***	***99% CI***
Level 1				
PBFW	.07	-.01, .16	.57	.02, 15.66
Premenstrual phase (yes)	.01	-.02, .04	.36	.05, 2.39
Menstruation day (yes)	.01	-.03, .04	.37	.05, 2.74
Direct partner contact	.00	-.00, .00	1.02	.98, 1.06
Indirect partner contact	.00	-.00, .01	1.08	.96, 1.22
Level 2				
Hormonal contraception (yes)	.02	-.02, .06	1.15	.43, 3.05
Cross-level interaction				
PBFW:Hormonal contraception	-.09	-.21, .03	.48	.03, 7.46
Premens:Hormonal contraception	-.00	-.05, .05	.87	.22, 3.51
Mens:Hormonal contraception	-.03	-.08, .02	.57	.13, 2.41
ICC		.07		.55
N		364		364
Observations		12119		12119
Marginal R^2 / Conditional R^2		.001/.070		.036/.571

Outcomes of mixed effects models with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of women in monogamous relationships were analysed. All estimates are unstandardised. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation. Models display mixed effects models using an identity (Model 1) or a logit link (Model 2). Both models should be interpreted with caution.

2. Standardised estimates of all outcomes of interest

Supplementary Table S3 | Men's ratings of women's attractiveness across the ovulatory cycle

	Men rate women's attractiveness			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	-.13	.07	-.32, .06	.081
Premenstrual phase (yes)	-.07	.03	-.15, .01	.032
Menstruation day (yes)	-.10	.03	-.19, -.01	.004
Direct partner contact	.03	.00	.02, .03	<.001
Indirect partner contact	.02	.01	.01, .03	<.001
Level 2				
Hormonal contraception (yes)	.05	.08	-.15, .25	.512
Cross-level interaction				
PBFW:Hormonal contraception	.07	.11	-.21, .36	.518
Premens:Hormonal contraception	.04	.05	-.08, .17	.351
Mens:Hormonal contraception	.06	.05	-.08, .19	.273
ICC				.51
N				384
Observations				11855
Marginal R^2 / Conditional R^2				.023/.519

Outcomes of mixed effects model 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. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S4 | Men's ratings of women's general sexual desire across the ovulatory cycle

	Men rate women's general sexual desire			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	.16	.08	-.04, .36	.039
Premenstrual phase (yes)	-.09	.03	-.18, -.01	.005
Menstruation day (yes)	-.17	.04	-.27, -.08	<.001
Direct partner contact	.04	.00	.03, .04	<.001
Indirect partner contact	.02	.01	.01, .04	.001
Level 2				
Hormonal contraception (yes)	.23	.07	.05, .41	.001
Cross-level interaction				
PBFW:Hormonal contraception	-.21	.11	-.50, .09	.072
Premens:Hormonal contraception	.07	.05	-.05, .20	.134
Mens:Hormonal contraception	.06	.06	-.08, .20	.272
ICC				.38
N				384
Observations				11855
Marginal R^2 / Conditional R^2				.051/.411

Outcomes of mixed effects model 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. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S5 | Men's ratings of women's wish for contact to others across the ovulatory cycle

	Men rate women's wish for contact with others			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	-.09	.08	-.29, .12	.280
Premenstrual phase (yes)	.05	.03	-.14, .03	.097
Menstruation day (yes)	-.10	.04	-.19, -.01	.004
Direct partner contact	-.01	.00	-.02, -.01	<.001
Indirect partner contact	-.00	.01	-.01, .01	.457
Level 2				
Hormonal contraception (yes)	.08	.07	-.11, .27	.275
Cross-level interaction				
PBFW:Hormonal contraception	.22	.12	-.08, .53	.060
Premens:Hormonal contraception	.13	.05	.00, .25	.009
Mens:Hormonal contraception	.13	.05	-.00, .27	.012
ICC				
N				384
Observations				11855
Marginal R^2 / Conditional R^2				.014/.440

Outcomes of mixed effects model 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. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S6 | Men's ratings of men's jealousy across the ovulatory cycle

	Men rate their jealousy			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	.10	.09	-.13, .32	.278
Premenstrual phase (yes)	.01	.04	-.09, .11	.761
Menstruation day (yes)	-.01	.04	-.11, .09	.816
Direct partner contact	.00	.00	-.00, .01	.275
Indirect partner contact	-.00	.01	-.02, .01	.757
Level 2				
Hormonal contraception (yes)	.09	.08	-.11, .29	.231
Cross-level interaction				
PBFW:Hormonal contraception	-.10	.13	-.44, .23	.438
Premens:Hormonal contraception	.00	.06	-.14, .15	.957
Mens:Hormonal contraception	.00	.06	-.15, .15	.968
ICC				.36
N				364
Observations				11433
Marginal R^2 / Conditional R^2				.002/.362

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S7 | Women's ratings of men's jealousy across the ovulatory cycle

	Women rate men's jealousy			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	.12	.08	-.08, .32	.126
Premenstrual phase (yes)	-.02	.04	-.12, .08	.639
Menstruation day (yes)	-.03	.04	-.13, .06	.336
Direct partner contact	-.00	.00	-.01, .00	.750
Indirect partner contact	.01	.01	-.01, .02	.196
Level 2				
Hormonal contraception (yes)	.01	.06	-.16, .18	.871
Cross-level interaction				
PBFW:Hormonal contraception	-.11	.12	-.41, .19	.345
Premens:Hormonal contraception	.03	.06	-.12, .17	.620
Mens:Hormonal contraception	.03	.05	-.11, .16	.618
ICC				.26
N				364
Observations				11945
Marginal R^2 / Conditional R^2				.001/.258

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of women in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S8 | Men's ratings of men's attention to their partners across the ovulatory cycle

	Men rate their attention to their partners			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	.11	.07	-.07, .30	.106
Premenstrual phase (yes)	.01	.04	-.08, .10	.728
Menstruation day (yes)	-.01	.04	-.11, .08	.730
Direct partner contact	.08	.00	.07, .08	<.001
Indirect partner contact	.07	.01	.05, .08	<.001
Level 2				
Hormonal contraception (yes)	.08	.06	-.08, .25	.179
Cross-level interaction				
PBFW:Hormonal contraception	-.10	.10	-.37, .17	.342
Premens:Hormonal contraception	.03	.05	-.11, .16	.627
Mens:Hormonal contraception	.05	.05	-.09, .19	.338
ICC				.32
N				364
Observations				11433
Marginal R^2 / Conditional R^2				.157/.428

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S9 | Women's ratings of men's attention to them across the ovulatory cycle

	Women rate men's attention to them			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1				
PBFW	.01	.08	-.19, .21	.923
Premenstrual phase (yes)	-.06	.04	-.15, .04	.131
Menstruation day (yes)	-.05	.04	-.15, .05	.170
Direct partner contact	.07	.00	.06, .07	<.001
Indirect partner contact	.06	.01	.05, .08	<.001
Level 2				
Hormonal contraception (yes)	.13	.06	-.03, .29	.031
Cross-level interaction				
PBFW:Hormonal contraception	-.09	.11	-.38, .21	.452
Premens:Hormonal contraception	.06	.06	-.09, .20	.301
Mens:Hormonal contraception	.03	.06	-.11, .18	.578
ICC				.31
N				364
Observations				11945
Marginal R^2 / Conditional R^2				.126/.400

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of women in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S10 | Men's ratings of their wish for contact with their female partners across the ovulatory cycle

	Men rate their wish for contact to their partners			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1		.		
PBFW	.00	.08	-.21, .22	.966
Premenstrual phase (yes)	-.04	.04	-.14, .06	.301
Menstruation day (yes)	.00	.04	-.10, .10	.929
Direct partner contact	-.01	.00	-.01, -.00	<.001
Indirect partner contact	.03	.01	.01, .04	<.001
Level 2				
Hormonal contraception (yes)	.10	.08	-.10, .31	.199
Cross-level interaction				
PBFW:Hormonal contraception	.01	.12	-.30, .32	.929
Premens:Hormonal contraception	.08	.06	-.07, .22	.175
Mens:Hormonal contraception	.00	.06	-.14, .15	.944
ICC				.44
N				364
Observations				11433
Marginal R^2 / Conditional R^2				.009/.447

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

Supplementary Table S11 | Men's ratings of their in-pair sexual desire across the ovulatory cycle

	Men rate their in-pair sexual desire			
	Std.Est.	*SE*	*99% CI*	*p*
Level 1		.		
PBFW	.06	.08	-.13, .26	.403
Premenstrual phase (yes)	-.07	.03	-.15, .02	.053
Menstruation day (yes)	-.11	.04	-.20, -.01	.004
Direct partner contact	.04	.00	.03, .04	<.001
Indirect partner contact	.04	.01	.03, .06	<.001
Level 2				
Hormonal contraception (yes)	.19	.08	-.01, .39	.015
Cross-level interaction				
PBFW:Hormonal contraception	-.17	.11	-.46, .12	.128
Premens:Hormonal contraception	.01	.05	-.12, .14	.846
Mens:Hormonal contraception	-.01	.05	-.15, .13	.863
ICC				.51
N				364
Observations				11307
Marginal R^2 / Conditional R^2				.045/.533

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions. Only data of men in monogamous relationships were analysed. 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 bleedings 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), *Std. Est.* = standardised estimate, *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

3. Complete tables of main results

Table S12 | Complete overview of male ratings of women's cues to fertility across the ovulatory cycle including random effects

