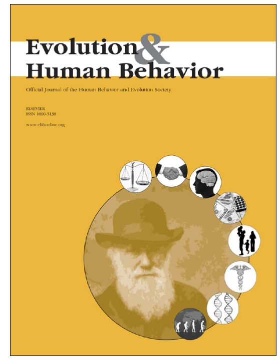
Journal Pre-proof



Variation in sociosexuality across natural menstrual cycles: Associations with ovarian hormones and cycle phase

Urszula M. Marcinkowska, M. Mijas, K. Koziara, Nicholas M. Grebe, G. Jasienska

PII: S1090-5138(20)30077-5

DOI: https://doi.org/10.1016/j.evolhumbehav.2020.06.008

Reference: ENS 6337

To appear in: *Evolution and Human Behavior*

Received date: 24 June 2019

Revised date: 17 June 2020

Accepted date: 18 June 2020

Please cite this article as: U.M. Marcinkowska, M. Mijas, K. Koziara, et al., Variation in sociosexuality across natural menstrual cycles: Associations with ovarian hormones and cycle phase, *Evolution and Human Behavior* (2020), https://doi.org/10.1016/j.evolhumbehav.2020.06.008

Variation in Sociosexuality Across Natural Menstrual Cycles: Associations with Ovarian Hormones and Cycle Phase

Urszula M. Marcinkowska[1,*] ummarcinkowska@gmail.com, M. Mijas[1], K. Koziara[2], Nicholas M. Grebe[3], G. Jasienska[1]

[1]Department of Environmental Health, Faculty of Health Sciences, Jagiellonian University Medical College, Grzegorzecka st. 20, 31-531, Cracow, Poland

[2]Institute of Psychology, Faculty of Philosophy, Jagiellonian University, Ingardena st. 6, 30-060, Cracow, Poland

[3]Evolutionary Anthropology Department, Duke University, Durham, NC 27708-9976, USA

[*]Corresponding author.

Abstract

The psychological construct of sociosexuality—one's sexual openness or propensity to engage in uncommitted sexual relationships—has been broadly examined within numerous cultures and mating contexts. Although there is some evidence suggesting that components of sociosexuality, namely behavior, desire and attitude, change within-person, relatively little research has investigated potential sources of such variation. The aim of our study was to explore if the individual components of sociosexuality change across the menstrual cycle, either as a function of cycle phase or ovarian hormones. One hundred and two naturally cycling women, both single and in a committed relationship, completed questions from the the SOI-R (Sociosexuality Revised) questionnaire three times during a menstrual cycle, scheduled to coincide with their early follicular, peri-ovulatory, and luteal phases. Women provided saliva samples and performed luteinizing hormone tests to distinguish between ovulatory and anovulatory cycles. Women reported slightly more openness to uncommitted sexual relationships during the peri-ovulatory session, but significant differences were restricted only to women who exhibited the luteinizing hormone surge. Ovarian hormone concentrations within cycles significantly predicted SOI Attitude and Desire scores, with estradiol positively related, and progesterone negatively related to openness to uncommitted sexuality. These effects were generally modest in size. The results of this study suggest that sociosexuality can vary within short periods of time, such as a single menstrual cycle.

Keywords: Sociosexuality, SOI-R, Menstrual cycle, LH tests, Estradiol, Progesterone, Peri-ovulatory shifts

1. Introduction

Sociosexuality is defined as one's propensity towards engaging in uncommitted sexual relationships (Penke & Asendorpf, 2008; Simpson & Gangestad, 1991). The self-report scale measuring sociosexuality, the Sociosexual Orientation Inventory (SOI; Simpson & Gangestad, 1991), along with an updated version, the SOI-R (Penke & Asendorpf, 2008), have been adapted to a number of different languages and validated for use in a variety of cultural contexts (Bailey, Kirk, Zhu, Dunne, & Martin, 2000; Marcinkowska et al., 2019; Nascimento, Hanel, Monteiro, Gouveia, & Little, 2018; Penke & Asendorpf, 2008). There are three components of sociosexuality, each covering somewhat different aspects: Behavior (asking about past experiences of uncommitted sexual encounters), Attitude (about one's opinions on uncommitted sexual encounters) and Desire (about one's wish to engage in uncommitted sexual relations). Sociosexuality has emerged as an important construct within human sexuality, as findings have linked SOI scores to numerous aspects of human mating systems. Some of these features are relatively stable within individuals, such as biological sex (Clark, 2006), facial sexual dimorphism, or facial attractiveness (Boothroyd, Jones, Burt, DeBruine, & Perrett, 2008). Sociosexuality is also facultative, however, and varies depending on ecological factors such as mate availability (Arnocky, Woodruff, & Schmitt, 2016), relationship status or relationship satisfaction (Penke & Asendorpf, 2008), or national health indices (Marcinkowska et al. 2019). Thus, while most research assesses sociosexuality as a relatively stable, trait-like characteristic (e.g. Gettler et al., 2019; Penke & Asendorpf, 2008), a number of studies suggest that, at least to some extent, components of sociosexuality can change depending on both broader sociocultural context (Schmitt, 2005) and individual factors.

Relatedly, a growing body of evidence suggests that women's sexual feelings and behaviors vary as a function of overall fertility (i.e., reproductive state: Marcinkowska, Jasienska, & Prokop, 2017), position in the menstrual cycle (e.g. Arslan et al., 2018), and sex hormone concentrations (i.e., estradiol, progesterone and testosterone: Jones et al., 2018; Roney & Simmons, 2013). Within this body of findings, women's overall sexual motivation (Sheldon, Cooper, Geary, Hoard, & DeSoto, 2006; Roney & Simmons, 2013), frequency of sexual fantasies (Sherwin, Gelfand, & Brender, 1985), and in-pair versus extra-pair sexual interests (Grebe, Thompson, & Gangestad, 2016) have all been linked to concentrations of sex hormones. Three predominant accounts for these hormone-linked changes have been proposed. The "dual-sexuality hypothesis" proposes that women's sexual behavior changes depending on conception probability: women direct their attention towards putative indicators of mate genetic quality when conception is likely, and towards more investing males when conception is unlikely (Gangestad, Thornhill, & Garver-Apgar, 2005). The "motivational priority hypothesis" states that sexual motivation functions as a means of promoting general sexual behavior whenever possibility for conception is high (and hence it balances out the costs of mating efforts and risks of sexually transmitted diseases; Roney & Simmons, 2013; Roney, 2018). The "spandrel hypothesis" predicts that within-woman changes in mating behavior are a by-product of an adaptation based on between-woman variation in levels of sex hormones and related reproductive behavior (Havlicek, Cobey, Barrett, Klapilova, & Roberts, 2015). While all of these hypotheses propose that women's sexuality does fluctuate in relation to their conception probability throughout the menstrual cycle, debate continues regarding the precise nature of these relationships, and whether hormone-linked changes are broader or targeted in nature (e.g. Grebe et al., 2016; Marcinkowska et al., 2016; Marcinkowska, Kaminski, Little, & Jasienska, 2018; Junger et al., 2018; Gangestad et al., 2019). If women's sexuality in general varies throughout the menstrual cycle, mediated by changing levels of sex hormones, one might expect that sociosexuality is one component of that shifts (Charles &

