8-2020

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Hormones and Behavior 125 (2020) 104823

Contents lists available at ScienceDirect

Hormones and Behavior

journal homepage: www.elsevier.com/locate/yhbeh

Changes in prenatal testosterone and sexual desire in expectant couples☆

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ARTICLE INFO

Keywords:
Transition to parenthood
Pregnancy
Sexual desire
Testosterone

ABSTRACT

During the transition to parenthood (TTP), both women and men report declines in sexual desire, which are thought to reflect an evolutionarily adaptive focus on parenting over mating. New parents also show changes in testosterone, a steroid hormone implicated in both parenting and mating, suggesting that changes in sexual desire may be associated with changes in testosterone. To test these associations, we followed a sample of heterosexual couples expecting their first child across the prenatal period. We examined prenatal changes in testosterone and two forms of sexual desire (solitary, dyadic). Expectant mothers showed prenatal increases in testosterone, and women's higher testosterone was associated with lower dyadic desire. Expectant fathers showed prenatal decreases in testosterone, and declines in men's testosterone were associated with lower dyadic desire. Testosterone was unrelated to men's or women's solitary desire. Our findings provide support for the idea that prenatal changes in testosterone contribute to an evolutionarily adaptive focus on parenting over mating during the TTP.

1. Introduction

Expectant parents experience many psychological and physiological changes during the transition to parenthood, including pre- to postpartum declines in sexual desire (Radoš et al., 2015). Perinatal changes in sexuality are thought to reflect an evolutionarily adaptive trade-off between parenting and mating: A diminished sex drive is adaptive insofar as it allows parents to prioritize parental investment, while temporarily putting future reproductive effort on hold (Gray, 2013). Physiologically, expectant parents also show changes in hormones, including testosterone, a steroid hormone associated with aggression and dominance (at higher levels) as well as caregiving and nurturance (at lower levels) (van Anders et al., 2011). Specifically, expectant mothers show large prenatal increases in testosterone, which return to pre-pregnancy levels postpartum (Edelstein et al., 2015; Fleming et al., 1997); expectant fathers show prenatal *declines* in testosterone, which rebound somewhat within the first postpartum year (Edelstein et al., 2015; Rosenbaum et al., 2018). Changes in testosterone are also thought to be adaptive in that they may facilitate infant protection, increase commitment to the relationship, and/or reduce mating effort in favor of caregiving and nurturant behaviors (Gettler et al., 2011).

Given the widespread belief that testosterone is related to sexual desire (Baumeister et al., 2001; Petersen and Hyde, 2011), and research implicating testosterone in parenting and mating (Barrett et al., 2013; Gettler et al., 2017; Gray et al., 2005), it has been assumed that declines in sexual desire during pregnancy may be due to prenatal changes in testosterone (Regan et al., 2003). In fact, there is some evidence to suggest that changes in testosterone may precede changes in sexual desire: Men who suffer from erectile dysfunction and women who report clinical levels of sexual dysfunction (e.g., due to hypoactive sexual disorder or menopause) show significant improvements in sexual desire after the administration of synthetically produced testosterone (Achilli et al., 2017; Bolour and Braunstein, 2005; Corona et al., 2016; Corona et al., 2014; Isidori et al., 2005). These findings suggest that increases in testosterone may promote sexual desire; however, it is important to note that such evidence comes primarily from studies of people with clinically low levels of sexual desire (or testosterone) and administration of synthetically-produced testosterone. Thus, it is difficult to extrapolate findings from these studies to the general population (Sader et al., 2005; van Anders, 2012; van Anders et al., 2005). Indeed, a growing body of research with healthy men and women provides contrary evidence, showing null or even negative associations between testosterone and sexual desire (Davis et al., 2005; Goldey and van Anders, 2011; Jones et al., 2018; McIntyre et al., 2006; van Anders,

☆ This research was supported by grants to Robin Edelstein from the Institute for Research on Women and Gender, University of Michigan and the Society for the Psychological Study of Social Issues.

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https://doi.org/10.1016/j.yhbeh.2020.104823
Received 6 February 2020; Received in revised form 27 May 2020; Accepted 22 July 2020

2012). Moreover, to our knowledge, testosterone-sexual desire associations have rarely been tested among expectant women, let alone couples, making it impossible to assess whether such associations can help to explain changes observed in both men and women throughout the transition to parenthood.

Further, more recent research suggests that the relation between testosterone and sexual desire may depend on the *type* of sexual desire and participants' biological sex. Contemporary theories, based primarily on studies of college-aged and young adult participants, suggest that human sexuality includes both erotic and nurturant components (van Anders et al., 2011): Motivation for *solitary* erotic experiences, such as masturbation, which are arguably more erotic than nurturant, is thought to be facilitated by higher testosterone. Motivation for *dyadic* or paired sexual experiences, however, which tend to be more nurturant or intimacy-building, is thought to be facilitated by lower testosterone (van Anders, 2013). Nurturant experiences may be more socially accepted (and more easily achieved than erotic experiences) for women (Goldey et al., 2016); coupled with the fact that women's dyadic sexual desire may involve relational components that are not necessarily related to genital pleasure (van Anders, 2013), associations between testosterone and dyadic sexual desire may be stronger among women (especially heterosexual women) compared to men. For instance, in two cross-sectional assessments of 157 and 177 healthy college-aged men and women, van Anders and colleagues found that people with higher testosterone reported greater desire to engage in *solitary* sexual activities, but only women with *lower* testosterone reported greater desire to engage in paired sexual activities (Raisanen et al., 2018; van Anders, 2012). Further, men's testosterone was not related to their dyadic or solitary sexual desire.

Dyadic sexual desire may also be more sensitive to changes that occur during the transition to parenthood compared to solitary sexual desire: Expectant couples report declines in interest for most paired sexual activities (except hugging and kissing), but no changes in interest for solitary sexual activity (e.g., masturbation frequency; von Sydow et al., 2001). Thus, dyadic sexual desire may be more closely tied to changes in testosterone during pregnancy than solitary sexual desire. Moreover, given that pregnant women undergo large prenatal increases in testosterone, whereas expectant fathers undergo prenatal declines, associations between prenatal (dyadic) sexual desire and testosterone may also differ by sex.