	Model 1				Model 2				Model 3			
	Men rate women's attractiveness				Men rate women's 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	.081	0.21	0.10	-0.05, 0.48	.039	-0.10	0.09	-0.33, 0.13	.280
Premenstrual phase (yes)	-0.06	0.03	-0.14, 0.01	.032	-0.12	0.04	-0.24, -0.01	.005	-0.06	0.04	-0.16, 0.03	.097
Menstruation day (yes)	-0.09	0.03	-0.17, -0.01	.004	-0.23	0.05	-0.36, -0.11	<.001	-0.12	0.04	-0.22, -0.01	.004
Direct partner contact	0.03	0.00	0.02, 0.03	<.001	0.05	0.00	0.04, 0.05	<.001	-0.01	0.00	-0.02, -0.01	<.001
Indirect partner contact	0.02	0.01	0.01, 0.03	<.001	0.03	0.01	0.01, 0.05	.001	-0.00	0.01	-0.02, 0.01	.457
Level 2												
Hormonal contraception (yes)	0.05	0.07	-0.14, 0.23	.512	0.31	0.09	0.06, 0.55	.001	0.09	0.08	-0.12, 0.30	.275
Cross-level interaction												
PBFW:Hormonal contraception	0.06	0.10	-0.19, 0.32	.518	-0.28	0.15	-0.67, 0.12	.072	0.25	0.13	-0.09, 0.59	.060
Premens:Hormonal contraception	0.04	0.04	-0.07, 0.15	.351	0.10	0.06	-0.07, 0.26	.134	0.14	0.05	0.00, 0.28	.009
Mens:Hormonal contraception	0.05	0.05	-0.07, 0.17	.273	0.08	0.07	-0.11, 0.27	.272	0.15	0.06	-0.00, 0.30	.012
Random effects												
σ^2	0.41				1.07				0.71			
τ_{00}	0.41_{men}				0.65_{men}				0.52_{men}			
τ_{11}	0.35_{pbfw}				0.66_{pbfw}				0.62_{pbfw}			
	$0.05_{premenstrual\_phase}$				$0.06_{premenstrual\_phase}$				$0.06_{premenstrual\_phase}$			
	$0.07_{menstruation\_day}$				$0.16_{menstruation\_day}$				$0.10_{menstruation\_day}$			
ρ_{01}	-0.17				-0.24				-0.17			
	-0.13				-0.13				-0.23			
	-0.13				-0.18				-0.09			

ICC	0.51	0.38	0.43
N	384 men	384 men	384 men
Observations	11855	11855	11855
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. 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, σ^2 = residual variance, τ_{00} = between-subject variance, τ_{11} = variance random slope, ρ_{01} = correlation random intercept and random slope, *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).

Table S13 | Complete overview of male and female ratings of men's mate retention tactics across the ovulatory cycle including random effects

	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	.278	0.06	0.04	-0.04, 0.17	.126	0.12	0.07	-0.07, 0.30	.106
Premenstrual phase (yes)	0.01	0.02	-0.05, 0.06	.761	-0.01	0.02	-0.06, 0.04	.639	0.01	0.04	-0.08, 0.10	.728
Menstruation day (yes)	-0.01	0.02	-0.06, 0.05	.816	-0.02	0.02	-0.06, 0.03	.336	-0.01	0.04	-0.11, 0.08	.730
Direct partner contact	0.00	0.00	-0.00, 0.00	.275	-0.00	0.00	-0.00, 0.00	.750	0.08	0.00	0.07, 0.08	<.001
Indirect partner contact	-0.00	0.00	-0.01, 0.01	.757	0.00	0.00	-0.00, 0.01	.196	0.07	0.01	0.05, 0.08	<.001
Level 2												
Hormonal contraception (yes)	0.05	0.04	-0.06, 0.17	.231	0.01	0.03	-0.08, 0.09	.871	0.08	0.06	-0.08, 0.25	.179
Cross-level interaction												
PBFW:Hormonal contraception	-0.06	0.08	-0.25, 0.14	.438	-0.06	0.06	-0.21, 0.10	.345	-0.10	0.10	-0.37, 0.17	.342
Premens:Hormonal contraception	0.00	0.03	-0.08, 0.09	.957	0.01	0.03	-0.06, 0.09	.620	0.03	0.05	-0.11, 0.16	.627
Mens:Hormonal contraception	0.00	0.03	-0.09, 0.09	.968	0.01	0.03	-0.06, 0.08	.618	0.05	0.06	-0.09, 0.20	.338
Random effects												
σ^2	0.22				0.20				0.60			
τ_{00}	0.15 $_{men}$				0.07 $_{women}$				0.26 $_{men}$			
τ_{11}	0.19 $_{pbfw}$				0.06 $_{pbfw}$				0.15 $_{pbfw}$			
	0.03 $_{premenstrual\_phase}$				0.02 $_{premenstrual\_phase}$				0.06 $_{premenstrual\_phase}$			
	0.03 $_{menstruation\_day}$				0.01 $_{menstruation\_day}$				0.08 $_{menstruation\_day}$			
ρ_{01}	-0.50				-0.15				-0.08			
	-0.34				-0.16				-0.09			
	-0.46				-0.56				-0.05			
ICC	0.36				0.26				0.32			
N	364 $_{men}$				364 $_{women}$				364 $_{men}$			
Observations	11433				11945				11433			

Marginal R^2 / Conditional R^2	0.002 / 0.362				0.001 / 0.258				0.157 / 0.428			

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. 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, σ^2 = residual variance, τ_{00} = between-subject variance, τ_{11} = variance random slope, ρ_{01} = correlation random intercept and random slope, *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).

Table S13 |continued

	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	.923	0.00	0.08	-0.21, 0.22	.966	0.07	0.09	-0.16, 0.30	.403
Premenstrual phase (yes)	-0.06	0.04	-0.16, 0.04	.131	-0.04	0.04	-0.14, 0.06	.301	-0.08	0.04	-0.18, 0.03	.053
Menstruation day (yes)	-0.05	0.04	-0.15, 0.05	.170	0.00	0.04	-0.10, 0.10	.929	-0.12	0.04	-0.24, -0.01	.004
Direct partner contact	0.07	0.00	0.06, 0.07	<.001	-0.01	0.00	-0.01, -0.00	<.001	0.04	0.00	0.04, 0.05	<.001
Indirect partner contact	0.06	0.01	0.05, 0.08	<.001	0.03	0.01	0.01, 0.04	<.001	0.05	0.01	0.03, 0.07	<.001
Level 2												
Hormonal contraception (yes)	0.13	0.06	-0.03, 0.29	.031	0.10	0.08	-0.10, 0.31	.199	0.22	0.09	-0.01, 0.46	.015
Cross-level interaction												
PBFW:Hormonal contraception	-0.09	0.12	-0.39, 0.21	.452	0.01	0.12	-0.30, 0.32	.929	-0.20	0.13	-0.54, 0.14	.128
Premens:Hormonal contraception	0.06	0.06	-0.09, 0.20	.301	0.08	0.06	-0.07, 0.22	.175	0.01	0.06	-0.14, 0.16	.846
Mens:Hormonal contraception	0.03	0.06	-0.12, 0.18	.578	0.00	0.06	-0.14, 0.15	.944	-0.01	0.06	-0.17, 0.15	.863
Random effects												
σ^2	0.64				0.59				0.65			
τ_{00}	0.24 $_{women}$				0.47 $_{men}$				0.64 $_{men}$			
τ_{11}	0.36 $_{pbfw}$				0.45 $_{pbfw}$				0.57 $_{pbfw}$			
	0.09 $_{premenstrual\_phase}$				0.10 $_{premenstrual\_phase}$				0.10 $_{premenstrual\_phase}$			

	0.10 $_{menstruation\_day}$	0.10 $_{menstruation\_day}$	0.14 $_{menstruation\_day}$
ρ_{01}	-0.09	-0.22	-0.14
	0.02	-0.24	-0.05
	-0.12	-0.21	-0.08
ICC	0.31	0.44	0.51
N	364 $_{women}$	364 $_{men}$	364 $_{men}$
Observations	11945	11433	11307
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. 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, σ^2 = residual variance, τ_{00} = between-subject variance, τ_{11} = variance random slope, ρ_{01} = correlation random intercept and random slope, *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).

