

# SEX HORMONES AND COMPETITIVE BIDDING\*

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## Abstract

We correlate competitive bidding and profits in symmetric independent private value first-price auctions with salivary testosterone, estradiol, progesterone, and cortisol in more than 200 subjects. Bids are significantly positively correlated and profits are significantly negatively correlated with basal salivary progesterone but only for females who do not use hormonal contraceptives. Surprisingly, we have null findings for basal testosterone, estradiol, and cortisol for both males and females. We show that our finding for progesterone is not mediated by risk aversion or bidding mistakes. No hormone responds to total profits in the auctions except for a small positive response of the stress hormone cortisol in males.

**Keywords:** Hormones, Steroids, Testosterone, Estradiol, Progesterone, Cortisol, Contraceptives, Auctions, Gender, Competition, Aggression, Risk-taking, Endocrinological economics.

**JEL-Classifications:** C72, C91, C92, D44, D81, D87.

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# 1 Introduction

Auction games are one of the most important classes of mechanisms used to optimally allocate objects among agents with unknown valuations. They are widely used in financial markets and business-to-business relationships (like online advertising auctions, FCC spectrum auctions, and timber auctions) but also in business-to-consumer relationships (like Ebay, charity auctions, etc.) some involving a huge number of transactions and billions of dollars in revenues. One of the theoretically best-understood auction formats is the first-price auction. In a first-price auction, the highest bidder wins and pays his/her bid.

There is independently replicated experimental evidence that on average women bid higher and earn lower profits than men in first-price auctions (Casari, Ham, and Kagel, 2007, Ham and Kagel, 2006, Chen, Katuščák, and Ozdenoren, 2013, Pearson and Schipper, 2013).<sup>1</sup> These differences are substantial. For instance, Pearson and Schipper (2013) find that women earn on average 25% less than men in two-bidder first-price auctions with symmetric independent private values.

Chen, Katuščák, and Ozdenoren (2013) and Pearson and Schipper (2013) go beyond plain gender differences by studying how the bidding and profits of women differ across the menstrual cycle. Women differ from men in circulating levels of some hormones. Hormones are chemical messengers released by glands and certain neurons in the brain. They carry signals in the bloodstream that are important for the functioning of the body and affect behavior (see Nelson, 2011). Some hormones such as estradiol and progesterone fluctuate over the menstrual cycle. Thus, menstrual cycle information allows us to indirectly measure some hormones in females. Unfortunately, self-reported menstrual cycle information suffers from measurement errors because of imperfect recall of the last menstruation or the fact that ovulation in humans is concealed. It is therefore not very surprising that both studies come to slightly different conclusions. Chen, Katuščák, and Ozdenoren (2013) report that women bid higher than men in *all* phases of their menstrual cycle, while Pearson and Schipper (2013) report that naturally cycling women bid significantly higher than men and earn significantly lower profits than men in all phases except during the midcycle when fecundity is highest. The latter study also finds that women who use hormonal contraceptives bid significantly higher and earn substantially lower profits than men. The correlation between the use of hormonal contraceptives and bidding or profits may be due to a selection effect or to hormones contained in contraceptives. All hormonal contraceptives contain synthetic versions of the sex hormone progesterone and some also contain a version

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<sup>1</sup>More generally, gender differences have been demonstrated in a number of economically relevant domains, including investment (e.g. Barber and Odean, 2001) and the labor market (see Blau and Kahn, 2000, for a review). There is a sizeable literature that attempts to trace these gender differences back to differences in preferences between men and women such as risk preferences, social preferences, and preferences for competition (see Croson and Gneezy, 2009, Eckel and Grossman, 2008a, b, Byrnes, Miller, and Schafer, 1999, and Niederle and Vesterlund, 2011, for surveys). The biological mechanisms underlying many of the gender differences are still not understood.

of estradiol, another sex hormone. To sum up, the existing evidence suggests that biological mechanisms such as sex hormones underly some of the variations in bidding and profits observed in auctions. But the evidence is far from conclusive.