Alexander, 2011; Jones et al., 2018; Shirazi et al., 2019; van Stein, Strauss, & Brenk-Franz, 2019).

Shimoda et al. (2018) reported changes in extrapair (P = 0.01), but not in-pair (P = 0.07), sexual desire between peri-ovulatory and luteal phase (no levels of sex hormones were measured and only 35 women took part in the study). Other recent, albeit larger study by Jones et al. (2018), based on 584 naturally cycling women, found no evidence that facial masculinity preference is related to changes in women’s salivary steroid hormone levels. Another large study by Shirazi et al. (2019), based on 348 naturally cycling women, found that an increase in estradiol predicted elevated sociosexual desire, however changes in sex hormones were not associated with general sexual desire. Even within this relatively narrow research question of hormonal underpinnings of sexual desire and behavior, evidence thus far has been mixed, with both positive and null results concerning propensity towards uncommitted sexual relationships.

A better understanding of the links between ovarian hormone concentrations, cycle phase, and sociosexuality is necessary to evaluate the plausibility of various proposed underlying evolutionary mechanisms. The present study investigates whether multiple components of women’s sociosexuality vary between cycle phases using a large sample of menstrual cycles. Building upon analyses based on cycle phase, we also collected multiple saliva samples from women during their cycles to assess both within-woman and between-woman relationships of ovarian hormone concentrations and reported sociosexuality. Finally, we also had women complete daily LH tests mid-cycle to distinguish ovulatory cycles from anovulatory ones. Following the “dual-sexuality hypothesis”, we would expect to see a significant increase in women’s sociosexuality during fertile phase, and a positive correlation with estradiol’s and negative with progesterone’s daily levels. If, on the other hand, the “spandrel hypothesis” was in place, we would expect to see sociosexuality significantly related to between women (i.e. average) hormone levels, rather than within women (i.e. daily) ones. As we did not measure in-pair vs extra-pair sexual desire, based on this set of data it would be difficult to directly confirm or deny "motivational priority hypothesis". More broadly if conception probability *per se* was driving changes in women's sexuality, then we might expect to see different results for ovulatory versus anovulatory cycles.

2. Methods

2.1. Participants

One hundred and two women, on average 29 years old (mean=28.8, SD=4.67), participated in the study. Criteria for inclusion were: regular menstrual cycles (difference between length of consecutive cycles not greater than 5 days); no diagnosed health problems of the reproductive system (e.g. polycystic ovary syndrome); and not being pregnant, breast feeding or using hormonal contraceptives for at least 3 months prior to participation in the study. The data analyzed here were collected as part of a larger project conducted by the authors in Southern Poland between 2014 and 2019 (Marcinkowska, Galbarczyk, & Jasienska, 2017; Marcinkowska et al., 2018, Marcinkowska 2020).

2.2 Procedure

Each woman participated in the study throughout one entire menstrual cycle. Participants were instructed to collect daily saliva samples every morning starting from the first day of menstrual bleeding until the end of the cycle marked by the onset of next menstrual bleeding. A subset of these saliva samples was assayed for measurement of estradiol (E2) and progesterone (P) concentrations (see section 2.3 for details on sample selection). Women also took daily urine luteinizing hormone ovulation tests (LH tests) between the 10th and 20th day of the cycle (or until a positive test result). Levels of luteinizing hormone (LH) usually peak just before ovulation, and the LH surge can be used as a reliable physiological estimate of the fertile window within menstrual cycle (Dunson, Weinberg, Baird, Kesner, & Wilcox, 2001).

Based on the LH test results, participants were divided in two groups: 1) *LH+* group included participants that obtained a positive result of LH test before the 20th day of the cycle (N=75); 2) *LH-* group included participants who did not obtain a positive LH test result throughout the cycle (N=27).

During the menstrual cycle, participants attended three in-person meetings: 1) in the early follicular phase, during the first week of the cycle (M=5.17 days after the onset of the menses, SD=2.11); 2) in the peri-ovulatory period, as soon as possible after obtaining a positive LH test result, or on the last day of conducting LH tests (i.e. 20th day of the cycle) if only negative results were obtained (M=12.11 days before the onset of the next menses, SD=3.65); and 3) in the luteal phase, approximately one week after the second meeting (M=4.11 days before the onset of the next menses, SD=3.63). During each meeting women completed a survey consisting of sociodemographic questions and the SOI-R questionnaire (Penke & Asendorpf, 2008).

The SOI-R questionnaire consists of nine questions (three per component), which participants answer on a 1-9 scale; scores for each of the three questions are averaged to yield an SOI component score. For questions on SOI Behavior (SOI-B), participants report their number of sexual partners in the last year, number of sexual partners with whom they had intercourse only once, and number of sexual partners with whom they did not have long-term relationship plans. For SOI Attitude (SOI-A), participants express how much they agree with the statement “sex without love is ok” and whether they can imagine themselves having casual sex with someone they are not in a long-term relationship with. In the SOI Desire (SOI-D) component, participants report how frequently they have sexual fantasies or experience sexual arousal concerning someone they are not in a long-term relationship with, or have spontaneous sexual fantasies involving someone they have just met. Participants completed SOI Attitude and SOI Desire components at all three in-person meetings. As SOI Behavior reflects current sociosexuality (i.e. sexual openness on the day of the meeting) to a lesser extent than the other two components, it was measured only once, during the last meeting (following Jones et al., 2018).