4. Robustness analyses

4.1 *Women's attractiveness*

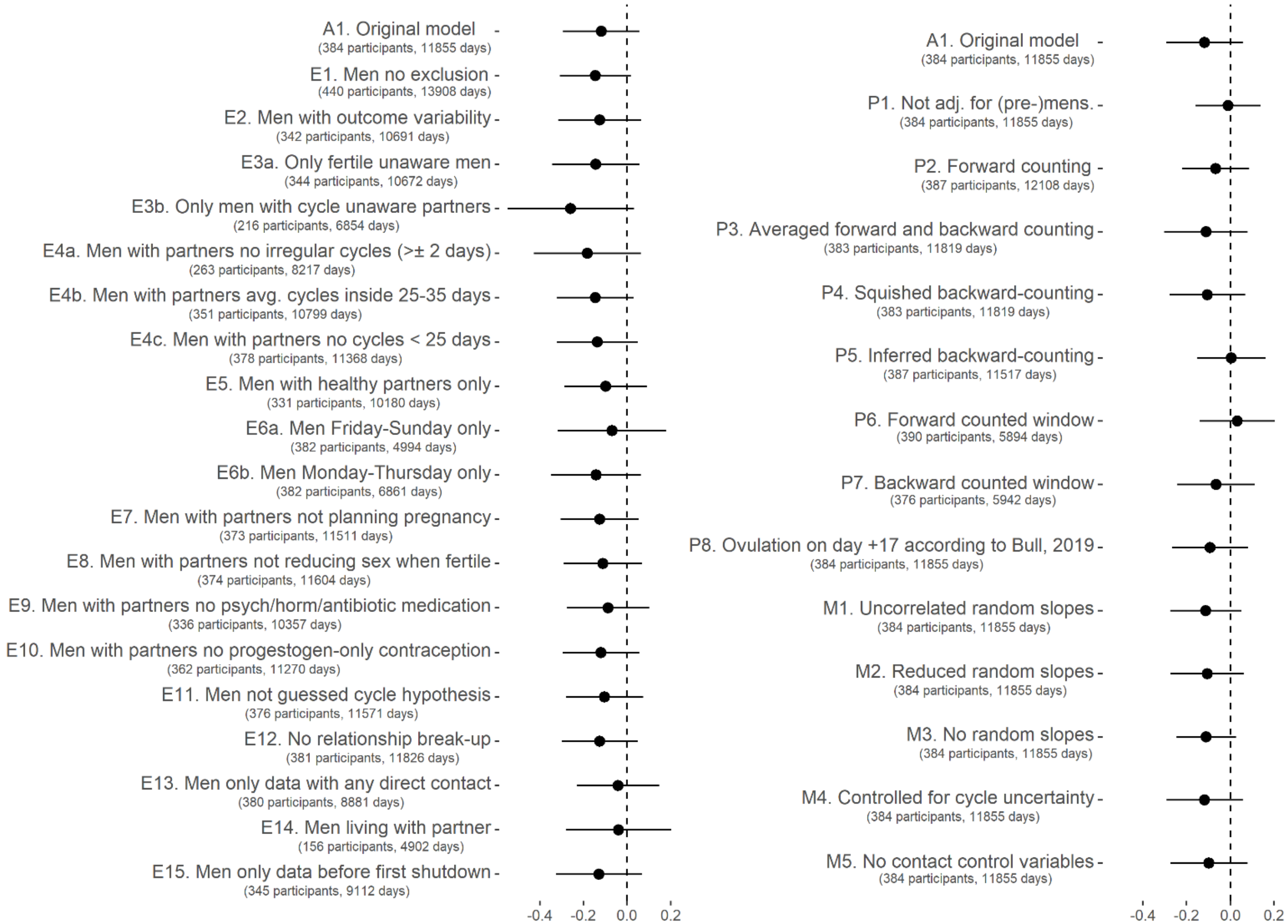

Fig. S1. Robustness analyses for men's ratings of women's attractiveness across the ovulatory cycle. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S14 | Men's ratings of women's attractiveness across the ovulatory cycle with contact of couple as moderator variable

	Men rate women's attractiveness			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	-0.20	0.10	-0.46, 0.07	.057
Premenstrual phase (yes)	-0.11	0.05	-0.23, 0.01	.020
Menstruation day (yes)	-0.14	0.05	-0.26, -0.02	.004
Hormonal contraception (yes)	0.14	0.08	-0.07, 0.35	.084
Contact aggregated	0.03	0.00	0.02, 0.04	<.001
PBFW:Hormonal contraception	-0.00	0.15	-0.39, 0.39	.999
Premens:Hormonal contraception	0.05	0.07	-0.13, 0.23	.475
Mens:Hormonal contraception	0.02	0.07	-0.16, 0.21	.746
PBFW:Contact aggregated	0.01	0.01	-0.02, 0.04	.344
Premens:Contact aggregated	0.01	0.01	-0.01, 0.02	.224
Mens:Contact aggregated	0.01	0.00	-0.01, 0.02	.196
Hormonal contraception:Contact aggregated	-0.01	0.01	-0.03, 0.00	.016
PBFW:Hormonal contraception:Contact aggregated	0.01	0.02	-0.03, 0.05	.564
Premens:Hormonal contraception:Contact aggregated	-0.00	0.01	-0.02, 0.02	.842
Mens:Hormonal contraception:Contact aggregated	0.00	0.01	-0.02, 0.02	.618
ICC				0.51
N				384
Observations				11855
Marginal R^2 / Conditional R^2				0.024 / 0.519

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Data of all men regardless of relationship type were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.2 Women's general sexual desire

Supplementary Table S15 | Men's ratings of women's general sexual desire across the ovulatory cycle with contact of couple as moderator variable

	Men rate women's sexual desire			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	0.02	0.16	-0.40 ,0.43	.923
Premenstrual phase (yes)	-0.11	0.07	-0.29, 0.08	.137
Menstruation day (yes)	-0.20	0.08	-0.40 – -0.00	.010
Hormonal contraception (yes)	0.34	0.11	0.05, 0.63	.003
Contact aggregated	0.05	0.01	0.03, 0.06	<.001
PBFW:Hormonal contraception	-0.27	0.24	-0.89, 0.34	.253
Premens:Hormonal contraception	0.00	0.11	-0.27, 0.28	.966
Mens:Hormonal contraception	0.03	0.12	-0.27, 0.33	.815
PBFW:Contact aggregated	0.03	0.02	-0.02, 0.07	.129
Premens:Contact aggregated	-0.00	0.01	-0.02, 0.02	.789
Mens:Contact aggregated	-0.00	0.01	-0.03, 0.02	.553
Hormonal contraception:Contact aggregated	-0.01	0.01	-0.03, 0.02	.511
PBFW:Hormonal contraception:Contact aggregated	0.00	0.03	-0.06, 0.07	.949
Premens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.02, 0.04	.290
Mens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.03, 0.04	.570
ICC				0.38
N				384
Observations				11855
Marginal R^2 / Conditional R^2				0.052 / 0.409

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Data of all men regardless of relationship type were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.3 *Women's wish for contact with others*

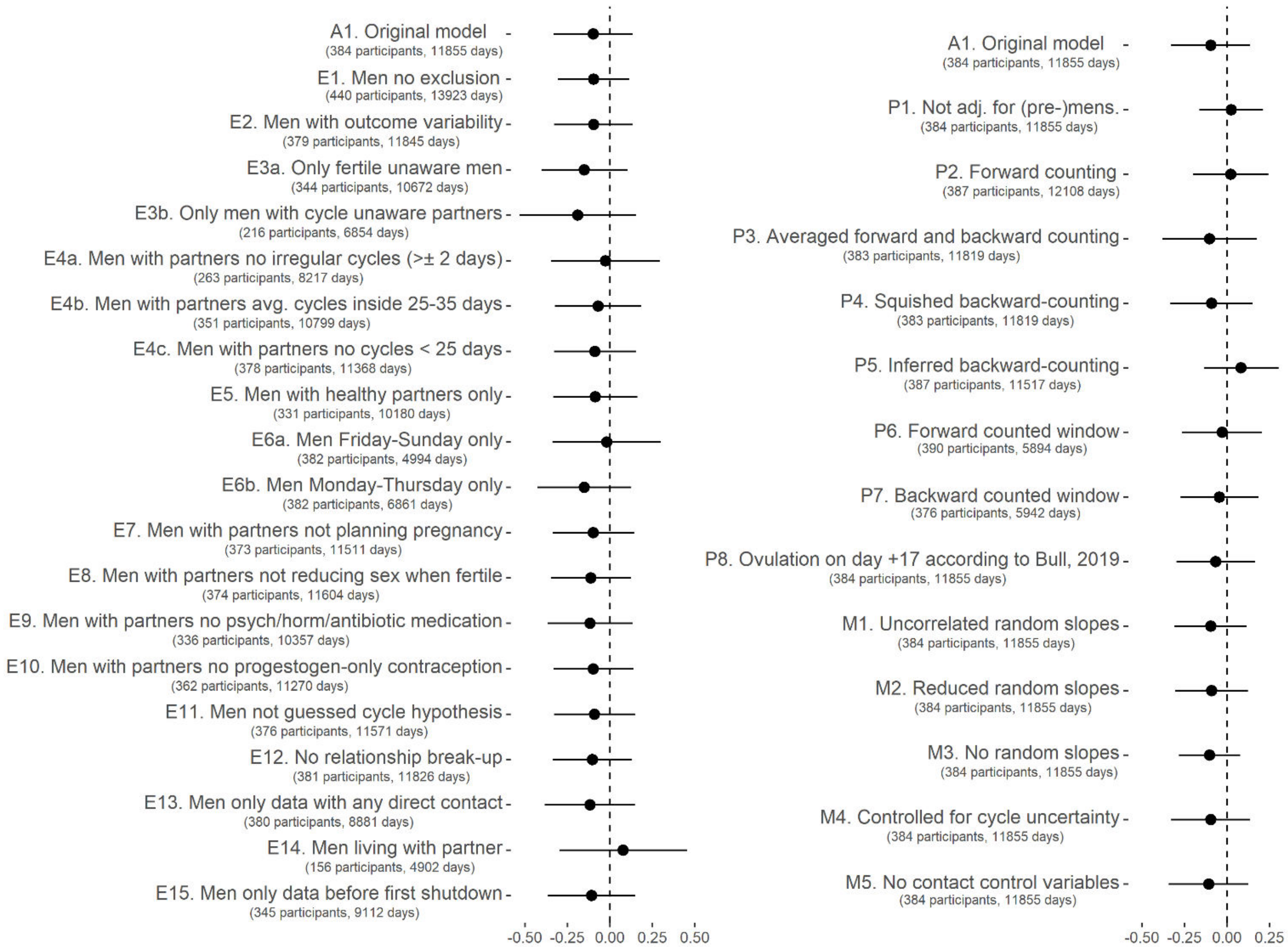

Fig. S2. Robustness analyses for men's ratings of women's wish for contact with others. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S16 | Men's ratings of women's wish for contact with others across the ovulatory cycle with contact of couple as moderator variable