In order to get a clearer understanding of the role of sex hormones in competitive bidding in first-price auctions, we conduct an auction experiment in which we also collect salivary steroid hormones such as testosterone, estradiol, progesterone, and cortisol. Males and females differ in basal levels of testosterone. For males, there is some evidence that basal testosterone is significantly negatively correlated with risk aversion (Apicella et al. 2008, Schipper, 2014). Risk aversion may be important because theory predicts that it increases equilibrium bids in first-price auctions. Testosterone may affect bidding and profits via risk aversion. Basal testosterone has also been found positively correlated with “aggression” (see Archer, 1991, Dabbs and Hargrove, 1997, Mazur and Booth, 1998, Mehta and Josephs, 2006, etc.), which may be another channel through which basal testosterone affects bidding in auctions (see Section 3). The rationale for including estradiol and progesterone in the study is that they play a prominent role in the menstrual cycle. We also include cortisol in our study. Like testosterone, estradiol, and progesterone, it is a steroid hormone and mostly associated with stress. We believe that there is an intuitive relationship between stress, risk-taking, and competition.

We replicate previous findings that females bid significantly higher and earn significantly lower profits than males. Moreover, females who use hormonal contraceptives bid significantly higher and earn significantly lower profits. With respect to salivary basal hormones, we find that bids are significantly positively correlated and profits are negatively correlated with basal salivary progesterone but only in females who do not use hormonal contraceptives. No significant correlations are observed between bidding or profits and salivary basal testosterone, estradiol, and cortisol. This is surprising given the positive association of testosterone with risk-taking and aggression in the literature mentioned above, the prominent role of estradiol in the menstrual cycle and our intuition about cortisol, stress, risk-taking, and competition. Our observation with respect to basal progesterone and bidding remains marginally significant when conservative Bonferroni adjustments are made for multiple testing of the four hormones.

How could basal progesterone affect bidding and profits in first-price auctions? We follow up on this question with two post hoc hypotheses, one according to which the effect of progesterone is mediated by risk aversion and another in which a sedation effect of progesterone leads to more mistakes and thus higher bids on average. In order to control for risk aversion, we measure risk preferences for gains and losses with a lottery choice task due to Holt and Laury (2002) and Laury and Holt (2008). We reject the hypothesis that progesterone affects bidding through risk aversion. We also reject the hypothesis that basal progesterone leads to more mistakes that drive the positive association with bidding.

The relationship between hormones and behavior is bidirectional (see Schultheiss and Stanton,

2009). Not only may bidding be affected by hormones, but events in the auction game could also influence hormone levels. The collection of a second saliva sample at the end of the experiment allows us to assess how salivary hormones respond to total profits in the auction game. In line with the literature that finds a positive association between testosterone responses and winning competitions, such as for chess (Mazur et al., 1992), tennis (Booth et al., 1989), badminton (Jimenez et al., 2012), and bets on coin flips (McCaul et al., 1992), we hypothesize that higher total profits should lead to larger positive testosterone responses in males. We also hypothesize that higher profits are associated with larger cortisol responses. Larger gains are typically due to lower bids and thus relatively more “risk-taking”. More “risk-taking” may be more stressful and thus lead to positive cortisol responses. We observe a small positive response of cortisol to total profits for males but no testosterone responses.

## 2 Experimental Design

Subjects were recruited from the campus of the University of California, Davis, using the ORSEE recruitment system by Greiner (2004).<sup>2</sup> Since our experiment included auction games, it was advertised as a “market game” mostly via announcements in big classes, in advertisements on Facebook, and through the distribution of leaflets. All sessions were run between February 8 and March 16, 2010, at 16:00. Upon arrival at the lab, subjects were seated randomly at one of nine desks with computer terminals separated by dividers. Each subject faced the wall of the room. Subjects were given a consent form to read and sign. At every session, the same male native-English speaking experimenter was present to explain the instructions and supervise the experiment. Every session of the experiment was divided into eight phases:

1. *First Saliva Sample*: Subjects received written instructions for saliva sampling (see Appendix A.2) and a styrofoam cup that contained a 4.5 ml sterile Nunc Cryo Tube<sup>®</sup> vial. The cup functioned simply as a container to prevent the vial from falling over. Each vial had been labeled prior to the experiment with the session and subject number. Subjects also received one piece of chewing gum - Trident<sup>®</sup> Original Flavor - to stimulate saliva (see Dabbs, 1991) as well as a sterilized plastic straw through which to drool about 2.5 ml saliva into the vial. After depositing the saliva, each subject closed the vial by screwing the top and placed it back into the cup. The cups with the vials were collected by the experimenter and immediately frozen. Further details of the salivary hormone methodology are contained in Appendix A.