2.3. Hormonal Analysis

Daily concentrations of estradiol (E2) and progesterone (P) were assessed from the day of in-person meetings, one day before meetings and two days before meetings, which allowed for exploration of time-lagged effects of these hormones. Sample sizes for time-lagged hormones were reduced due to financial constraints, which necessitated us prioritizing day-of saliva samples for both hormones, followed by mid-cycle measurements of E2, and luteal phase measurements of P. We obtained 285 E2 and P measurements for the day-of the in-person meeting, 145 E2 and 136 P measurements for one day before the meeting and 148 E2 measurements and 127 P measurements for 2 days before the meeting. E2 and P hormonal assays were conducted with DRG International ELISA plates SLV4188 (sensitivity: 0.4 pg/ml, standard range: 1 – 100 pg/ml) for estradiol and SLV3140 for progesterone (sensitivity: 2.5 pg/ml, standard range: 10–5000 pg/ml). All measurements were conducted in duplicates. Inter-assay and intra-coefficients of variation were within an acceptable range: 10.01% and 7.5% for E2, and 14.1% and 4.9% for P, respectively (Schultheiss & Stanton, 2009).

2.4. Data analysis

We conducted a series of linear mixed-effect models (LMM) using the *lme4* package (Bates, Machler, Bolker, & Walker, 2015) in R. To account for within-participant dependency of responses, we included a participant-level random intercept in models predicting the

Attitude component (SOI-A) and Desire component (SOI-D) of sociosexuality. As the Behavior component (SOI-B) was measured only once, we ran linear regressions for this measure rather than LMMs. Within the family of models predicting each SOI component, we conducted one set of analyses with test session (our proxy of cycle phase) as the key predictor of interest, and a parallel set of models with *z*-scored E2 and P concentrations as the predictors of interest.

Finally, within the set of analyses assessing ovarian hormones, we performed separate regressions for day-of hormone concentrations, one day lagged concentrations, and two day lagged concentrations. All analyses contained LH status (confirmed vs. not) and relationship status (single vs. in a committed relationship) as between-woman factors, and included two-way interactions between each of these factors and ovarian hormone concentrations / cycle phase. All degrees of freedom were estimated using Satterthwaite approximation and are reported to the nearest whole number.

In LMM analyses using ovarian hormones, one can assess two orthogonal measures of variation for each hormone: within-woman (levels mean-centered within-woman), and between-woman (variation across woman-specific means; see West et al., 2011). We entered both terms in our analyses and reported results for each. As an alternative analytic strategy, grand-mean centering hormone levels (as opposed to separating within-woman and between-woman components) allows for analysis of the total association of a hormonal measure with an outcome (e.g., Kreft et al., 1995); we report these alternative models in our Electronic Supplementary Materials (ESM 2).

All data and analysis scripts necessary to reproduce our results are available in Electronic Supplementary Material (ESM).

3. **Results**

3.1. *Within-Woman Correlations of SOI-D and SOI-A*

Table 1 reports the within-woman correlations of SOI-D and SOI-A scores across sessions. Within SOI components, correlations are high: $0.77 < r < 0.85$ for SOI-D; $0.77 < r < 0.78$ for SOI-A. Correlations between components' scores at the same session are somewhat weaker, though still exceeding 0.5.

3.2. *SOI Desire*

3.2.1. *Cycle Phase*

In our model predicting SOI-D from cycle phase and its interactions with LH status and relationship status, we found a non-significant main effect of phase: $F(2,190) = 1.49$, $p = 0.227$. Predicted SOI-D scores were slightly higher during the peri-ovulatory session (3.23 ± 0.16 on a 9-point scale) than the follicular session (3.07 ± 0.16) or luteal session (2.97 ± 0.16); no pairwise comparisons between phases reached statistical significance. The main effect of relationship status was highly significant ($t(100) = -4.00$, $p < 0.001$), with single women reporting higher SOI-D (4.04 ± 0.28) than women in relationships (2.73 ± 0.17). The interaction between cycle phase and relationship status was non-significant ($F(2, 190) = 1.13$, $p = 0.326$); the interaction between LH status and cycle phase fell just short of statistical significance ($F(2, 189) = 2.56$, $p = 0.080$). Post-hoc pairwise comparisons of the LH status × cycle phase interaction revealed just one statistically significant difference that survived *p*-value adjustment for multiple comparisons: SOI-D differences between the peri-ovulatory phase and luteal phase in LH+ women (peri-ovulatory scores exceeded luteal scores by 0.48 ± 0.14, $p = 0.008$).

3.2.2. *Ovarian Hormones*

In the model assessing concurrent, within-woman centered concentrations of E2 and P, along with women's average concentrations of these hormones across all measurements, we found significant, opposing effects of within-woman variation for the two hormones: positive for E2 ($t(174) = 2.18$, $p = 0.031$) and negative for P ($t(174) = -2.08$, $p = 0.039$). Between-woman effects of these hormones were weaker and non-significant, though directionally consistent with within-woman effects: $t(95) = 0.82$, $p = 0.416$ for E2; $t(96) = -1.26$, $p = 0.210$ for P. No interactions between these hormonal effects and relationship status or LH status reached statistical significance; as with results for cycle phase, the main effect of relationship status was significant, with single women scoring higher on SOI-D ($t(92) = -3.84$, $p < 0.001$). See Table 2 for full model results.

Lagged within-woman effects of hormone concentrations, based on a substantially reduced number of measurements, were uniformly non-significant predictors of SOI-D; see Table S1 in ESM 1.