Surprisingly, there is little published data on associations between testosterone and sexual desire during pregnancy; longitudinal work that tracks testosterone-sexual desire associations in expectant couples across pregnancy is also critically lacking. An early (and the only) review of studies that assessed *either* women's testosterone or sexual desire prenatally concluded that women's testosterone increased, while sexual desire decreased, during pregnancy (Regan et al., 2003); however, none of the studies reviewed measured *both* testosterone and sexual desire, and none assessed these constructs in men. A more recent cross-sectional assessment of 589 healthy pregnant women showed that expectant mothers' lower sexual function (including sexual desire) was not related to their prenatal testosterone (Erol et al., 2007). This study is limited by its cross-sectional design, and exclusive focus on women, which tells us little about how *changes* in prenatal testosterone might be associated with sexual desire in both couple members. Both the review and empirical study are further limited in that solitary and dyadic forms of sexual desire were not distinguished. An overall null association between testosterone and sexual desire may mask divergent associations between testosterone and solitary versus dyadic sexual desire.

2. The current study

The goal of the current study was to assess associations between prenatal testosterone and sexual desire in a sample of first-time heterosexual expectant couples. Although Erol et al. (2007) found no association between sexual function and testosterone in a relatively large sample of 589 expectant mothers, they did not differentiate between solitary and dyadic sexual desire, which may be differentially associated with testosterone. Coupled with findings showing that expectant mothers' testosterone increases, while expectant fathers' testosterone decreases, prenatally (Edelstein et al., 2015), we sought to examine whether we would observe different testosterone-sexual desire associations between expectant mothers and fathers. Expectant couples came to our lab to complete a self-report measure of sexual desire and provide saliva samples, which were assayed for testosterone, up to three and four time points, respectively, across pregnancy. Based on cross-sectional findings in healthy men and women, we hypothesized that testosterone would be positively associated with solitary sexual desire for both expectant mothers and fathers. Further, based on findings suggesting that associations between testosterone and dyadic sexual desire may be stronger among women than men, we further hypothesized that testosterone would be negatively associated with expectant mothers' dyadic sexual desire but unrelated to expectant fathers' dyadic sexual desire.

Past research also suggests that an individual's *partner's* testosterone has important implications for relationship markers, such as relationship satisfaction and commitment, and parenting outcomes (e.g., Edelstein et al., 2014). For instance, previous findings from this sample demonstrated that expectant mothers reported greater postpartum relationship quality, more support, and more help with household tasks when their *partners* showed greater prenatal declines in testosterone (Edelstein et al., 2017; Saxbe et al., 2017). Thus, we assessed potential partner effects in the current study to determine whether, for example, expectant mothers' testosterone was associated with expectant fathers' sexual desire.

3. Method

3.1. Participants

Participants were 58 individuals (29 heterosexual couples) who were part of a larger study of neuroendocrine and psychological changes among first-time expectant parents. Findings regarding testosterone changes in expectant couples have been published elsewhere (see Edelstein et al., 2017; Edelstein et al., 2015; Saxbe et al., 2017 for more details); however, this is the first report to include data on sexual desire. The initial sample consisted of 32 couples, which was dictated by funding constraints and the difficulty of recruiting expectant couples early enough in their first trimester; three of these couples were ultimately excluded from the study,[1] leaving a final sample of 29 couples. To our knowledge, ours is the first study to examine testosterone-sexual desire associations across the prenatal period, and one of very few that have included both expectant mothers and fathers" testosterone. These rare exceptions include a longitudinal investigation by Berg and Wynne-Edwards (2002) that followed 9 couples during the prenatal period, and a cross-sectional study by Storey et al. (2000) that examined expectant couples' testosterone with a combined sample of 20 couples during the prenatal period (12 early prenatal; 8 late prenatal). Our sample size is thus comparable to (and somewhat larger than) existing studies that have examined testosterone in expectant couples during pregnancy. Couples were recruited via online and print advertisements and they received $25 per session ($50/couple) for participating. To be eligible, expectant mothers and fathers had to be between the ages of 18 and 45 (because of age-related changes in hormones; Leifke et al., 2000), living together, expecting their first child, and within the first two trimesters of pregnancy. One father had a child

[1] Three additional couples began the study but are not included in this report because they (1) were not in fact first-time parents; (2) terminated the pregnancy early due to chromosomal abnormalities, or (3) did not respond to our requests to schedule subsequent follow-up sessions.

from a previous relationship, but this was the first child together for all couples and the first full-term pregnancy for all expectant mothers. Exclusion criteria included smokers and people with medical conditions that could influence hormones (e.g., autoimmune disorders; see Schultheiss and Stanton, 2009).

Expectant mothers ranged in age from 20 to 38 (M = 29.07 years, SD = 4.09); fathers ranged in age from 20 to 42 (M = 30.10 years, SD = 4.45). Self-reported race/ethnicity was 72.4% Caucasian, 6.9% Asian, 3.4% African American, 5.2% Hispanic, and 5.2% Other; 6.9% did not provide a response. Median household income was $50,000–$75,000, and a majority of the participants had at least a college degree (72%).

3.2. Procedure

All procedures were reviewed and approved by the University of Michigan Institutional Review Board. Prenatal laboratory sessions were scheduled, according to anticipated due dates, at approximately 8-week intervals (roughly weeks 12, 20, 28, and 36 gestation). These intervals were modeled after those used by Fleming et al. (1997), who aimed to assess women at each trimester and the very end of pregnancy (0–16 weeks, 20–27 weeks, 28–35 weeks, and 36–42 weeks); however, we began our study at 12 weeks because of difficulty recruiting couples earlier in the first trimester and we targeted the beginning of the ranges used by Fleming et al. for subsequent sessions.

Expectant couples were tested throughout the year, with initial sessions occurring between July 2011 and November 2012. Several couples began the study during the second trimester of pregnancy, and some did not complete the third or fourth sessions because their babies were born before their scheduled sessions, so there was some variability in the number of sessions completed by each couple (M = 3.55 sessions, SD = 0.69). Three couples completed two sessions, 7 couples completed three sessions, and 19 couples completed all four sessions.

Informed consent was obtained during the initial session and participants were told that they could withdraw from the study at any time without penalty. During each session, expectant parents provided two saliva samples to assess hormone levels, the first after a 20-min adaptation period and the second 20 min later, to increase measurement reliability. Participants also completed an adapted version of the Sexual Desire Inventory-2 (SDI; see below), as well as several additional questionnaires (e.g., assessing personality and relationship quality) that are not considered here.