	Men rate women's wish for contact with others			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	-0.06	0.14	-0.41, 0.30	.671
Premenstrual phase (yes)	-0.04	0.06	-0.19, 0.12	.537
Menstruation day (yes)	-0.14	0.06	-0.30, 0.02	.026
Hormonal contraception (yes)	0.05	0.10	-0.21, 0.30	.642
Contact aggregated	-0.02	0.00	-0.03, -0.00	.002
PBFW:Hormonal contraception	0.36	0.20	-0.17, 0.88	.079
Premens:Hormonal contraception	0.16	0.09	-0.07, 0.39	.069
Mens:Hormonal contraception	0.16	0.09	-0.08, 0.40	.090
PBFW:Contact aggregated	-0.00	0.01	-0.04, 0.03	.732
Premens:Contact aggregated	-0.00	0.01	-0.02, 0.01	.601
Mens:Contact aggregated	0.00	0.01	-0.01, 0.02	.649
Hormonal contraception:Contact aggregated	0.01	0.01	-0.01, 0.03	.357
PBFW:Hormonal contraception:Contact aggregated	-0.02	0.02	-0.07, 0.04	.464
Premens:Hormonal contraception:Contact aggregated	-0.00	0.01	-0.03, 0.02	.797
Mens:Hormonal contraception:Contact aggregated	-0.00	0.01	-0.03, 0.03	.957
ICC				0.43
N				384
Observations				11855
Marginal R^2 / Conditional R^2				0.014 / 0.439

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Data of all men regardless of relationship type were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.4 Men's jealousy rated by men

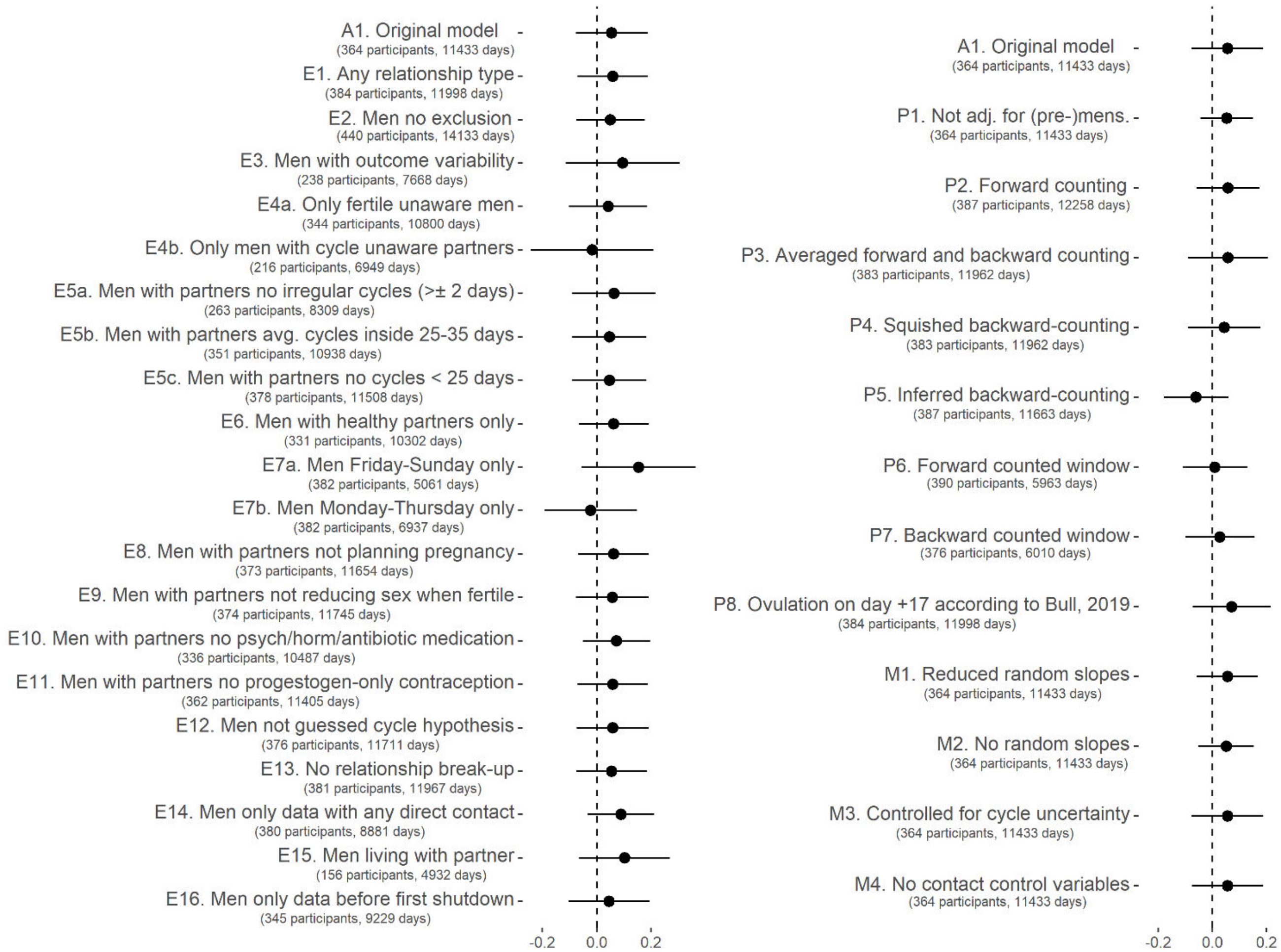

Fig. S3. Robustness analyses for men's ratings of their jealousy. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness analyses with 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase. The model of uncorrelated random slopes did not converge and is therefore omitted.

Supplementary Table S17 | Men's ratings of their jealousy across the ovulatory cycle with contact of couple as moderator variable

	Men rate their jealousy			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	-0.06	0.08	-0.27, 0.14	.420
Premenstrual phase (yes)	-0.02	0.03	-0.11, 0.07	.563
Menstruation day (yes)	-0.03	0.04	-0.13, 0.06	.328
Hormonal contraception (yes)	-0.03	0.05	-0.17, 0.11	.597
Contact aggregated	-0.01	0.00	-0.01, 0.00	.055
PBFW:Hormonal contraception	0.11	0.11	-0.19, 0.40	.349
Premens:Hormonal contraception	0.04	0.05	-0.09, 0.17	.400
Mens:Hormonal contraception	0.06	0.05	-0.08, 0.19	.277
PBFW:Contact aggregated	0.02	0.01	-0.00, 0.04	.043
Premens:Contact aggregated	0.00	0.00	-0.01, 0.01	.311
Mens:Contact aggregated	0.00	0.00	-0.01, 0.01	.267
Hormonal contraception:Contact aggregated	0.01	0.00	0.00, 0.02	.006
PBFW:Hormonal contraception:Contact aggregated	-0.02	0.01	-0.05, 0.01	.058
Premens:Hormonal contraception:Contact aggregated	-0.01	0.01	-0.02, 0.01	.302
Mens:Hormonal contraception:Contact aggregated	-0.01	0.01	-0.02, 0.01	.177
ICC				0.36
N				364
Observations				11433
Marginal R^2 / Conditional R^2				0.002 / 0.362

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.5 Men's jealousy rated by women