3.3. SOI Attitude

3.3.1. Cycle Phase

Like SOI-D, SOI-A did not differ significantly across cycle phases $F(2,189) = 1.92$, $p = 0.149$), though predicted scores were once again slightly higher for the peri-ovulatory session (4.40 ± 0.25) compared to either the follicular session (4.27 ± 0.25) or luteal session (3.95 ± 0.25). Here, the main effect of relationship status fell just short of significance ($t(99) = -1.96$, $p = 0.054$), but ran in the same direction as the SOI-D model (4.94 ± 0.44 for singles vs. 3.93 ± 0.27 for women in relationships). The interaction between cycle phase and relationship status was non-significant ($F(2, 189) = 0.18$, $p = 0.837$), as was the interaction between LH status and cycle phase ($F(2, 188) = 1.88$, $p = 0.155$). Post-hoc pairwise comparisons of the LH status × cycle phase interaction revealed just one statistically significant difference that survived *p*-value adjustment (the same significant comparison from

SOI-D analyses): SOI-A scores during the peri-ovulatory session were higher than luteal session scores in LH+ women (difference of 0.66 ± 0.23, $p = 0.047$).

3.2.2 Ovarian Hormones

Results for hormonal predictors of SOI-A were qualitatively similar to results for SOI-D. Relationship status was significant as a main effect ($t(90) = -2.30$, $p = 0.024$). E2 and P had differing within-woman effects on SOI-A: we observed a non-significant effect for E2 ($t(173) = 0.96$, $p = 0.338$), but a significant and negative effect for P ($t(174) = -2.53$, $p = 0.012$). Between-woman main effects of both hormones were non-significant ($t(95) = 1.48$, $p = 0.143$ for E2; $t(96) = -0.97$, $p = 0.335$) for P), but both were qualified by interactions with LH status (Table 3). Decomposing these interactions, the simple slope of average E2 concentrations on SOI-A scores was significant and positive for LH-negative women (1.54 ± 0.61), but negative and non-significant for LH-positive women (-0.53 ± 0.30). The simple slope of average P concentrations was significant and negative for LH-negative women (-1.14 ± 0.54), but positive and non-significant for LH-positive women (0.51 ± 0.34). We observed no comparable interactions of within-woman hormone concentrations and LH status. No interactions between any hormonal measurements and relationship status reached statistical significance. See Table 3 for full results.

Lagged within-woman effects of hormone concentrations were uniformly non-significant predictors of SOI-A, whether one-day or two-day lagged, though there was once again substantially reduced statistical power in these analyses; see Table S2 in ESM 1.

3.3 SOI Behavior

SOI-B was only assessed during the third session, precluding an analysis of how scores varied across sessions. In a model including both concurrent and average hormone concentrations as predictors on SOI-B, hormonal main effects trended in the same direction as for SOI-D and SOI-A analyses, but were uniformly non-significant. Between-woman E2 significantly interacted with relationship status in this model, such that for single women, the slope of E2 was negative and significant (-0.99 ± 0.46), and for paired women, was positive and non-significant (0.13 ± 0.25). See Table 4 for full results.

3.4 Combined SOI Scores

While our focus in this study was on predictors of individual SOI components, one might also wonder how cycle phase or ovarian hormones predict SOI-R overall. This question can be assessed in two different ways: first, via models that predict the sum of SOI-D and SOI-A (the two components measured multiple times across the cycle); and second, via models that predict the sum of all three components (SOI-D, SOI-A, and SOI-B), although analyses here are restricted to the third session in which women completed all three SOI components.

For the SOI-D + SOI-A sum, differences between cycle phases fell short of significance, $F(2,189) = 2.46$, $p = 0.088$), with peri-ovulatory scores (7.64 ± 0.37) slightly exceeding either follicular (7.34 ± 0.37) or luteal scores (6.92 ± 0.37). Reflecting results from individual components, peri-ovulatory scores were significantly higher than luteal scores in LH+ women only ($t(189) = 4.02$, $p = 0.001$). In models with ovarian hormones as predictors, within-woman E2 showed a positive relationship that fell just short of significance ($t(172) = 1.77$, $p = 0.079$), whereas within-woman P showed a significant negative relationship ($t(172) = -2.87$, $p = 0.005$). See Figure 1. Also reflecting previous results, between-woman main effects of both hormones were non-significant, but qualified by interactions with LH status. The simple slope of average E2 concentrations was significant and positive for LH-negative women (2.01

± 0.93), but negative and non-significant for LH-positive women (-0.62 ± 0.45). The simple slope of average P concentrations was negative and nearly significant for LH-negative women (-1.57 ± 0.81), but positive and non-significant for LH-positive women (0.42 ± 0.52).

Figure 1. Predicted marginal effects of within-woman estradiol and progesterone on SOI-R Combined scores (SOI-D + SOI-A). Shaded bands represent 95% confidence intervals.

For the SOI-D + SOI-A + SOI-B sum, within-woman E2 and P showed opposing, significant effects: $t(68) = 2.49$, $p = 0.015$ for E2; $t(68) = -2.07$, $p = 0.042$ for P. In addition, average ovarian hormone concentrations were found to interact with LH and relationship status in some cases. Average E2 interacted with relationship status, such that its effect was negative in single women only. Average P interacted with LH status, such that its effect was negative in LH- women only. See Table S3 in ESM1.

3.5 Robustness Analyses

We assessed the sensitivity of our results to a number of alternative, defensible analytic strategies: i.e., models using log-transformed instead of raw hormone concentrations; models using a logged hormone ratio (ln(E/P); cf. Baird et al., 1991; Gangestad et al., 2019) rather than individual concentrations; and models substituting grand-mean centered hormone concentrations for individual within-woman and between-woman components. We present the full results of these robustness analyses in our Electronic Supplementary Material. In general, significant within-woman main effects of hormones were robust to alternative model specifications, and grand-mean centered main effects of hormones closely tracked within-woman centered effects. In contrast, the significant interactions between average hormone levels and relationship status or LH status, reported above, exhibited less robustness when assessed in alternative models. See ESM 2 for full results.

4. Discussion

In this study, we assessed women's self-reported sociosexuality at multiple time points to determine whether it might differ as a function of cycle phase or ovarian hormone concentrations. We found only limited evidence that sociosexuality varies between putative cycle phases: while women reported slightly less restricted sociosexuality around the peri-ovulatory period, pairwise comparisons revealed only one robust difference, in which peri-ovulatory sociosexuality scores were less restricted than luteal phase scores in LH+ women only. While inextricably linked to cycle phase, actual ovarian hormones exhibited somewhat more consistent associations with sociosexuality. In most analyses performed, within-woman E2 was positively related to SOI scores, and within-woman P was negatively related. Exceptions to these general patterns emerged in analyses with smaller sample sizes—either lagged hormonal measurements, or the SOI B component that was only measured once. Additionally, SOI scores strongly depended on relationship status—single women showed more interest in uncommitted sexual relationships than paired ones, likely due to the costs of extra-pair mating women in relationships could incur.