All couples came to the laboratory together for each session. Sessions were conducted on the same day of the week and at the same time (as possible) for each couple to control for diurnal and day-to-day variations in hormone levels. Because hormone levels are most stable in the afternoon and evening (e.g., Schultheiss and Stanton, 2009), all couples were tested between 12:30 h and 18:30 h. Participants also completed up to two additional online postpartum follow-up sessions, which included measures of parenting and other postpartum outcomes that are not relevant to the current aims and thus are not considered here (see Edelstein et al., 2017; Saxbe et al., 2017).

3.3. Measure

The Sexual Desire Inventory-2 (SDI; Spector et al., 1996) is a 14-item questionnaire that measures people's interest in and wish for sexual activity.[2] The SDI includes a 3-item *solitary sexual desire* scale, which includes items such as, “How strong is your desire to engage in sexual behavior by yourself?” and “How important is it for you to fulfill your desires to behave sexually by yourself?” and an 8-item *dyadic sexual desire* subscale, which includes items such as, “When you have sexual thoughts, how strong is your desire to engage in sexual behavior with a partner?” and “How important is it for you to fulfill your sexual desire through activity with a partner?”. Items are rated on an 8-point Likert scale (1 = no desire/not at all important to 8 = strong desire/extremely important).

The SDI was administered at three time points during the study.[3] Depending on when participants began the study, they completed the SDI during the first (N = 29; M_{weeks} = 15.10), third (N = 25; M_{weeks} = 29.52), and/or fourth (N = 20; M_{weeks} = 35.65) session. We calculated separate alphas for each time point. Across the different visits, there was good internal consistency for both dyadic (α = 0.78 to 0.86) and solitary sexual desire (α = 0.69 to 0.77).

3.3.1. Salivary Hormones: Collection and Assessment.

Participants were asked to refrain from eating, drinking (except for water), smoking, or brushing their teeth for 1 h prior to the beginning of each session. After rinsing their mouths with water, participants used polypropylene tubes to provide two 7.5 mL saliva samples during each of the in-lab sessions. Samples were frozen until further processing at the University of Michigan Core Assay Facility.[4]

Testosterone was assayed by radioimmunoassay (RIA) using commercially available kits from Siemens. The inter-assay coefficient of variation (CV) for testosterone was 14.97% and 5.26% at low and high levels, respectively; the intra-assay CV was 9.86%. These values are well within acceptable ranges and similar values have been obtained in other studies that have assessed salivary testosterone in women using RIA, including those that find associations between women's testosterone and other outcomes (Liening et al., 2010; Raisanen et al., 2018). Analytical sensitivity (B_0–2 SD) for testosterone was 1.14 ng/mL. Samples were assayed in duplicate, and the average of duplicates was taken (r = 0.92 to 0.98).

Average testosterone values were inspected for outliers, separately by gender and session. To maximize the use of all available data, testosterone values that were larger than three standard deviations above the mean were replaced with values corresponding to three standard deviations above the mean for that particular variable (i.e., Winsorized; Reifman and Keyton, 2010; see also Edelstein et al., 2014, for a similar approach). Only one value – for one father – was replaced using this approach (< 1.00% of the total sample).

3.4. Overview of statistical analyses

As our data has a multilevel structure – participants were assessed repeatedly over time and are nested within dyads – individual observations cannot be treated as independent. To account for this multilevel structure and to model the interdependence of individuals within dyads, multilevel modeling (MLM) procedures for dyadic data with repeated measures (i.e., SPSS Mixed; Kenny et al., 2006) were conducted. We first examined the pooled associations between sexual desire and testosterone across pregnancy by running a “stacked” actor-

[2] Following van Anders (2012), we added one item to the original SDI measure, “During the last month, how often have you had sexual thoughts?”. However, for the purposes of the present study, we did not consider this item, or the additional 3 items in the original measure that that tap on a broader index of desire that does not explicitly distinguish between desire for solitary or dyadic sexual activity (e.g., “During the last month, how often had you had sexual thoughts?” and “How long could you go comfortable without having sexual activity of some kind?”).

[3] Although most measures were assessed at all four time points, some (including the SDI) were administered at two or three to decrease participant burden.

[4] We also measured estradiol, progesterone, and cortisol as part of the larger study. Because testosterone has been most often assessed in relation to sexual desire, and because we found the most reliable changes in expectant fathers' testosterone compared to other hormones (Edelstein et al., 2015), we focus exclusively on testosterone here.

partner-interdependence model (APIM), a variant of MLM, using the Statistical Package for the Social Sciences (SPSS, version 25). The "stacked" APIM treats time as a replication and uses multiple waves of data to gain more precise estimates of cross-sectional associations by pooling information from participants over multiple waves (Kashy and Donnellan, 2012). For instance, instead of obtaining three separate estimates of the association between testosterone and sexual desire (one for each timepoint), the stacked APIM produces a single, more precise estimate of this association, pooled together from all information in the dataset.

Next, we tested whether sexual desire and testosterone changed over time. To do so, we ran dyadic growth curve analyses. Dyadic growth curve models are an extension of MLM, and they provide estimates of change over time while accounting for the statistical dependence of related individuals (e.g., couples; Kashy and Donnellan, 2008). MLM procedures were ideal for our purposes because they also allowed us to model the initial levels (i.e., intercepts) and changes (i.e., slopes) in sexual desire across pregnancy. MLM procedures additionally adjust for the fact that couples came into the lab at different weeks of pregnancy and allowed us to include all available data for participants who had missing data at one or more sessions.

At Level 1 of our model, we examined the linear effect of time by entering participants' week of pregnancy as our predictor. As couples entered the study at different weeks of pregnancy, we centered time at week 9 to approximate week of study entry; thus, the values for the intercept in each model correspond to an individual's average level of sexual desire (or testosterone) at study entry. Next, at Level 2, we included week of first visit to the laboratory and the total number of weeks that had elapsed from the first visit to the last visit as centered covariates, which allowed us to control for between-couple heterogeneity in their week of participation in our study.

Finally, we tested whether changes in actor and partner testosterone were associated with changes in sexual desire over pregnancy. To test these associations, we built on the 2-level dyadic growth curve model with sexual desire as our outcome variable by including as a predictor a percentage change in testosterone score (i.e., testosterone at the first assessment was subtracted from testosterone at the last assessment and divided by testosterone at the first assessment and the total number of weeks elapsed between these two assessments, multiplied by 100 to obtain a percentage score).