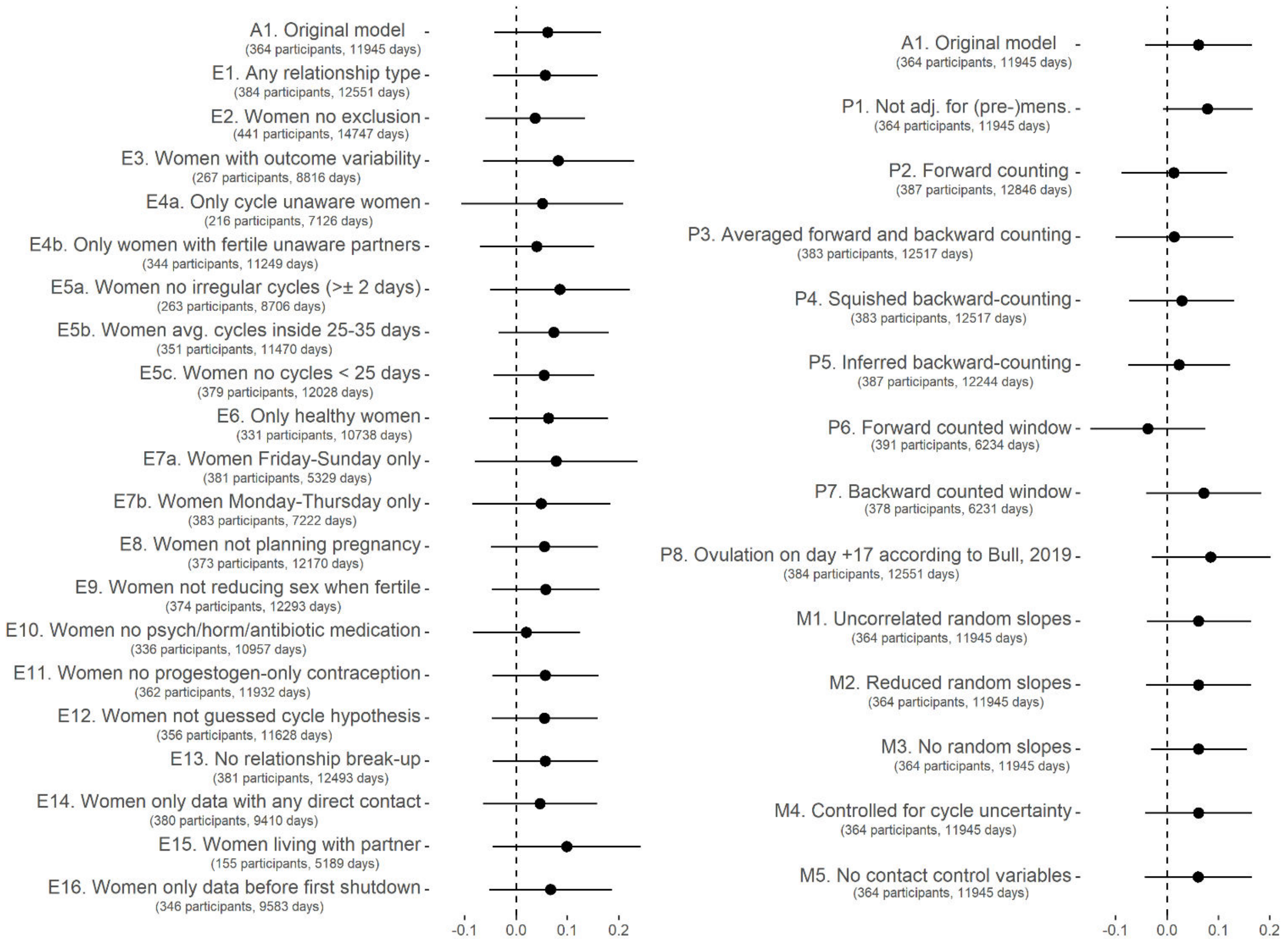

Fig. S4. Robustness analyses for women's ratings of men's jealousy. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness analyses with 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S18 | Women's ratings of men's jealousy across the ovulatory cycle with contact of couple as moderator variable

	Women rate men's jealousy			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	0.01	0.07	-0.16, 0.18	.896
Premenstrual phase (yes)	-0.02	0.03	-0.10, 0.05	.421
Menstruation day (yes)	-0.02	0.03	-0.10, 0.06	.495
Hormonal contraception (yes)	-0.01	0.04	-0.12, 0.10	.783
Contact aggregated	-0.00	0.00	-0.01, 0.00	.234
PBFW:Hormonal contraception	-0.01	0.10	-0.26, 0.24	.922
Premens:Hormonal contraception	0.02	0.05	-0.10, 0.14	.645
Mens:Hormonal contraception	0.01	0.04	-0.11, 0.12	.889
PBFW:Contact aggregated	0.01	0.01	-0.01, 0.03	.303
Premens:Contact aggregated	0.00	0.00	-0.01, 0.01	.501
Mens:Contact aggregated	0.00	0.00	-0.01, 0.01	.879
Hormonal contraception:Contact aggregated	0.00	0.00	-0.01, 0.01	.476
PBFW:Hormonal contraception:Contact aggregated	-0.01	0.01	-0.03, 0.02	.538
Premens:Hormonal contraception:Contact aggregated	-0.00	0.00	-0.01, 0.01	.838
Mens:Hormonal contraception:Contact aggregated	0.00	0.00	-0.01, 0.01	.839
ICC				0.26
N				364
Observations				11945
Marginal R^2 / Conditional R^2				0.001 / 0.259

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

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4.6 Men's attention to their partners rated by men

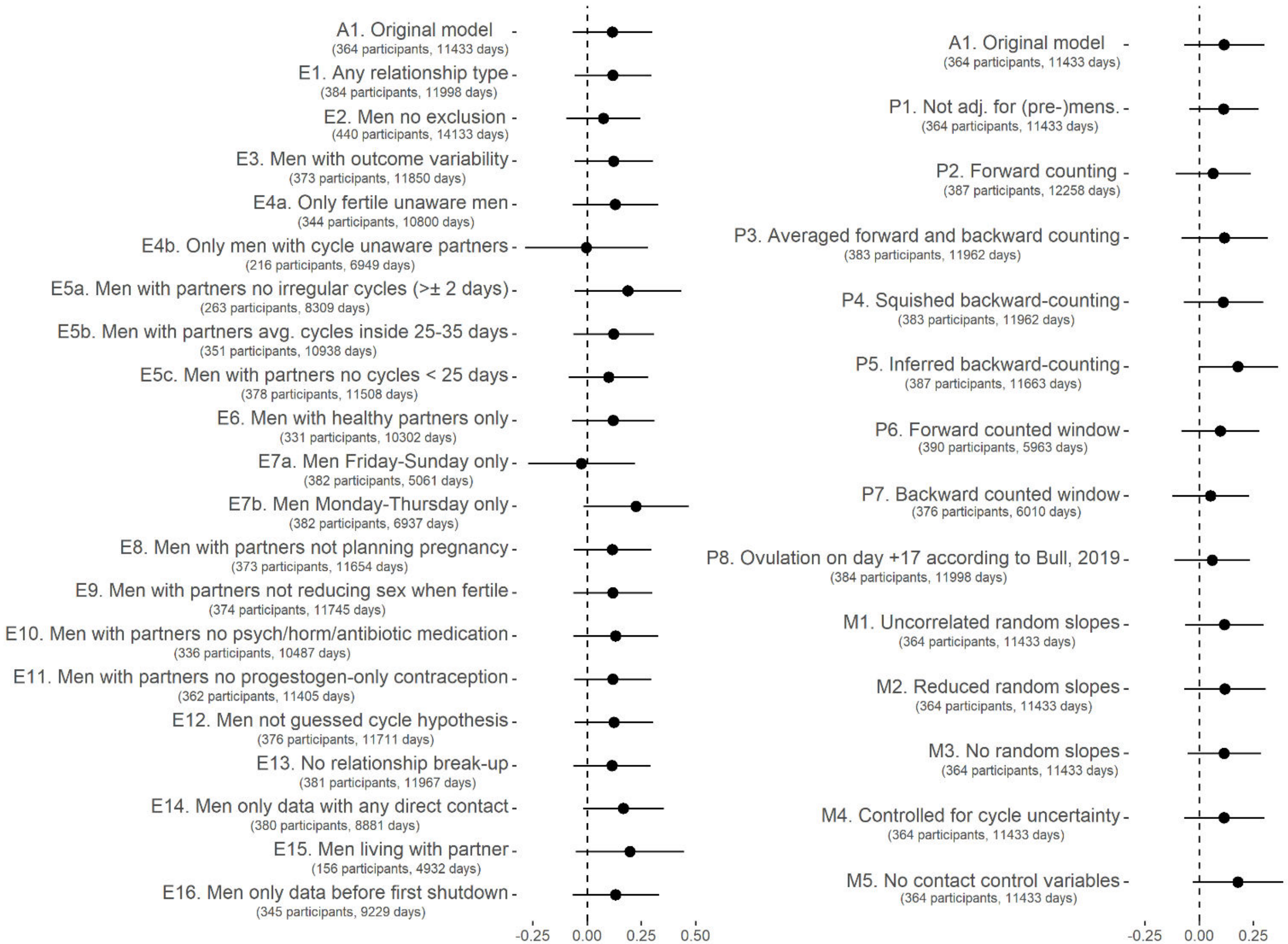

Fig. S5. Robustness analyses for men's ratings of their attention paid to their partners. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S19 | Men's ratings of their attention paid to their partners across the ovulatory cycle with contact of couple as moderator variable

	Men rate their attention to their partners			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	0.18	0.12	-0.13, 0.49	.132
Premenstrual phase (yes)	0.11	0.06	-0.04, 0.26	.051
Menstruation day (yes)	0.01	0.06	-0.14, 0.16	.849
Hormonal contraception (yes)	0.20	0.08	-0.01, 0.40	.014
Contact aggregated	0.08	0.00	0.07 – 0.10	<.001
PBFW:Hormonal contraception	-0.32	0.17	-0.76, 0.12	.064
Premens:Hormonal contraception	-0.11	0.08	-0.32, 0.11	.204
Mens:Hormonal contraception	-0.04	0.09	-0.27, 0.18	.635
PBFW:Contact aggregated	-0.01	0.01	-0.04, 0.02	.463
Premens:Contact aggregated	-0.01	0.01	-0.03, 0.00	.027
Mens:Contact aggregated	-0.00	0.01	-0.02, 0.01	.564
Hormonal contraception:Contact aggregated	-0.02	0.01	-0.03, 0.00	.017
PBFW:Hormonal contraception:Contact aggregated	0.03	0.02	-0.02, 0.08	.097
Premens:Hormonal contraception:Contact aggregated	0.02	0.01	-0.01, 0.04	.048
Mens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.01, 0.04	.161
ICC				0.32
N				364
Observations				11433
Marginal R^2 / Conditional R^2				0.158 / 0.428