Our results provide further, broader analysis that supplements and expands upon previously published studies. Our results are partially consistent with Shirazi et al. (2019), who also found that within-woman changes in E2 positively predicted SOI-D and total SOI scores (but not SOI-A), though changes in P did not significantly predict any element of SOI. Our results contrast with Jones et al. (2018), who reported no evidence that within-woman changes in sociosexuality track ovarian hormone concentrations. Lastly, Van Stein et al. (2019) did not find changes in SOI-R total score or its components across the menstrual cycle; however, they did not have hormonal data and did not control for relationship status. Importantly, when conducting the SOI-R questionnaire multiple times within short time periods, inclusion of the SOI Behavior component will decrease the total score variation, as responses to questions, e.g. about overall lifetime number of short-term sexual relationships, are unlikely to vary as much as attitudes or desires concerning uncommitted sexual relationships. Based on the results of our study, we suggest that for within-individual designs, SOI-R components should be analyzed separately.

Additionally, our results suggest that estimated cycle phase, in absence of other information about women's cycles, might be too noisy of a variable to reliably detect cyclic variation in SOI, perhaps due to variation in cycle length, inter-individual variation in sex hormones and/or an appreciable number of cycles in which the expected LH surge does not occur. Indeed, we only found significant differences in sociosexuality between cycle phases when restricting analyses to LH+ cycles. In contrast, the relatively consistent relationships between sociosexuality and ovarian hormone fluctuations provides further evidence supporting the notion that gonadal hormone fluctuations mediate shifts in women's sexuality (Grebe et al., 2016; Roney & Simmons, 2013).

Differences in sociosexuality between the peri-ovulatory and luteal phases, and as a function of ovarian hormone fluctuation across the cycle, are consistent with both the dual-sexuality and, indirectly, for motivational priority hypotheses (Roney, 2018; Gangestad et al., 2019). As the SOI-R measures openness towards uncommitted sexual relationships in general, in this study we could not discriminate between in-pair and extra-pair sexual attitude and desire, which would be necessary to adjudicate between these two hypotheses. In contrast, our results do not support the "spandrel hypothesis" (Havlicek et al., 2015), as between-woman differences in ovarian hormones did not predict reported sociosexuality.

While more work should be done to determine whether the interactions we report between average ovarian hormones and LH status are robust, it is interesting that the significant between-women hormonal effects were found in non-ovulatory cycles only. As these interactions were not as robust as within-woman main effects in supplementary analyses

(ESM 2), one possibility is simply that these interactions are spurious. However, if these patterns proved robust, it could be because anovulatory cycles could putatively be characterized by a greater variation in hormonal levels (which could then lead to a lack of ovulation). A second possibility is that varying lengths of follicular and luteal phases made it sometimes impossible for LH tests conducted between the 10th and 20th day of the cycle to correctly detect timing of ovulation, and the peri-ovulatory meeting accordingly. More in-depth analysis of anovulatory cycles would be needed to distinguish between these possibilities.

There are three main limitations relevant to the interpretation of our results. The first is the effect size of our significant results. Taking SOI-D as an example, our standardized coefficients predict that SOI-D increases by just 0.2 points for every one SD increase a woman experiences from her average E2, and decreases by just 0.16 points for every one SD increase from her average P concentrations. While these effect size estimates are likely attenuated by measurement error, such a modest magnitude suggests that there are other characteristics, both circumstantial and intrinsic to the individual, that explain the vast majority of the variation in sociosexuality. Small effect sizes also suggest that a large number of observations is likely necessary to achieve the power necessary to detect true associations. Additionally, following previously suggested statistical approach ((Jones, Marcinkowska, & DeBruine, 2019; Stern, Arslan, Gerlach, & Penke, 2019), however see (Gangestad, Dinh, Grebe, Del Giudice, & Thompson, 2019)), we have conducted multiple robustness tests (see ESM 2), where we have tested whether observed results are sensitive to specific analytic decisions.

We did not find any associations between lagged hormone concentrations and sociosexuality, even though Roney and Simmons (2013) do report some significant associations with overall sexual desire. While this pattern of effects could be interpreted as evidence that only general sexual desire, not sociosexuality, tracks ovarian hormones concentrations from days prior, it could simply be due to the fact that we had a much smaller number of lagged hormone measurements available, and we missed true effects that were small in magnitude. Even a large sample such as ours likely has limited statistical power when missing data is pervasive.

A second limitation is a lack of randomization in the order of meetings and questionnaire administration. It is possible that due to the repetitive answering of the same questions in a particular order, variation in responses would reflect simply a rehearsed answer (wherein participants tried to match their previous scores instead of giving a new answer) instead of showing real variation in actual sociosexuality. However, if that was the case, we would have expected to see a flat or linear trend from the 1st to 3rd meeting. Instead, we observed a slight bell curve pattern in the scores obtained.

A third, rarely addressed, possible limitation is related to the fact that all sociosexuality measurements were self-reported. According to the 'social desirability hypothesis', participants completing surveys will respond in a manner viewed by others as favorable (Meston, Heiman, Trapnell, & Paulhus, 1998). It is thus possible that the scores for sociosexuality would be highest in the peri-ovulatory phase not because of an actual shift in feelings towards uncommitted sexual relationships, but because of lower *social desirability* of participants (in a similar manner as, for example, social anxiety is related to changing levels of sex hormones (Reynolds et al., 2018)). In that case, the changes observed would be in the realm of general openness to discuss issues related to one's own sexuality, not in sociosexuality *per se*. This may be particularly likely for the SOI Attitude component, as it "reflects social self-representation and cultural socialization" (Penke & Asendorpf, 2008). However, assuming such bases for observed variability, one could speculate that the mechanism driving the decrease of *social desirability* (and hence increase in openness to share one's true sexual openness) could be unique to reported changes in sociosexuality. In the future this could be accounted for by including measures of actual sexual behaviors and, therefore, testing the predictive validity of changes in sociosexuality for variation in sexual behavior.