For all analyses, both intercepts and slopes in the interaction models were initially treated as random (i.e., allowed to vary across individuals); however, as specified below, we used random intercept-only models when we encountered issues with model convergence.

4. Results

4.1. Preliminary analyses

Descriptive information for testosterone and each type of sexual desire is presented in Table 1 by gender and session (i.e., the approximate 8-week increment in which participants were tested). Expectant mothers and fathers showed a pattern of decreasing dyadic sexual desire, while solitary sexual desire appeared to stay relatively unchanged across pregnancy. Across pregnancy, expectant mothers' testosterone increased, while fathers' testosterone decreased. These data are presented for broad descriptive purposes only; all subsequent analyses were conducted by week of pregnancy.

To examine within-couple correlations, we correlated partners' testosterone levels separately at each time point, while statistically controlling for time of day. Testosterone was not significantly correlated within couples for the first three timepoints ($r_{1–3}$'s = −0.04, 0.21 and 0.27, p = .18–.85) but was significantly and positively correlated at the fourth timepoint (r = 0.44, p = .03). Given that the within-couple correlations were in the positive direction for 3 out of 4 timepoints, our result suggests some level of interdependence between expectant mothers and fathers' testosterone, especially toward the end of pregnancy.

We also ran within-person and within-couple correlations for sexual desire at each time point and by gender. Supporting the distinction between dyadic and solitary sexual desire, we found no significant within-person associations between dyadic and solitary sexual desire for expectant fathers ($r_{1–4}$'s = 0.27, 0.59, 0.04 and 0.06, p = .21–.85) or mothers ($r_{1,2,4}$'s = 0.40, 0.11 and 0.36, p = .06–.89), except for a significant correlation at T3 for expectant mothers (r = 0.40, p = .04). Also consistent with the literature that couple members may have different levels of sexual desire (Mark, 2012; Mark and Murray, 2012; McCarthy and McDonald, 2009), there were no significant within-couple associations for dyadic sexual desire ($r_{1,2,4}$'s = 0.38, 0.30 and 0.25, p = .08–.71), except for a significant correlation at T3 (r = 0.40, p = .04), or solitary sexual desire ($r_{1–4}$'s = 0.15, −0.11, 0.28 and 0.18, p = .17–.89).

4.2. Are Testosterone and Sexual Desire Associated During Pregnancy?

To examine the pooled associations between testosterone and different types of sexual desire (dyadic and solitary), we ran a stacked APIM, which allowed us to assess whether an individual's testosterone is associated with their own and/or their partner's sexual desire. We included participants' sexual desire and actor and partner testosterone at each visit in the model. We also examined whether gender moderated the associations between sexual desire and testosterone (i.e., whether associations between testosterone and sexual desire differed between expectant mothers and fathers). As mentioned, we included centered starting week and the total number of weeks that elapsed as covariates; results were virtually identical when we re-ran the models without these covariates.

Full results for the pooled associations between testosterone and sexual desire are presented in Table 2, with solitary sexual desire on the left and dyadic sexual desire on the right. The coefficients reflect the pooled correlations between each form of sexual desire and the corresponding variable (e.g., mean levels of actor and partner testosterone). We conducted separate analyses for each type of sexual desire (i.e., dyadic, solitary), resulting in two stacked APIM models.

Our results revealed a significant interaction between actor testosterone and gender for dyadic sexual desire (shown in the right column of Table 2). Decomposing this interaction revealed that, for expectant mothers, testosterone levels were negatively associated with their own dyadic sexual desire, (b = −0.01, SE = 0.00, t = −3.18, p = .003, 95% CI [−0.02, −0.00]); fathers' testosterone levels were not associated with their dyadic sexual desire (b = 0.01, SE = 0.01, t = 1.42, p = .16, 95% CI [−0.00, 0.02]). No other effects, including partner effects, were significant in this model, and there were no significant associations between testosterone and solitary sexual desire.

4.2.1. Summary

When we pooled across all timepoints, we found a negative association between dyadic sexual desire and testosterone for expectant mothers, but there were no significant associations between expectant mothers' solitary sexual desire and testosterone. Additionally, we did not find any significant associations between solitary or dyadic sexual desire and testosterone for expectant fathers.

4.3. How do testosterone and sexual desire change across pregnancy?

To examine the longitudinal trajectories of testosterone and sexual desire over pregnancy, we ran dyadic growth curve models. At Level 1, we tested separate models with each form of sexual desire and testosterone as independent outcome variables predicted by week of pregnancy. Then at Level 2, we included both the centered starting week of pregnancy and centered total number of weeks elapsed variables in the model as covariates; results were virtually identical when re-ran the

Table 1
Descriptive statistics for sexual desire and testosterone by gender and time point.

	Time 1 (N = 23 couples) (M_{week} = 12.78)	Time 2 (N = 27 couples) (M_{week} = 21.15)	Time 3 (N = 28 couples) (M_{week} = 28.71)	Time 4 (N = 25 couples) (M_{week} = 36.28)
Expectant mothers				
Dyadic sexual desire	5.36 (1.13)	4.91 (2.16)	5.07 (1.07)	4.68 (1.25)
Solitary sexual desire	3.27 (1.78)	1.88 (1.75)	3.30 (1.90)	2.90 (1.88)
Testosterone (ng/mL)	9.89 (4.80)	16.25 (7.74)	23.47 (11.79)	54.15 (24.30)
Expectant fathers				
Dyadic sexual desire	6.18 (0.90)	6.09 (0.58)	5.90 (0.86)	5.78 (0.87)
Solitary sexual desire	3.99 (1.60)	3.19 (1.14)	4.00 (1.53)	3.65 (1.54)
Testosterone (ng/mL)	50.23 (11.25)	49.79 (16.54)	48.45 (14.32)	47.62 (17.09)

Note. Total N = 58 people (29 couples). Although we ran descriptives based on session number (to approximate each trimester and at the end of pregnancy), it is important to note that we reclassified couples' session number if they began study participation during their second (N = 4 couples) or third (N = 2 couples) trimester of pregnancy. In doing so, we were able to obtained sexual desire scores from 23 couples at T1, 4 couples at Time 2 (because we did not administer the sexual desire measure to couples at their second visit), 26 couples at Time 3, and 21 couples at Time 4.

models without these covariates. We ran random slopes and random intercepts models for sexual desire, but only random intercepts models for testosterone due to issues with model convergence. We conducted separate analyses for testosterone and each type of sexual desire (i.e., dyadic, solitary), resulting in three dyadic growth curve models.