2. *Holt-Laury Lottery Task*: Subjects received written instructions on the Holt-Laury lottery task (see Appendix D). Subject had five minutes to read the instructions. Then the experimenter

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<sup>2</sup>None of the subjects participated previously in a similar experiment run in 2007 that focused on the digit ratio (2D:4D) and menstrual cycle information. The correlation between bidding behavior with the menstrual cycle and digit ratio has been analyzed in Pearson and Schipper (2012, 2013), respectively, who use both the 2007 data and data from the current experiment. No saliva was collected in the 2007 experiment.

publicly explained the task to all subjects, after which any questions were answered also in public. The task was conducted on paper-sheets for both gains and losses. All subjects made decisions in private first for the gain domain and only then for the loss domain.<sup>3</sup> In order to eliminate as much as possible any wealth effect on the following tasks, the lotteries were not played out immediately after completing the tasks. After all subjects completed their choices, the paper sheets were collected by the experimenter. Decisions in the lottery tasks will be used as control for risk aversion in the analysis of auction behavior.

3. *Auction Game:* Each subject received printed instructions for the auction game (see Appendix E). Subjects were given 5 to 7 minutes to read through the instructions, after which they were read aloud by the experimenter. Then subjects were given time to complete the review questions in private (see Appendix E). The experimenter went through the questions and answers aloud, after which the experimenter discussed and answered any additional questions from the subjects. In total, about 20 minutes of each experimental session was spent on the instructions. We were extremely careful to explain and train our subjects in the game. The auction game was computerized on z-tree (Fischbacher, 2007) using the same program as Chen, Katuščák, and Ozdenoren (2007, 2013) and Pearson and Schipper (2012, 2013).

Subjects repeatedly played a two-bidder first-price sealed bid auction with symmetric independent private values drawn from a piecewise linear distribution function constructed as follows: a bidder’s valuation is drawn separately and independently with probability 0.7 from the “low” distribution  $L$  and with probability 0.3 from the “high” distribution  $H$ . The support of both distributions is  $\{1, 2, \dots, 100\}$ . The respective densities,  $l$  and  $h$ , are given by<sup>4</sup>

$$l(x) = \begin{cases} \frac{3}{200} & \text{if } x \in \{1, 2, \dots, 50\} \\ \frac{1}{200} & \text{if } x \in \{51, 52, \dots, 100\} \end{cases} \quad h(x) = \begin{cases} \frac{1}{200} & \text{if } x \in \{1, 2, \dots, 50\} \\ \frac{3}{200} & \text{if } x \in \{51, 52, \dots, 100\}. \end{cases}$$

In each round, the highest bidder wins the imaginary object and pays its bid. If both bids are the same, each bidder wins with equal probability. The profit of the winning bidder is her/his value minus her/his bid. The losing bidder’s payoff is zero. Thus, as in the experimental auctions literature (e.g. Kagel, 1995, Chapter 7) we induce the bidder’s value for the object by essentially buying it back from the winner at the price that is her/his value.

Each session consisted of 8 subjects who were randomly re-matched after each round. Subjects played 2 practice rounds that did not count for the final payoff, and then 30 “real” rounds.

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<sup>3</sup>Laury and Holt (2008, p. 9) claim that the order of these tasks do not matter. However, their experiment differs from ours in that their tasks were separated by the play of a matching pennies game and additional Holt-Laury lottery tasks with varying payoffs were included.

<sup>4</sup>The main reason for choosing this process of drawing values (as opposed to uniform distribution) is to be able to replicate Chen, Katuščák, and Ozdenoren (2013). A second reason is to keep the option of comparing in a later study to auctions with ambiguity about values, in which subjects would be left ignorant about the probability with which the value is drawn from the low or high value distribution (see Chen, Katuščák, and Ozdenoren, 2007).

At the beginning of each round, bidders were privately informed on their computer screen of their valuation. Then they independently entered a bid on the computer. The winner of each pair was determined, each subject was reminded of her/his valuation and bid, and informed whose bid was the winning bid, whether she/he received the object, and her/his total payoff accumulated so far. (See the Appendix F for screenshots.)