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.7 Men's attention to their partners rated by women

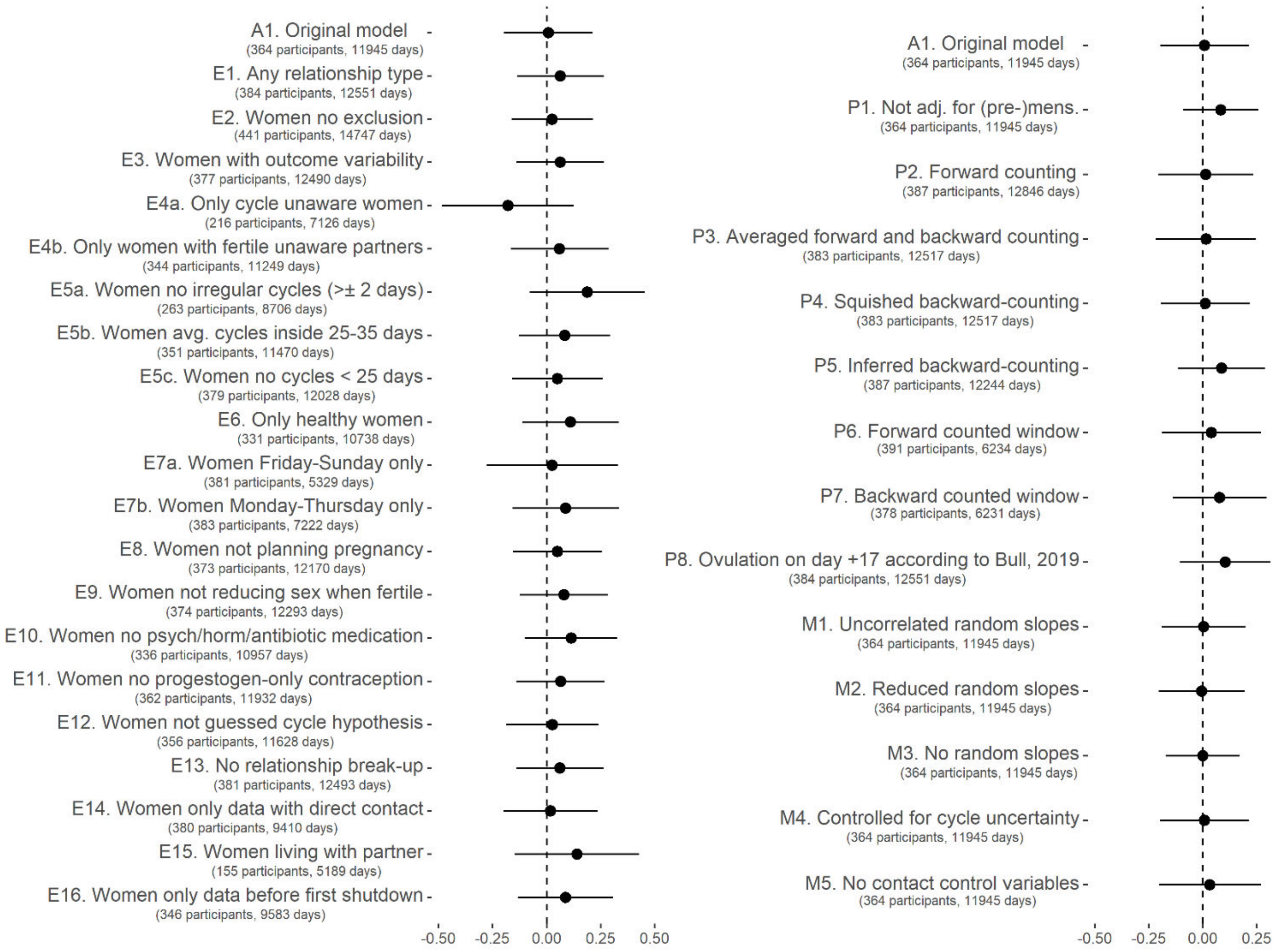

Fig. S6. Robustness analyses for women's ratings of men's attention paid to them. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S20 | Women's ratings of men's attention paid to them across the ovulatory cycle with contact of couple as moderator variable

	Women rate men's attention to them			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	0.10	0.12	-0.22, 0.42	.415
Premenstrual phase (yes)	-0.03	0.06	-0.18, 0.12	.651
Menstruation day (yes)	-0.03	0.06	-0.18, 0.12	.593
Hormonal contraception (yes)	0.22	0.08	0.02, 0.42	.005
Contact aggregated	0.07	0.00	0.06, 0.08	<.001
PBFW:Hormonal contraception	-0.27	0.18	-0.75, 0.20	.139
Premens:Hormonal contraception	-0.01	0.09	-0.24, 0.21	.902
Mens:Hormonal contraception	-0.05	0.09	-0.28, 0.18	.585
PBFW:Contact aggregated	-0.01	0.01	-0.05, 0.02	.327
Premens:Contact aggregated	-0.00	0.01	-0.02, 0.01	.468
Mens:Contact aggregated	-0.00	0.01	-0.02, 0.01	.615
Hormonal contraception:Contact aggregated	-0.01	0.01	-0.03, 0.01	.072
PBFW:Hormonal contraception:Contact aggregated	0.03	0.02	-0.03, 0.08	.198
Premens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.01, 0.03	.300
Mens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.01, 0.04	.235
ICC				0.31
N				364
Observations				11945
Marginal R^2 / Conditional R^2				0.126 / 0.400

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.8 Men's wish for contact with their partners

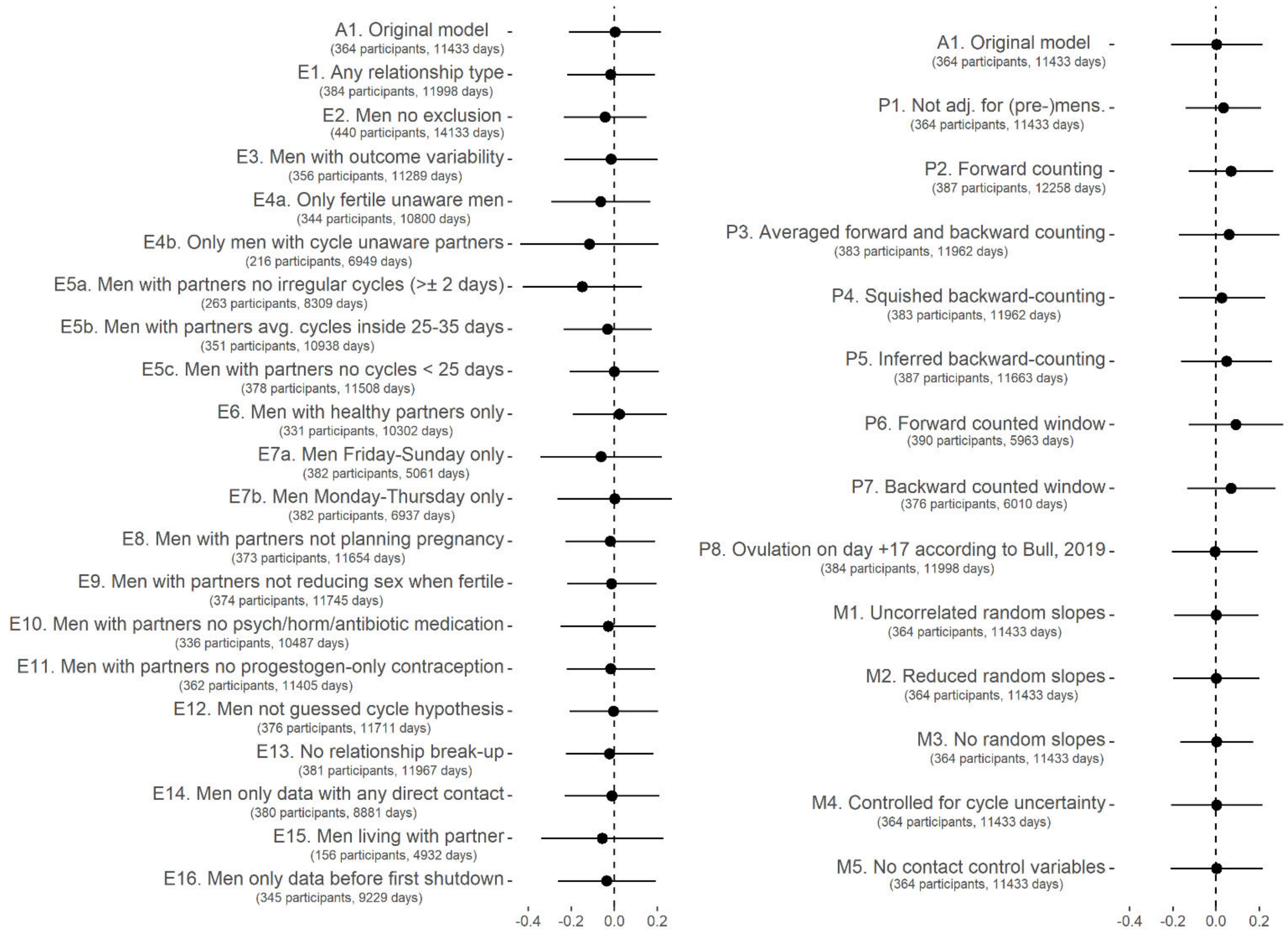

Fig. S7. Robustness analyses for men's ratings of their wish for contact with their partners. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S21 | Men's ratings of their wish for contact with their partners across the ovulatory cycle with contact of couple as moderator variable