4.3.1. Testosterone

When we examined changes over time in testosterone, we found an interaction between time and gender (b = 1.00, SE = 0.09, t = 11.70, p < .001, 95% CI [0.83, 1.17]). As reported previously from this sample (e.g., Edelstein et al., 2015), for expectant mothers, testosterone levels increased over time (b = 1.74, SE = 0.17, t = 10.49, p < .001, 95% CI [1.41, 2.06]); for expectant fathers, testosterone levels decreased over time (b = −0.27, SE = 0.11, t = −2.54, p = .01, 95% CI [−0.48, −0.06]).

4.3.2. Solitary sexual desire

Consistent with prior research, we found that expectant mothers reported lower average levels of solitary sexual desire compared to expectant fathers (b = −0.46, SE = 0.21, t = −2.16, p = .05, 95% CI [−0.92, −0.00]). In line with some findings in the literature, there were no changes in solitary sexual desire over time (b = −0.01, SE = 0.01, t = −0.62, p = .55, 95% CI [−0.02, 0.01]), and no interaction between time and gender, suggesting that neither men nor women showed changes in solitary desire during pregnancy.

4.3.3. Dyadic sexual desire

Consistent with previous research, we found that expectant mothers reported lower average levels of dyadic sexual desire compared to fathers (b = −0.45, SE = 0.13, t = −3.62, p = .001. 95% CI [−0.71, −0.20]). Again, paralleling previous findings in the literature, we found a main effect of time for both men and women, such that dyadic sexual desire decreased over pregnancy (b = −0.02, SE = 0.00, t = −4.09, p < .001, 95% CI [−0.03, −0.01]). We did not find an interaction between time and gender, indicating that the decrease in dyadic sexual desire over pregnancy did not differ between expectant mothers and fathers.

4.3.4. Summary

In line with our and others' previous research, testosterone increased for expectant mothers, while testosterone decreased for expectant fathers. Also consistent with previous findings, we found that dyadic, but not solitary, sexual desire decreased for expectant mothers and fathers over pregnancy.

4.4. Are Changes in Testosterone Associated with Changes in Sexual Desire During Pregnancy?

Finally, we examined whether changes in testosterone were associated with changes in sexual desire during pregnancy. To examine these associations, we built on the dyadic growth curve model with sexual desire as the outcome variable. We included all aforementioned Level 1 (i.e., week of pregnancy, starting week) and Level 2 (i.e., total number of weeks) variables and covariates; again, results were virtually identical when we re-ran the models without these covariates. In addition, we calculated the percentage change in testosterone score described earlier (i.e., (Testosterone_{t2}-Testosterone_{t1})/ Testosterone_{t1} * 100%)) and entered it as a Level-2 predictor to assess how changes in testosterone were associated with changes in sexual desire over pregnancy.

Full results are presented in Table 3. As before, solitary sexual desire is presented on the left and dyadic sexual desire is presented on the right. The tables include the coefficient for the intercepts (i.e., initial or "starting value" of each form of sexual desire at the beginning of study participation), changes in testosterone (i.e., calculated change score in testosterone), time (i.e., number of weeks) and gender (i.e., differences

Table 2
Multilevel model results for the pooled associations (Stacked APIM) between couples' sexual desire and testosterone during pregnancy.

	Solitary sexual desire				Dyadic sexual desire			
	b	*SE*	*t*	*CI*	*b*	*SE*	*t*	*CI*
Intercept	4.97	1.21	4.10**	[2.48, 7.46]	5.05	0.81	6.21**	[3.39, 6.71]
First week	−0.07	0.08	−0.91	[−0.22, 0.09]	0.01	0.05	0.19	[−0.09, 0.11]
Total number of weeks	−0.58	0.36	−1.62	[−1.33, 0.16]	0.08	0.24	0.32	[−0.41, 0.57]
Gender	−0.68	0.43	−1.57	[−1.55, 0.19]	−0.07	0.26	−0.29	[−0.59, 0.44]
Actor testosterone	−0.01	0.01	−0.91	[−0.02, 0.01]	−0.00	0.00	−0.40	[−0.01, 0.01]
Partner testosterone	−0.00	0.01	−0.79	[−0.02, 0.01]	−0.00	0.00	−0.74	[−0.01, 0.01]
Gender * Actor testosterone	0.00	0.01	0.31	[−0.01, 0.01]	−0.01	0.00	−2.88*	[−0.02, −0.00]
Gender * Partner testosterone	0.00	0.01	0.43	[−0.01, 0.01]	−0.00	0.00	−0.66	[−0.01, 0.01]

Note. Total N = 58 people (29 couples). ** p < .001, * p < .01.

Table 3
Multilevel model results for the associations between couples' sexual desire and change in testosterone during pregnancy.

	Solitary sexual desire				Dyadic sexual desire			
	b	*SE*	*t*	*CI*	*b*	*SE*	*t*	*CI*
Intercept	3.61	0.88	4.08***	[1.80, 5.41]	5.36	0.52	10.31***	[4.30, 6.42]
First week	−0.01	0.06	−0.19	[−0.13, 0.10]	0.01	0.03	0.23	[−0.06, 0.08]
Gender	−0.58	0.40	−1.44	[−1.39, 0.23]	−0.50	0.22	−2.26*	[−0.94, −0.06]
Time (by pregnancy weeks)	−0.01	0.01	−0.39	[−0.03, 0.02]	−0.02	0.01	−2.77**	[−0.04, −0.01]
Change in actor T	−0.15	1.81	−0.08	[−3.79, 3.49]	−1.39	1.06	−1.31	[−3.52. 0.75]
Change in partner T	−0.18	2.03	−0.09	[−4.29, 3.93]	0.36	1.16	0.31	[−1.97, 2.70]
Gender * time	0.01	0.01	1.01	[−0.01, 0.03]	−0.00	0.01	−0.18	[−0.02, 0.02]
Gender * change in actor T	0.39	1.81	0.22	[−3.25, 4.03]	1.34	1.06	1.26	[−0.80, 3.47]
Gender * change in partner T	−0.14	2.04	−0.07	[−4.26, 3.98]	0.62	1.16	0.54	[−1.71, 2.95]
Change in actor T * Time	−0.08	0.08	0.93	[−0.25, 0.09]	0.13	0.04	2.86**	[0.04, 0.21]
Change in partner T * Time	−0.02	0.08	−0.20	[−0.18, 0.14]	−0.06	0.06	−0.94	[−0.18, 0.06]
Gender * change in actor T * time	0.07	0.08	0.79	[−0.10, 0.24]	−0.13	0.04	−2.95**	[−0.22, −0.04]
Gender * change in partner T * time	−0.02	0.08	−0.30	[−0.18, 0.14]	−0.07	0.06	−1.24	[−0.19, 0.05]

Note. Total $N = 58$ people (29 couples). Change in T = calculated percentage change in testosterone score by subtracting testosterone values at first time point from testosterone values at last time point, divided by total number of weeks and 100. *** $p < .001$, ** $p < .01$, * $p < .05$.