In conclusion, the results of this study are consistent with the notion that sociosexuality can vary even within short periods of time, such as during a single menstrual cycle. Observed relationships also provide support for the idea that cyclic changes in multiple aspects of women's sexuality are mediated by shifts in their ovarian hormone concentrations.

Data Availability and Open Data

All data and code associated with this study are available in Electronic Supplementary Material 3 and 4 accordingly.

Funding

This work was supported to MM by Fulbright Commission (grant number PL/2018/24/JR) and to UMM by the Polish National Science Center (grant number 2014/12/S/NZ8/00722) and by the structural funds of Jagiellonian University Medical College (grant number K/DSC/004283).

Author contributions

UMM, MM and GJ participated in the design of the study, UMM and MM collected field data, KK and NG carried out the statistical analyses. All authors drafted and critically revised the manuscript and gave final approval for publication and agree to be held accountable for the work performed therein.

Ethical Statement

This research was approved by the Human Ethics Committee at Jagiellonian University, approval number: KBET/250/B/2014.

Acknowledgements

Authors would like to thank Victoria Harries for the linguistic support.

Competing Interests

The authors have declared that no competing interests exist.

Table 1. Correlation table for SOI-A and SOI-D scores across sessions.

	Follicular SOI-D	Peri-Ovulatory SOI-D	Luteal SOI-D	Follicular SOI-A	Peri-Ovulatory SOI-A	Luteal SOI-A
Follicular SOI-D	1					
Peri-Ovulatory SOI-D	0.85	1				
Luteal SOI-D	0.77	0.81	1			
Follicular SOI-A	0.64	0.69	0.58	1		
Peri-Ovulatory SOI-A	0.61	0.67	0.52	0.77	1	
Luteal SOI-A	0.44	0.52	0.51	0.78	0.77	1

Table 2. Linear mixed models predicting SOI-D scores. For cycle phase results, effects represent differences between listed phase and overall mean. Effects with *p* < 0.10 in italics; *p* < 0.05 in bold.

Cycle Phase					
Effect	Estimate (γ)	SE	DF	*t*	*p*
Phase (follicular)	-0.02	0.07	190	-0.30	0.766
Phase (peri-ovulatory)	0.12	0.07	189	1.63	0.103
Relationship Status	**-0.66**	**0.16**	**100**	**-4.00**	**< 0.001**
LH Status	-0.09	0.17	98	-0.57	0.572
Phase (foll) × Relationship	0.03	0.07	191	0.42	0.673
Phase (peri) × Relationship	-0.10	0.07	190	-1.47	0.144
Phase (foll) × LH	0.03	0.07	189	0.41	0.680
Phase (peri) × LH	**-0.15**	**0.07**	**189**	**-2.14**	**0.036**
Hormone Levels					
Effect	Estimate (γ)	SE	DF	*t*	*p*
Relationship Status	**-0.65**	**0.17**	**92**	**-3.84**	**< 0.001**
LH Status	-0.04	0.17	90	-0.24	0.815
Within-Woman Centered Hormones					
Estradiol	**0.20**	**0.09**	**174**	**2.18**	**0.031**

Progesterone	**-0.16**	**0.08**	**174**	**-2.08**	**0.039**
E2 × Relationship	-0.09	0.09	175	-0.98	0.328
P × Relationship	0.10	0.08	173	1.27	0.205
E2 × LH Status	-0.12	0.10	174	-1.29	0.198
P × LH Status	-0.01	0.08	173	-0.09	0.931
Between-Woman (Average) Hormones					
Estradiol	0.18	0.22	95	0.82	0.416
Progesterone	-0.27	0.22	96	-1.26	0.210
E2 × Relationship	-0.11	0.18	99	-0.63	0.533
P × Relationship	-0.15	0.20	96	-0.78	0.437
E2 × LH Status	0.29	0.22	94	1.29	0.200
P × LH Status	-0.18	0.20	96	-0.86	0.392

Table 3. Linear mixed models predicting SOI-A scores. For cycle phase results, effects represent differences between listed phase and overall mean. Effects with *p* < 0.10 in italics; *p* < 0.05 in bold.

Cycle Phase					
Effect	Estimate (γ)	SE	DF	*t*	*p*
Phase (follicular)	0.14	0.12	189	1.17	0.245
Phase (peri-ovulatory)	0.10	0.12	188	0.82	0.412
Relationship Status	*-0.50*	*0.26*	*99*	*-1.96*	*0.053*
LH Status	-0.23	0.26	97	-0.89	0.377
Phase (foll) × Relationship	-0.06	0.11	190	-0.53	0.595
Phase (peri) × Relationship	0.00	0.11	189	0.02	0.983
Phase (foll) × LH	0.11	0.11	188	1.01	0.316

Phase (peri) × LH	*-0.21*	*0.11*	*188*	*-1.94*	*0.054*
Hormone Levels					
Effect	Estimate (γ)	SE	DF	*t*	*p*
Relationship Status	**-0.59**	**0.25**	**90**	**-2.30**	**0.024**
LH Status	-0.13	0.26	89	-0.49	0.624
Within-Woman Centered Hormones					
Estradiol	0.14	0.15	173	0.96	0.338
Progesterone	**-0.33**	**0.13**	**174**	**-2.53**	**0.012**
E2 × Relationship	0.13	0.15	175	0.87	0.387
P × Relationship	0.09	0.13	173	0.67	0.503
E2 × LH Status	0.10	0.16	173	0.63	0.528
P × LH Status	-0.12	0.13	173	-0.92	0.357
Between-Woman (Average) Hormones					
Estradiol	0.50	0.34	95	1.48	0.143
Progesterone	-0.32	0.33	96	-0.97	0.335
E2 × Relationship	0.06	0.28	99	0.21	0.831
P × Relationship	-0.46	0.30	86	-1.52	0.132
E2 × LH Status	**1.03**	**0.34**	**93**	**3.04**	**0.003**
P × LH Status	**-0.82**	**0.31**	**95**	**-2.66**	**0.009**

Table 4. Multiple regression predicting SOI-B scores. Effects with *p* < 0.10 in italics; *p* < 0.05 in bold.