4. *Questionnaire:* After the auction task, subjects completed a computerized questionnaire (see Appendix G). This questionnaire elicited demographic information, menstrual cycle information, information relevant for assessing the quality of saliva, information on sexual orientation and sexual behavior, social lifestyle, personality characteristics, emotions during the experiment, dietary preferences, academic grades, etc. The motivation for the large questionnaire is twofold. First, we needed to generate a sufficiently long waiting period before collecting the second saliva sample. Second, many factors beyond age, gender, race, such as the use of hormonal contraceptives, pregnancy, menstrual cycle phases etc. may be correlated with salivary hormone levels. See Appendix A.5 for an analysis of some of those factors.

5. *Playing out the Holt-Laury Lottery Task:* Once subjects finished the questionnaire, the previously completed paper-sheets on the Holt-Laury lottery tasks were played out in front of the subjects. For each subject, a ten-sided die was rolled four times. The first roll decided which binary choice in the gain domain was selected. The second roll played this lottery out in the gain domain. The third roll decided which binary choice in the loss domain was selected. The final fourth roll played this lottery out in the loss domain. Payoffs for each subject were noted on the decision sheet of each subject.

6. *Hand Scan:* After playing out the lottery tasks, each subject's right hand (and the right hand only) was scanned with a conventional office image scanner. The purpose of the hand scan was to measure the length of the 2nd and 4th finger and to analyze the digit ratio (2D:4D); see Pearson and Schipper (2012) and Schipper (2014) for the analysis.

7. *Second Saliva Sample:* About 20–30 minutes after the auction task, subjects were asked for a second saliva sample in the same manner as for the first saliva sample. It takes about 15–30 minutes before salivary hormones can respond to events in the auction game (see for similar examples Schultheiss et al., 2005, Kivlighan, Granger, and Booth, 2005, Edwards and O'Neal, 2009, Saad and Vongas, 2009).

8. *Payment:* At the end of the experiment, subject received in private their total cash payment from the show up fee, the auction task, and the lottery tasks. The average total earning was US\$ 19.03 with a maximum of US\$ 48.39 and a minimum of US\$ 5.00. The entire procedure took about 1 hour and 20-30 minutes. The average earning is above what a typical student job would earn in Davis for about the same amount of time. Our lottery experiment may involve losses as well. Losses can typically not be collected from subjects. Yet, subjects knew that they could earn money in the gain domain of the lottery task as well as from the auctions.

## 3 Ex Ante Hypotheses

### 3.1 Basal Hormones

Although there is no theory of how basal salivary hormones collected at the beginning of the experiment should affect bidding behavior, we can derive hypotheses from prior observations in the literature.<sup>5</sup> In the case of basal testosterone, the first hypothesis explores the risk aversion channel (see the left side of Figure 1). Both Apicella et al. (2008) and Schipper (2012) find a significant negative correlation between basal salivary testosterone and risk aversion in choice tasks under risk for males. Sapienza et al. (2009) find an insignificant weak negative association between salivary testosterone and risk aversion in males but a significant negative relationship in females. Stanton et al. (2011a) find a negative association for both genders in a gambling task that had not been incentivized. Schipper (2012) finds a null result for females. Stanton et al. (2011b) report a u-shaped relationship between risk attitudes and salivary testosterone in both genders, where individuals with high or low testosterone are approximately risk neutral and individuals with intermediate levels of testosterone are risk averse. Using a placebo-controlled experiment and a sample of 200 postmenopausal women, Zethraeus et al. (2009) did not find a significant association between randomly administered testosterone or estrogen and risk-taking. The effects of risk aversion in first-price auctions with symmetric independent private values are well established in theory (see Krishna, 2002, Chapter 4.1). Risk aversion increases equilibrium bids above risk-neutral Nash equilibrium. A higher bid translates into a higher probability of winning the auction, but it also leads to a lower profit conditional on winning the auction.<sup>6</sup> Although the experimental evidence for risk aversion in first-price auctions with symmetric independent private values is at best mixed (see for a survey, Kagel, 1995), we hypothesize, as shown at the left side of Figure 1, that basal testosterone in males is negatively correlated with bidding via the risk aversion channel.