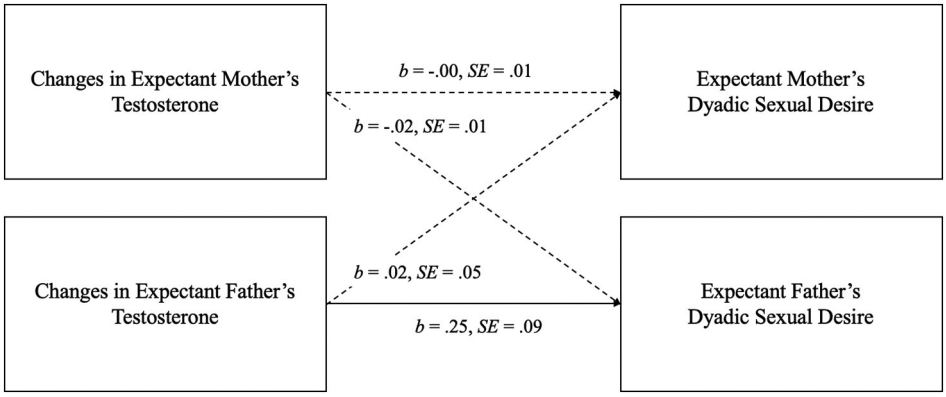

Fig. 1. Actor-Partner Interdependence Model examining actor and partner effects of percent change in expectant mothers' and fathers' prenatal testosterone on mothers' and fathers' dyadic sexual desire. The current model controls for week of pregnancy at study entry. Significant paths are represented by unbroken arrows and non-significant paths are represented by broken arrows.

between expectant mothers and fathers); we examined all 2-way and 3-way interactions in the model. We ran two models to account for each type of sexual desire.

We found a significant 3-way interaction between change in testosterone, time, and gender for dyadic sexual desire. Decomposing this interaction revealed that increases in expectant fathers' testosterone were associated with increases in their own dyadic sexual desire ($b = 0.25$, $SE = 0.09$, $t = 2.93$, $p = .005$, 95% CI [0.08, 0.43]; see Fig. 1); changes in expectant mothers' testosterone were not associated with changes in their dyadic sexual desire ($b = -0.00$, $SE = 0.01$, $t = -0.37$, $p = .71$, 95% CI [−0.03, 0.02]). No other effects were significant in this model. There were also no significant partner effects, and no significant associations between changes in testosterone and solitary sexual desire.[5]

4.4.1. Summary

In sum, we found longitudinal evidence that prenatal changes in testosterone were associated with changes in expectant fathers', but not expectant mothers', sexual desire. Specifically, we found that increases in fathers' testosterone were associated with increases in their own dyadic sexual desire.

[5] Due to our relatively small sample size, and potential issues with statistical power, we also re-ran the model separately by gender (i.e., two separate models, one for expectant mothers and one for expectant fathers, testing the interaction between changes in testosterone and time) as an additional check. Our results were virtually identical to those that came from the more complex 3-way interaction (gender x change in testosterone x time) presented earlier.

5. Discussion

The goal of the current study was to examine associations between expectant parents' testosterone and sexual desire during pregnancy. Prior research with clinical samples hints at a positive correlation between testosterone and sexual desire; however, the generalizability of findings from clinical to non-clinical populations has been questioned (van Anders, 2012). Moreover, there are reasons to expect that associations may differ for solitary versus dyadic sexual desire (van Anders and Dunn, 2009; van Anders et al., 2011). Because both women and men exhibit changes in testosterone and sexual desire during the transition to parenthood (Berg and Wynne-Edwards, 2001; Schock et al., 2016), we sought to reexamine associations between testosterone and different kinds of sexual desire in this sample.

Consistent with past research and as reported previously (Edelstein et al., 2015; Regan et al., 2003), expectant mothers' testosterone increased during pregnancy; cross-sectionally, we observed that women with higher testosterone reported lower dyadic sexual desire. Also as reported previously (Edelstein et al., 2015), expectant fathers' testosterone decreased during pregnancy; longitudinally, we found that declines in expectant fathers' testosterone were related to lower levels of their own dyadic sexual desire. Consistent with other research, we found that expectant mothers' dyadic sexual desire was not correlated with fathers' sexual desire (Mark and Murray, 2012). Finally, contrary to our hypotheses, we did not find any cross-sectional or longitudinal associations between expectant parents' testosterone and solitary sexual desire.

Our findings are generally consistent with previous cross-sectional research showing negative associations between women's testosterone and dyadic sexual desire. Lower levels of testosterone are thought to be

associated with more nurturant aspects of intimacy, such as cuddling, close body contact, and motivation for paired sexual activity (van Anders et al., 2011). Perhaps our finding, that women with higher levels of testosterone are less motivated to seek out partnered physical intimacy, is simply capturing this general pattern, regardless of women's pregnancy status. Yet, unique factors associated with pregnancy may also magnify this association: Perhaps pregnant women with higher levels of testosterone are more preoccupied with their baby than their partners during pregnancy, which might reduce their desire for paired sexual activity (Bartellas et al., 2000; Carter, 1998; Clark et al., 2009; van Anders et al., 2011). Indeed, higher levels of testosterone have been implicated in protective aggression and offspring defense (van Anders et al., 2011). Our findings may appear to contradict an earlier investigation of testosterone and sexual dysfunction – Erol et al. (2007) documented *null* associations between testosterone and sexual dysfunction in a sample of 589 expectant mothers. It is, however, important to note that their outcome of interest was a general conceptualization of sexual dysfunction and not *sexual desire* (sexual desire was one facet of several other subconstructs of sexual dysfunction). Thus, the significant negative association between testosterone and sexual desire in Erol et al.'s study may have been masked by positive associations between testosterone and other subconstructs in their measure of sexual dysfunction. Our results are in line, at least, with other cross-sectional studies (albeit in non-pregnant samples) that have found significant negative associations between testosterone and sexual desire (e.g., in two independent studies of 78 and 91 healthy college-aged women; see Raisanen et al., 2018; van Anders, 2012). Although the precise mechanism linking women's testosterone and dyadic sexual desire remains unclear, our findings support existing assumptions that expectant women's prenatal testosterone is related to their diminished (dyadic) sex drive during pregnancy.