Effect	Estimate (b)	SE	DF	*t*	*p*
Relationship Status	-0.22	0.22	68	-1.01	0.318
LH Status	-0.09	0.16	68	-0.53	0.600

Within-Woman Centered Hormones					
Estradiol	0.25	0.23	68	1.09	0.280
Progesterone	-0.23	0.38	68	-0.59	0.556
E2 × Relationship	0.18	0.23	68	0.78	0.436
P × Relationship	-0.13	0.31	68	-0.43	0.667
E2 × LH Status	0.23	0.24	68	0.99	0.325
P × LH Status	-0.33	0.31	68	-1.04	0.301
Between-Woman (Average) Hormones					
Estradiol	-0.43	0.28	68	-1.57	0.122
Progesterone	0.17	0.33	68	0.51	0.615
E2 × Relationship	**0.56**	**0.25**	**68**	**2.26**	**0.027**
P × Relationship	-0.46	0.30	68	-1.55	0.125
E2 × LH Status	0.26	0.23	68	1.16	0.251
P × LH Status	-0.32	0.20	68	-1.61	0.111

References

Arnocky, S., Woodruff, N., & Schmitt, D. P. (2016). Men's sociosexuality is sensitive to changes in mate availability. *Personal Relationships, 23*(1), 172-181. doi:10.1111/pere.12118

Bailey, J. M., Kirk, K. M., Zhu, G., Dunne, M. P., & Martin, N. G. (2000). Do individual differences in sociosexuality represent genetic or environmentally contingent strategies? Evidence from the Australian twin registry. *Journal of Personality and Social Psychology, 78*(3), 537-545. doi:10.1037//0022-3514.78.3.537

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *2015, 67*(1), 48. doi:10.18637/jss.v067.i01

Bates, D., Machler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48. Retrieved from <Go to ISI>://WOS:000365981400001

Boothroyd, L. G., Jones, B. C., Burt, D. M., DeBruine, L. M., & Perrett, D. I. (2008). Facial correlates of sociosexuality. *Evolution and Human Behavior, 29*(3), 211-218. doi:10.1016/j.evolhumbehav.2007.12.009

Charles, N. E., & Alexander, G. M. (2011). The Association Between 2D:4D Ratios and Sociosexuality: A Failure to Replicate. *Archives of Sexual Behavior, 40*(3), 587-595. doi:10.1007/s10508-010-9715-z

Clark, A. P. (2006). Are the correlates of sociosexuality different for men and women? *Personality and Individual Differences, 41*(7), 1321-1327. doi:10.1016/j.paid.2006.05.006

Dunson, D. B., Weinberg, C. R., Baird, D. D., Kesner, J. S., & Wilcox, A. J. (2001). Assessing human fertility using several markers of ovulation. *Statistics in Medicine, 20*(6), 965-978. doi:10.1002/sim.716

Gangestad, S. W., Dinh, T., Grebe, N. M., Del Giudice, M., & Thompson, M. E. (2019). Psychological cycle shifts redux: Revisiting a preregistered study examining preferences for muscularity. *Evolution and Human Behavior, 40*(6), 501-516.

Gangestad, S. W., Thornhill, R., & Garver, C. E. (2002). Changes in women's sexual interests and their partners' mate retention tactics across the menstrual cycle: evidence for shifting conflicts of interest. *Proceedings of the Royal Society B-Biological Sciences, 269*(1494), 975-982. doi:10.1098/rspb.2001.1952

Gangestad, S. W., Thornhill, R., & Garver-Apgar, C. E. (2005). Adaptations to ovulation - Implications for sexual and social behavior. *Current Directions in Psychological Science, 14*(6), 312-316. doi:10.1111/j.0963-7214.2005.00388.x

Gettler, L. T., Kuo, P. X., Rosenbaum, S., Avila, J. L., McDade, T. W., & Kuzawa, C. W. (2019). Sociosexuality, testosterone, and life history status: prospective associations and longitudinal changes among men in Cebu, Philippines. *Evolution and Human Behavior, 40*(2), 249-258. doi:10.1016/j.evolhumbehav.2018.11.001

Grebe, N. M., Thompson, M. E., & Gangestad, S. W. (2016). Hormonal predictors of women's extra-pair vs. in-pair sexual attraction in natural cycles: Implications for extended sexuality. *Hormones and Behavior, 78*, 211-219. doi:10.1016/j.yhbeh.2015.11.008

Havlicek, J., Cobey, K. D., Barrett, L., Klapilova, K., & Roberts, S. C. (2015). The spandrels of Santa Barbara? A new perspective on the peri-ovulation paradigm. *Behavioral Ecology, 26*(5), 1249-1260. doi:10.1093/beheco/arv064

Jones, B. C., Hahn, A. C., Fisher, C. I., Wang, H. Y., Kandrik, M., & DeBruine, L. M. (2018). General sexual desire, but not desire for uncommitted sexual relationships, tracks changes in women's hormonal status. *Psychoneuroendocrinology, 88*, 153-157. doi:10.1016/j.psyneuen.2017.12.015

Jones, B. C., Marcinkowska, U. M., & DeBruine, L. M. (2019). Assessing the evidentiary value of secondary data analyses: A commentary on Gangestad, Dinh, Grebe, Del Giudice, and Thompson (2019). *Evolution and Human Behavior, 40*(6), 531-532. doi:https://doi.org/10.1016/j.evolhumbehav.2019.08.004

Kreft, I. G. G., de Leeuw, J., & Aiken, L. S. (1995). The effect of different forms of centering in hierarchical linear models. *Multivariate Behavioral Research, 30*, 1–21.