	Men rate their wish for contact with their partners			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	-0.15	0.13	-0.48, 0.18	.253
Premenstrual phase (yes)	-0.11	0.06	-0.26, 0.05	.075
Menstruation day (yes)	-0.07	0.06	-0.22, 0.09	.251
Hormonal contraception (yes)	0.04	0.09	-0.21, 0.28	.692
Contact aggregated	-0.02	0.00	-0.03, -0.01	<.001
PBFW:Hormonal contraception	0.17	0.19	-0.32, 0.65	.374
Premens:Hormonal contraception	0.09	0.09	-0.14, 0.32	.302
Mens:Hormonal contraception	0.09	0.09	-0.14, 0.31	.330
PBFW:Contact aggregated	0.02	0.01	-0.01, 0.06	.106
Premens:Contact aggregated	0.01	0.01	-0.01, 0.03	.160
Mens:Contact aggregated	0.01	0.01	-0.01, 0.03	.109
Hormonal contraception:Contact aggregated	0.01	0.01	-0.01, 0.03	.115
PBFW:Hormonal contraception:Contact aggregated	-0.02	0.02	-0.07, 0.03	.238
Premens:Hormonal contraception:Contact aggregated	-0.00	0.01	-0.03, 0.02	.902
Mens:Hormonal contraception:Contact aggregated	-0.01	0.01	-0.04, 0.01	.234
ICC				0.45
N				364
Observations				11433
Marginal R^2 / Conditional R^2				0.006 / 0.450

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

4.9 Men's in-pair sexual desire

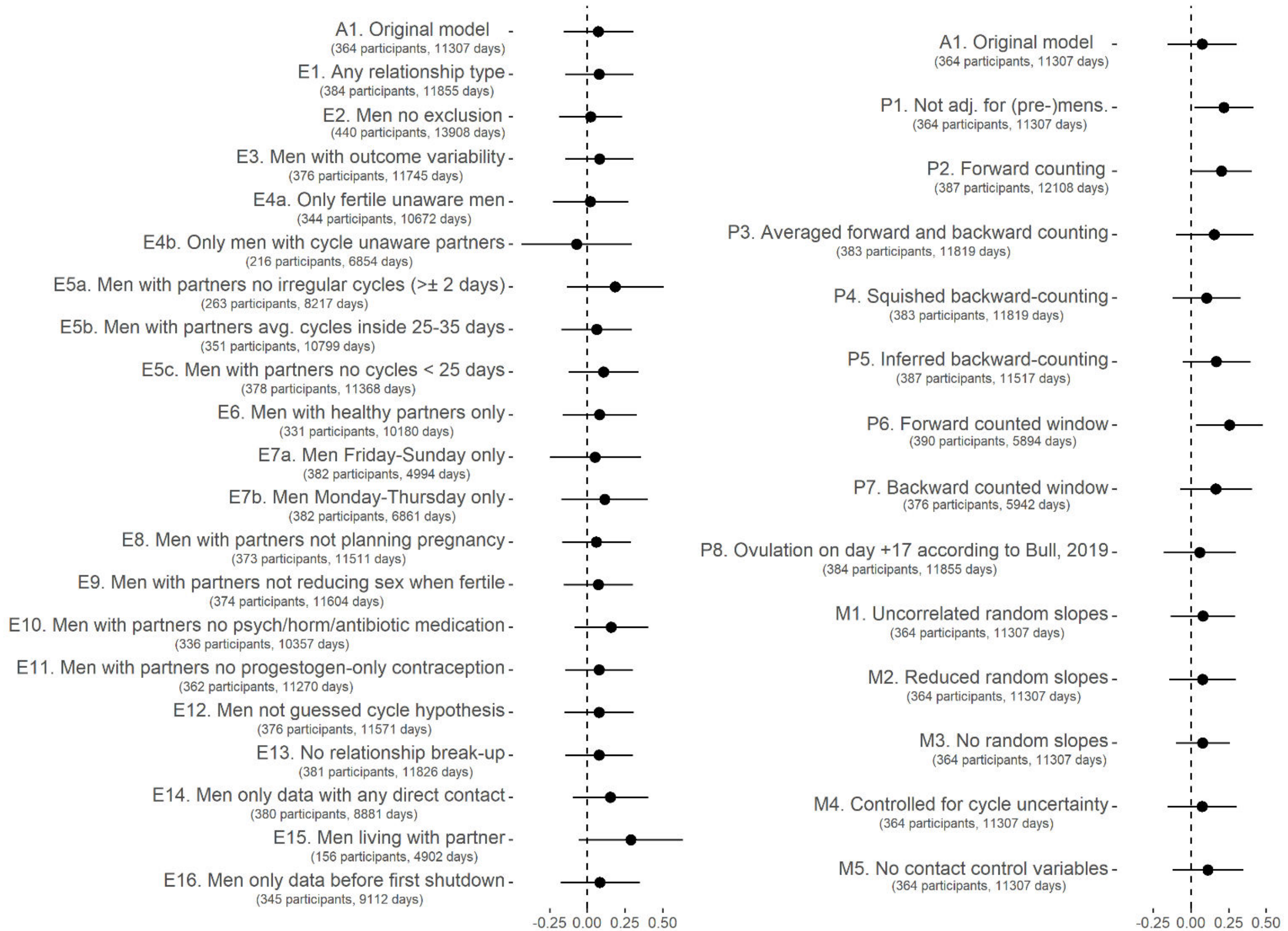

Fig. S8. Robustness analyses for men's in-pair sexual desire. The left column shows robustness analyses with different exclusion criteria, the right column shows different modelling decisions. A1 is the main model reported in the results section. Models starting with E are robustness analyses with different 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/antiobiotic = psychopharmacological, hormonal or antibiotic, adj. = adjusted, HC = hormonal contraception, (pre-)mens = premenstrual and menstrual phase.

Supplementary Table S22 | Men's ratings of their in-pair sexual desire across the ovulatory cycle with contact of couple as moderator variable

	Men rate their in-pair sexual desire			
Predictors	*Estimates*	*SE*	*99% CI*	*p*
PBFW	-0.01	0.14	-0.37, 0.34	.921
Premenstrual phase (yes)	-0.09	0.06	-0.25, 0.07	.164
Menstruation day (yes)	-0.13	0.07	-0.30, 0.04	.052
Hormonal contraception (yes)	0.33	0.11	0.06, 0.60	.002
Contact aggregated	0.05	0.00	0.03, 0.06	<.001
PBFW:Hormonal contraception	-0.18	0.20	-0.70, 0.34	.375
Premens:Hormonal contraception	-0.03	0.09	-0.27, 0.21	.773
Mens:Hormonal contraception	0.00	0.10	-0.25, 0.25	.976
PBFW:Contact aggregated	0.01	0.01	-0.03, 0.05	.426
Premens:Contact aggregated	0.00	0.01	-0.02, 0.02	.866
Mens:Contact aggregated	0.00	0.01	-0.02, 0.02	.992
Hormonal contraception:Contact aggregated	-0.01	0.01	-0.03, 0.00	.046
PBFW:Hormonal contraception:Contact aggregated	-0.00	0.02	-0.06, 0.05	.900
Premens:Hormonal contraception:Contact aggregated	0.01	0.01	-0.02, 0.03	.589
Mens:Hormonal contraception:Contact aggregated	-0.00	0.01	-0.03, 0.02	.805
ICC				0.51
N				364
Observations				11307
Marginal R^2 / Conditional R^2				0.045 / 0.534

Outcomes of mixed effects model with predictors on level 1 (daily measurements), nested in level 2 (persons) and cross-level interactions and aggregated direct and indirect contact control variables modelled as moderator. Only data of men in a monogamous relationship were analysed. 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 bleedings 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), *CI* = confidence interval, *N* = number of participants, *ICC* = intraclass correlation.

5. Comparisons of naturally cycling to quasi-control group

Supplementary Table 23 | Descriptive statistics of men and women according to hormonal contraceptive use

	Women			**Men**		
	Mean (Standard deviation)		**Hedges'g**	**Mean (Standard deviation)**		**Hedges'g**
Variable	**HC**	**NC**		**HC**	**NC**	
Age	22.70 (3.37)	24.60 (4.71)	**-.40**	24.10 (3.92)	26.20 (5.81)	**-.36**
Age at first time	16.98 (2.81)	16.80 (2.68)	.06	17.55 (2.50)	17.48 (3.39)	.02
Years of education	14.24 (3.87)	14.81 (4.49)	-.12	14.83 (4.53)	14.86 (5.15)	-.01
Religiosity (0-5)	2.18 (1.28)	2.25 (1.33)	-.05	1.92 (1.26)	1.98 (1.37)	-.04
Relationship duration (years)	2.61 (2.64)	3.52 (3.25)	**-.28**	2.62 (2.65)	3.55 (3.31)	**-.28**
Relationship satisfaction (0-5)	4.75 (0.59)	4.73 (0.62)	.03	4.78 (0.58)	4.63 (0.71)	**.21**
Average cycle length (days)	27.82 (2.18)	29.57 (3.74)	**-.46**	-	-	-
Number sexual partners	4.26 (5.58)	5.76 (7.87)	**-.19**	6.08 (8.52)	5.61 (7.76)	.06
BFI-Openness (0-5)	4.06 (0.69)	4.17 (0.64)	-.16	3.79 (0.72)	3.93 (0.74)	-.18
BFI-Conscientiousness (0-5)	3.91 (0.69)	3.68 (0.73)	**.31**	3.46 (0.70)	3.45 (0.72)	.01
BFI-Extraversion (0-5)	3.72 (0.82)	3.61 (0.81)	.14	3.47 (0.84)	3.51 (0.85)	-.05
BFI-Agreeableness (0-5)	3.19 (0.87)	3.08 (0.83)	.14	3.11 (0.82)	3.06 (0.77)	.06
BFI-Neuroticism (0-5)	3.36 (0.89)	3.41 (0.87)	-.05	2.56 (0.82)	2.60 (0.83)	-.04

Note. NC = naturally cycling (either woman or her male partner), HC = hormonal contraceptive user (either woman or her male partner), BFI = Big Five Inventory. Estimates of Hedge's g are printed in bold if comparisons of NC to HC were significant with p <.05.