Fewer studies have examined associations between men's testosterone and dyadic sexual desire, but results from these studies generally suggest that men's testosterone is unrelated to this form of sexual desire (Raisanen et al., 2018; van Anders, 2012; van Anders and Dunn, 2009). In our study, however, we found that *decreases* in expectant fathers' testosterone were related to lower dyadic sexual desire. Our findings could be an artifact of our small sample size (e.g., a false positive; Button et al., 2013); yet they may also reflect tradeoffs between parenting and mating, given that declines in testosterone are thought to help prepare men for fatherhood by increasing relationship investment and promoting parenting behavior (Edelstein et al., 2017; Fleming et al., 2002; Saxbe et al., 2017). For example, Gettler et al. (2013) showed that among 153 men transitioning from unmarried non-fathers to married new fathers, those who showed greater declines in testosterone also reported less frequent sexual activity. Thus, our findings suggest that prenatal testosterone changes may be functional insofar as they shift expectant fathers' attention from sexual activity toward parenting. Partnered men's testosterone has also been implicated in sociosexual desire (a facet of sociosexual orientation that measures one's desire for uncommitted sexual activity; Edelstein et al., 2011; McIntyre et al., 2006; Penke and Asendorpf, 2008), which captures one's motivation to allocate mating efforts to short-term versus long-term mating strategies. Thus, future research may benefit from including a measure of sociosexual desire to provide additional tests for the proposed mating-parenting tradeoff. For example, expectant fathers transitioning to parenthood may show a decrease in testosterone alongside a commensurate decrease in both dyadic and sociosexual desire.

Contrary to our expectations, we did not find associations between expectant parents' testosterone and their solitary sexual desire. Testosterone is implicated in erotic pleasure and motivation for solitary sexual activity (van Anders et al., 2011), and it has been correlated positively with men and women's solitary sexual desire (Goldey et al., 2018; van Anders, 2012; van Anders and Dunn, 2009). It is worth noting, however, that solitary sexual desire generally shows fewer changes over pregnancy compared to dyadic desire, including in our study, suggesting that it may be less sensitive to contextual changes (von Sydow et al., 2001). Stress associated with the transition to parenthood might also moderate desire-testosterone associations. For example, psychological stress associated with the transition to parenthood (e.g., preparing for the baby, fear of hurting the baby during intercourse) may reduce one's sexual motivation. Biological markers of stress, such as the stress hormone cortisol, may also reduce sexual arousal in both women and men (Goldey and van Anders, 2012; ter Kuile et al., 2007): Raisanen et al. (2018) found that associations between testosterone and solitary sexual desire were detectable only at relatively low levels of stress. Specifically, at lower levels of stress, testosterone and solitary desire were positively associated among men and negatively associated among women.[6] Thus, biological markers of stress (cortisol) and psychological stress experienced by expectant parents during this major life transition may have masked any testosterone-solitary desire associations. Also of importance, prior studies that have examined testosterone and sexual desire associations (including Erol et al. (2007)) often fail to distinguish between solitary and dyadic sexual desire, even though solitary and dyadic variants of sexual desire are likely to vary during pregnancy. Although our study provides new evidence that solitary sexual desire and testosterone are not related during pregnancy, more research is needed, with larger samples, to replicate the present finding.

It is also noteworthy that we found no dyadic associations between one person's testosterone and his or her partners' sexual desire. Recent research demonstrates interdependence within couples in a number of close relationship processes. For example, expectant fathers who reported greater relationship quality (especially perceived closeness) also reported more sexual satisfaction during pregnancy (Radoš et al., 2015). Moreover, our previous findings suggest that lower partner testosterone is associated with greater relationship satisfaction and commitment, and that larger prenatal declines in partner testosterone are associated with greater perceived postpartum support expectant in both mothers and fathers (Edelstein et al., 2017; Edelstein et al., 2014). However, to our knowledge, and perhaps surprisingly, no studies have examined *dyadic* associations between testosterone and sexuality, despite the inherently dyadic nature of sexuality in intimate relationships. This argument is perhaps bolstered by the fact that, in our study, (actor) associations emerged only in the context of dyadic sexual desire, which necessarily involves a partner. Given that larger sample sizes are typically necessary to detect partner versus actor effects, it is possible that we simply did not have the statistical power to detect any partner associations between testosterone and sexual desire. Or, perhaps there is something unique about pregnancy that dampens such associations. More research, with larger and more representative samples of both expectant and non-expectant couples, is needed to ascertain the generalizability of our claims.

An important strength of the present study is that we examined expectant couples' testosterone and sexual desire not only dyadically but also longitudinally. Our longitudinal design allowed us to assess whether *average* levels of testosterone, as well as *changes* in testosterone, are related to sexual desire. Cross-sectionally, our findings were generally consistent with previous (cross-sectional) work with larger

[6] Based on research on the dual-hormone hypothesis (i.e., that effects of testosterone depend on concentrations of cortisol), we might expect that associations between testosterone and sexual desire may also depend on one's own level of cortisol. Accordingly, we ran additional analyses to examine if testosterone-sexual desire associations may be moderated by expectant couples' cortisol levels, which we had available. However, we did not find support that expectant parents' cortisol moderated the association between testosterone and sexual desire in our study (all p's > 0.05). It is possible that biological stress may play a less important role in affecting testosterone-sexual desire associations during pregnancy or may depend on yet another variable that was not measured in the current study. We consider this an important direction for future research.

samples (*N's* > 100; Raisanen et al., 2018; van Anders, 2012): Expectant mothers' testosterone was negatively related to their dyadic sexual desire, while expectant fathers' testosterone was unrelated to their dyadic or solitary sexual desire. Longitudinally, however, our findings presented a different pattern: Changes in expectant mothers' testosterone were *not* related to their solitary or dyadic sexual desire, while decreases in expectant fathers' testosterone were associated with decreases in their dyadic sexual desire. Thus, reliance on cross-sectional assessments in previous research might explain some of the inconsistencies in associations between testosterone and sexual desire. More generally, our longitudinal findings contribute to a growing body of work that suggest that changes in, as well as absolute levels of, testosterone are associated with people's psychosocial outcomes (Edelstein et al., 2017; Kuo et al., 2016). We suggest that future research should adopt longitudinal designs to test how both baseline levels and changes in testosterone are associated with sexual desire and to clarify previous inconsistent associations.