Marcinkowska, U. M., Ellison, P. T., Galbarczyk, A., Milkowska, K., Pawlowski, B., Thune, I., & Jasienska, G. (2016). Lack of support for relation between woman's masculinity preference, estradiol level and mating context. *Hormones and Behavior, 78*, 1-7. doi:10.1016/j.yhbeh.2015.10.012

Marcinkowska, U. M., Galbarczyk, A., & Jasienska, G. (2017). La donna e mobile? Lack of cyclical shifts in facial symmetry, and facial and body masculinity preferences-A hormone based study. *Psychoneuroendocrinology, 88*, 47-53. doi:10.1016/j.psyneuen.2017.11.007

Marcinkowska, U. M., Jasienska, G., & Prokop, P. (2017). A Comparison of Masculinity Facial Preference Among Naturally Cycling, Pregnant, Lactating, and Post-Menopausal Women. *Archives of Sexual Behavior*. doi:10.1007/s10508-017-1093-3

Marcinkowska, U. M., Kaminski, G., Little, A. C., & Jasienska, G. (2018). Average ovarian hormone levels, rather than daily values and their fluctuations, are related to facial preferences among women. *Hormones and Behavior, 102*, 114-119. doi:https://doi.org/10.1016/j.yhbeh.2018.05.013

Marcinkowska, U. M., Rantala, M. J., Lee, A. J., Kozlov, M. V., Aavik, T., Cai, H., . . . Dixson, B. J. W. (2019). Women's preferences for men's facial masculinity are strongest under favorable ecological conditions. *Scientific Reports, 9*(1), 3387. doi:10.1038/s41598-019-39350-8

Marcinkowska, U. M. (2020). Importance of Daily Sex Hormone Measurements Within the Menstrual Cycle for Fertility Estimates in Cyclical Shifts Studies. Evolutionary Psychology, 18(1). doi: 10.1177/1474704919897913

Meston, C. M., Heiman, J. R., Trapnell, P. D., & Paulhus, D. L. (1998). Socially desirable responding and sexuality self-reports. *The Journal of Sex Research, 35*(2), 148-157. doi:10.1080/00224499809551928

Nascimento, B. S., Hanel, P. P. H., Monteiro, R. P., Gouveia, V. V., & Little, A. C. (2018). Sociosexuality in Brazil: Validation of the SOI-R and its correlates with personality, self-perceived mate value, and ideal partner preferences. *Personality and Individual Differences, 124*, 98-104. doi:10.1016/j.paid.2017.12.007

Penke, L., & Asendorpf, J. B. (2008). Beyond global sociosexual orientations: a more differentiated look at sociosexuality and its effects on courtship and romantic relationships. *Journal of Personality and Social Psychology, 95*(5), 1113-1135. doi:10.1037/0022-3514.95.5.1113

Puts, D. A., Pope, L. E., Hill, A. K., Cardenas, R. A., Welling, L. L. M., Wheatley, J. R., & Breedlove, S. M. (2015). Fulfilling desire: Evidence for negative feedback between men's testosterone, sociosexual psychology, and sexual partner number. *Hormones and Behavior, 70*, 14-21. doi:10.1016/j.yhbeh.2015.01.006

Reynolds, T. A., Makhanova, A., Marcinkowska, U. M., Jasienska, G., McNulty, J. K., Eckel, L. A., . . . Maner, J. K. (2018). Progesterone and women's anxiety across the menstrual cycle. *Horm Behav, 102*, 34-40. doi:10.1016/j.yhbeh.2018.04.008

Roney, J. R., & Simmons, Z. L. (2013). Hormonal predictors of sexual motivation in natural menstrual cycles. *Hormones and Behavior, 63*(4), 636-645. doi:10.1016/j.yhbeh.2013.02.013

Roney, J. R., & Simmons, Z. L. (2016). Within-cycle fluctuations in progesterone negatively predict changes in both in-pair and extra-pair desire among partnered women. *Hormones and Behavior, 81*, 45-52. doi:10.1016/j.yhbeh.2016.03.008

Schmitt, D. P. (2005). Sociosexuality from Argentina to Zimbabwe: A 48-nation study of sex, culture, and strategies of human mating. *Behavioral and Brain Sciences*, *28*(2), 247-+. doi:10.1017/s0140525x05000051

Schultheiss, O. C., & Stanton, S. J. (2009). *Assessment of salivary hormones* (E. Harmon-Jones & J. S. Beer Eds.). New York: Guilford Press.

Sheldon, M. S., Cooper, M. L., Geary, D. C., Hoard, M., & DeSoto, M. C. (2006). Fertility cycle patterns in motives for sexual behavior. *Personality and Social Psychology Bulletin, 32*(12), 1659-1673. doi:10.1177/0146167206292690

Sherwin, B. B., Gelfand, M. M., & Brender, W. (1985). Androgen enhances sexual motivation in females: a prospective, crossover study of sex steroid administration in the surgical menopause. *Psychosomatic Medicine, 47*(4), 339-351.

Shimoda, R., Campbell, A., & Barton, R. A. (2018). Women's emotional and sexual attraction to men across the menstrual cycle. *Behavioral Ecology, 29*(1), 51-59. doi:10.1093/beheco/arx124

Shirazi, T. N., Self, H., Dawood, K., Rosenfield, K. A., Penke, L., Carre, J. M., . . . Puts, D. A. (2019). Hormonal predictors of women's sexual motivation. *Evolution and Human Behavior, 40*(3), 336-344. doi:10.1016/j.evolhumbehav.2019.02.002

Simpson, J. A., & Gangestad, S. W. (1991). Individual differences in sociosexuality – evidence for convergent and discriminant validity. *Journal of Personality and Social Psychology, 60*(6), 870-883. doi:10.1037/0022-3514.60.6.870

Stern, J., Arslan, R. C., Gerlach, T. M., & Penke, L. (2019). No robust evidence for cycle shifts in preferences for men's bodies in a multiverse analysis: A response to Gangestad, Dinh, Grebe, Del Giudice, and Emery Thompson (2019). *Evolution and Human Behavior*, *40*(6), 517-525. doi:10.1016/j.evolhumbehav.2019.08.005

Team, R. C. (2019). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. doi:https://www.R-project.org/.

van Stein, K. R., Strauss, B., & Brenk-Franz, K. (2019). Ovulatory Shifts in Sexual Desire But Not Mate Preferences: An LH-Test-Confirmed, Longitudinal Study. *Evolutionary Psychology, 17*(2), 1-10. doi:10.1177/1474704919848116

Waynforth, D., Delwadia, S., & Camm, M. (2005). The influence of women's mating strategies on preference for masculine facial architecture. *Evolution and Human Behavior, 26*(5), 409-416. doi:10.1016/j.evolhumbehav.2005.03.003

West, S. G., Ryu, E., Kwak, O-M., & Chan, H. (2011). Multilevel modeling: Current and future applications in personality research. *Journal of Personality*, *79*, 1-50.