6. Detailed overview of contraception methods of female participants

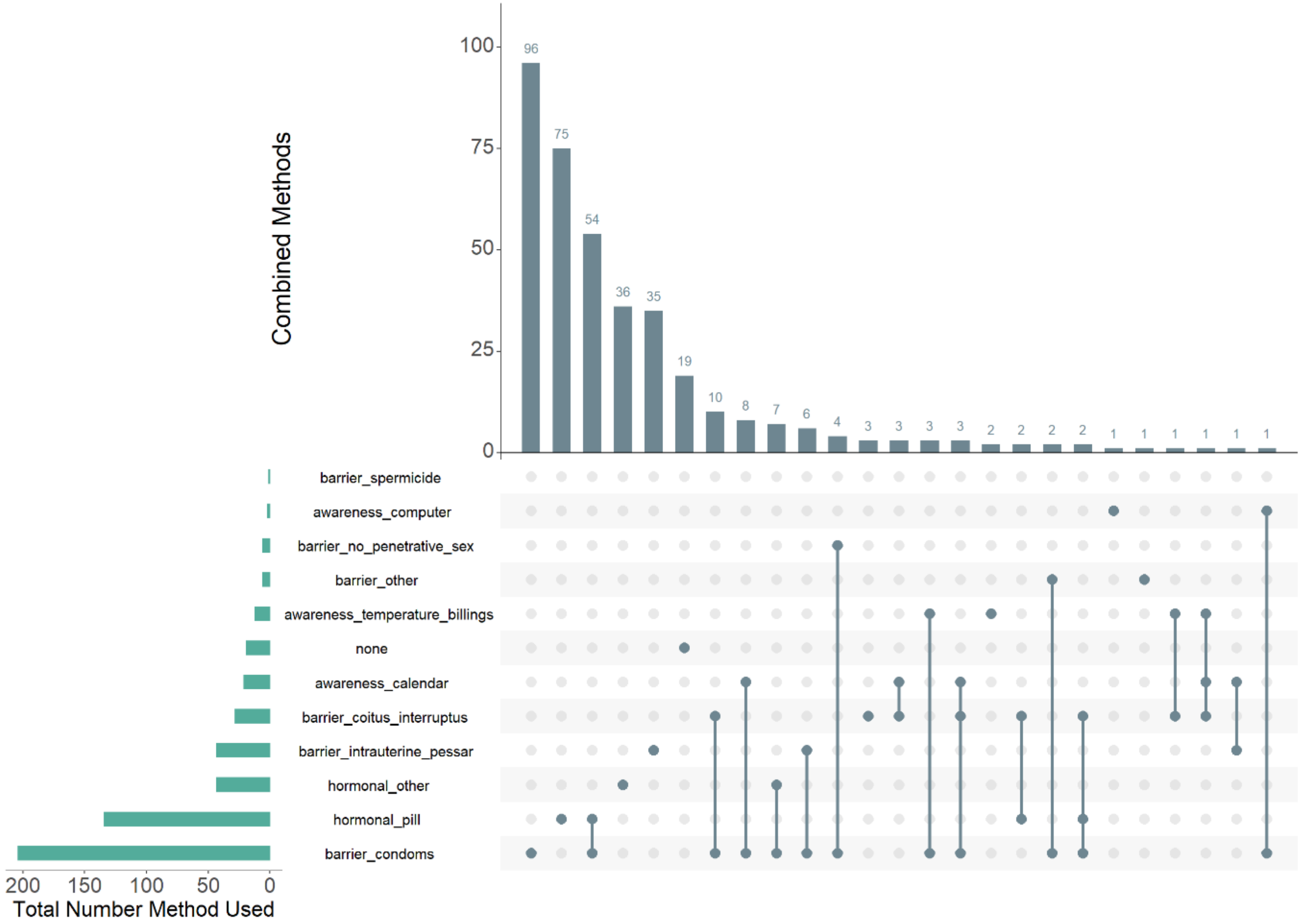

Fig. S9. Detailed contraception methods of 384 analysed women. The left-hand green bars show the overall number of women using a contraception method. The right-hand blue bars shows how many women use multiple contraception methods. The combination of contraception methods is indicated by the connecting lines and points. Fore comprehensibility, only the first 25 combinations are shown.

7. Overview of dyadic diary study design

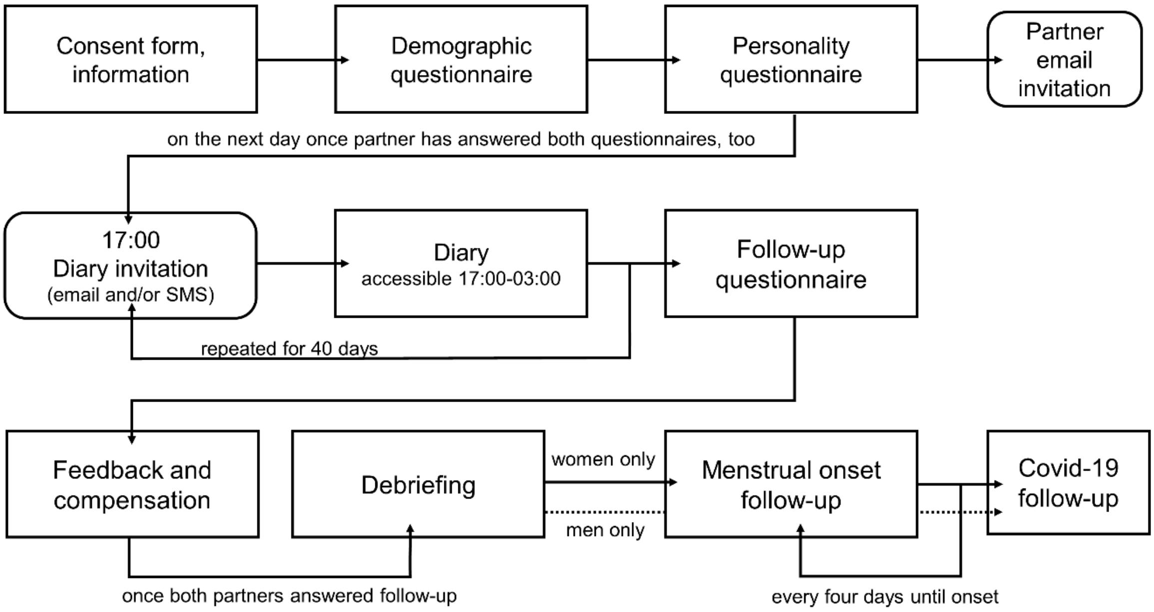

Fig. S10. Overview of study parts of the dyadic diary study.

8. Generalisability of within-subject change (multilevel reliability)

Supplementary Table 24 | Generalisability of within-subject change of measures when analysing male and female diary entries separately

For estimating the multilevel reliability of our items, variance of observations is decomposed into variance of persons, items and time using mixed effects models. Variance decomposition of time nested within people serves as generalisability of within person variations averaged over items.

Construct	Item (English Translation)	Response Format	Target	Rcn all	Rcn separate
Onset of menstrual bleedings	After having indicated to have had menstrual bleedings 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	.85	-*
Women's general sexual desire	"My partner was interested in sexual activity."	5-point Likert scale "not at all" – "very much"	Men	.86	.86
Women's wish for contact with others	"If my partner had had as much time as she wanted, she would have liked to have contact with other people besides me."	5-point Likert scale "not at all" – "very much"	Men	.85	.86
Men's jealousy	"I was jealous."	5-point Likert scale "not at all" – "very much"	Men	.86	.86
Men's jealousy	"My partner was jealous."	5-point Likert scale "not at all" – "very much"	Women	.86	.87
Men's attention to their partners	"I paid attention to my partner."	5-point Likert scale "not at all" – "very much"	Men	.86	.86
Men's attention to their partners	"My partner paid attention to me."	5-point Likert scale "not at all" – "very much"	Women	.86	.86
Men's wish for contact with partner	"If I had had as much time as I wanted, I'd have liked to have contact with my partner."	5-point Likert scale "not at all" – "very much"	Men	.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	.74	-*

Rcn all = Reliability of change or generalisability of within person variations averaged over items, analysing data of all participants, Rcn separate = Reliability of change or generalisability of within person variations averaged over items, analysing only data of respective target (men or women). * indicates that models did not converge with separate analyses per target.

Appendix D

Curriculum Vitae

[Curriculum vitae omitted from online version]