Our findings also contribute to a growing body of research focusing on men's sexuality across the transition to parenthood. Researchers have examined the *psychosocial* correlates of sexual desire declines during pregnancy (e.g., diminished sexual frequency, the need to focus on the baby; Alder, 1989; Olsson et al., 2010). In our study, we assessed testosterone fluctuations as a potential physiological correlate of these changes. Indeed, prior research has demonstrated that fathers showed lower levels of testosterone than unmarried non-fathers (Burnham et al., 2003; Gettler et al., 2011; Gray et al., 2005), but also after the birth of their child (Perini et al., 2012). Our research remains limited, however, by the fact that we did not examine testosterone before pregnancy or postpartum, so we cannot assess testosterone-sexual desire associations across the entire transition to parenthood. Additionally, we did not include a control group (e.g., single men or married men who are not transitioning to fatherhood). Thus, we are unable to determine whether decreases in expectant fathers' testosterone are related to the pregnancy per se (as compared to age-related declines in testosterone) or to compare testosterone-desire associations across groups. Despite these limitations, our study provides critical insight into father's sexuality during the prenatal period specifically, given that most relevant studies focus on the postpartum period (Radoš et al., 2015). Our study is also one of the first to incorporate prenatal assessments of expectant fathers' testosterone. Future research should include a comparison group of men not transitioning to fatherhood to increase the robustness and confidence of our findings, perhaps collecting testosterone from fathers at multiple time points to explore how men's testosterone-sexual desire associations vary before, during, and after pregnancy.

Despite its merits, we acknowledge important limitations in the present study. First, expectant couples in our sample were predominantly White, relatively wealthy, and highly educated, so the current findings may not necessarily generalize to other samples. For example, expectant couples in our study were all living together, and they were either married or engaged, which is not the case for many first-time parents (Martin et al., 2013). Additionally, different conceptions of sexuality in other cultures with more conservative attitudes toward sex, for instance, could moderate expectant mothers' and fathers' sexual desire during pregnancy (Tolman and Diamond, 2001). The homogeneity of our sample thus limits the generalizability of our findings.

Methodologically, the use of radioimmunoassays may have also limited our findings. Immunoassays are commonly used because of their cost effectiveness, accessibility, and ease of use (Taylor et al., 2015); however, they have been criticized for issues such as cross-reactivity (e.g., chemically similar compounds are measured in addition to the target hormone of interest, potentially affecting results) and quantification errors related to the variations in sensitivity and specificity of commercial assay kits (Prasad et al., 2019; Schultheiss et al., 2019; Welker et al., 2016). For instance, immunoassays may overestimate salivary testosterone levels at extremely high or low concentrations, and this may be especially problematic for research with women, who typically have lower levels of testosterone compared to men (Welker et al., 2016). In the present study, the concern of immunoassay reliabilities is somewhat mitigated by the fact that expectant mothers' testosterone unambiguously increases across pregnancy. However, it will be important for future research to employ more robust methods (e.g., liquid chromatography tandem mass spectrometry) to corroborate our findings.

Lastly, our sample of expectant couples was relatively small, which likely limited our statistical power to detect small effect sizes and especially partner effects (Kenny et al., 2006; Lane and Hennes, 2018). A small sample size also means that we were unable to use more sophisticated models that include potential moderators (e.g., body mass, diet; Sowers et al., 2001) that may affect testosterone-desire associations. Less intuitively, small sample sizes may also run the risk of *overestimating* effect sizes and culminate in false positives and low replicability rates (see Button et al., 2013). A study with a small sample size, may by chance, observe a significant finding based on an inflated effect size. It is important to consider that, despite our relatively small sample size, we assessed expectant couples' sexual desire three, and testosterone four, times across pregnancy, adding greater precision to our estimates of each. As our relatively small sample limits power when testing more sophisticated models (i.e., 3-way interactions), we conducted post hoc power analyses in hopes of improving confidence that we had enough power to detect even smaller effects than many of those highlighted here. Given the complexity of conducting power analyses in longitudinal dyadic analyses, we adopted similar procedures as other researchers who have used simpler models to provide a useful reference point for analyzing power when using the APIM (Weidmann et al., 2017). Specifically, we found that a cross-sectional APIM with 29 expectant couples, medium actor effects, and small partner effects had 33% power to detect actor effects (Ackerman and Kenny, 2016; Ackerman et al., 2016); however, multiple time points grants more statistical power. Thus, if we treat our data as a cross-sectional sample of 72 couples (the total number of data points we had for couples who had both testosterone and sexual desire scores at each time point), statistical power increases from 33% to 72% to detect actor effects. If we consider the longitudinal nature of our study, and that we had 29 couples contributing four assessments, there is greater confidence for testing actor effects in the present models. Relatedly, although we had less data from participants who might have missed sessions in our study (e.g., their babies were born before their last visit time points of the study), and we did not administer the sexual desire measure at all four time points in the study, the use of multilevel model analyses and the longitudinal design with repeated prenatal measures of testosterone and sexual desire in the present investigation is a significant methodological improvement from traditional cross-sectional assessments. In particular, the use of multiple within-person assessments of testosterone and sexual desire provides a more robust estimation of effects (especially for the stacked APIM, which used testosterone and sexual desire scores across all time points to calculate pooled correlations). Future research might recruit more heterogeneous and larger samples and assess hormones and sexual desire over more time points.

In conclusion, we explored testosterone-sexual desire associations during pregnancy in a sample of expectant parents. This is the first study to examine longitudinal associations between prenatal testosterone and sexual desire in expectant mothers, and to include assessments with expectant fathers. This is also the first study to examine associations between prenatal testosterone and distinct forms of sexual desire (solitary, dyadic). We provided empirical evidence that expectant mothers' testosterone is negatively associated with dyadic sexual desire, and that decreases in expectant fathers' prenatal testosterone were associated with decreases in dyadic sexual desire. Our findings provide some support for the prevailing belief that testosterone is related to sexual desire. However, more longitudinal research, with

larger samples, is needed to provide a more robust account of how hormones are related to sexual desire.

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