The second hypothesis with regard to basal testosterone and bidding explores the aggression/dominance channel (see the right side of Figure 1). There are several studies demonstrating a positive correlation of psychological notions of aggression and dominance with testosterone, especially in men (see Archer, 1991, Dabbs and Hargrove, 1997, Mazur and Booth, 1998, Mehta and Josephs, 2006, etc.). Yet, Apicella et al. (2011) find no significant correlation between salivary testosterone and self-selection into competitive versus piece-rate-paying tasks in males. Although there is no theory of how informal notions of “aggression” or “dominance” affect bidding and profits in first-price auctions, folk intuition suggests that bidding “more aggressively”

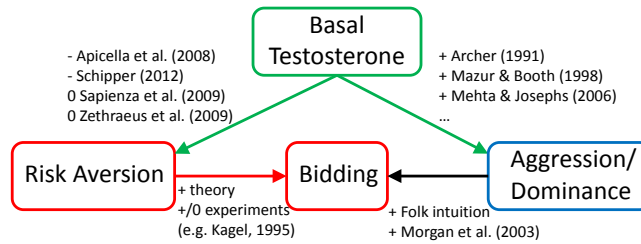
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<sup>5</sup>We stress that the hypotheses outlined in this section have been devised before the data were collected. We will introduce additional post hoc hypotheses in Section 5.

<sup>6</sup>We would like to point out, though, that various dispositions towards uncertainty, like anticipated regret from losing the auction (see Filiz and Ozbay, 2007), overconfidence in the winning probability of a bid, ambiguity aversion, etc. lead to similar behavioral predictions in first-price auctions with independent private values.

means bidding higher. More precisely, “dominance” is often interpreted as “dominance over others” and discussed in the context of evolutionary advantages. Evolutionary stability is closely tied to such relative payoff concerns (Schaffer, 1988). Morgan et al. (2003) show that relative payoff concerns increase bidding in first-price auctions with independent private values. This suggests that testosterone in males should be positively correlated with bidding in first-price auctions with independent private values via the aggression/dominance channel. Thus, we have two opposing hypotheses for how testosterone should affect bidding in men.

Figure 1: Two Hypotheses on Basal Testosterone



Both estradiol and progesterone play fundamental roles in the menstrual cycle (see Fritz and Speroff, 2011). Estradiol peaks shortly before ovulation and has a second smaller peak after ovulation. Progesterone rises after ovulation and declines again before menstruation. Pearson and Schipper (2013) report that naturally cycling women bid significantly higher and earn significantly lower profits than men in all menstrual cycle phases except during the midcycle. Since menstrual cycle information is just an imprecise measure of some hormones throughout the menstrual cycle, the current study was intended as a follow up on that study. For our current study, we hypothesize that both progesterone and estradiol are significantly correlated with bidding and profits in women. In particular, we expect that in women estradiol is negatively correlated with bidding and positively correlated with profits. Moreover, progesterone in women should be positively correlated with bidding and negatively correlated with profits. We do not expect estradiol and progesterone to play any role for bidding and profits in males.

Cortisol responds positively to stress (see Dickerson and Kemeny, 2004). We find it natural that risk aversion may be positively correlated with stress and thus positively associated with basal cortisol, although no empirical evidence was yet available when we designed the study.<sup>7</sup> As mentioned previously, theory predicts that risk aversion increases equilibrium bidding in first-price auctions with symmetric independent private-values although the empirical evidence for risk aversion in first-price auctions is mixed. Nevertheless, we hypothesize that basal cortisol is positively correlated with bidding and negatively correlated with profits. An alternative

<sup>7</sup>Only in a companion study, Schipper (2012) found that cortisol in females is positively correlated with risk aversion, but the relationship is just marginally significant.



hypothesis with respect to basal cortisol exploits the aggression channel. Some studies find a positive association between cortisol and aggression (e.g. van Bokhoven et al., 2005), other studies find a negative association (e.g. Poustka et al., 2010), and yet others find no association (e.g. Alink et al., 2008). We believe that a positive association is most plausible. Aggressive individuals should encounter more stress and thus have elevated cortisol levels. The direction of association for basal cortisol is the same for both the risk-taking and aggression channels.

### 3.2 Hormone Responses

The second saliva samples collected after the behavioral task allows us to study *hormone responses* (i.e., changes in hormones) with respect to outcomes in the auction. As mentioned earlier, some studies show a positive association between testosterone responses and winning competitions, such as chess (Mazur et al., 1992), tennis (Booth et al., 1989), badminton (Jimenez et al., 2012), and bets on coin flips (McCaul et al., 1992). Similar effects occur if favorite sporting teams (Bernhardt et al., 1998) or favored presidential candidates in elections win (Stanton et al., 2009, Apicella and Cesarini, 2011). All those studies focus only on men, except Jimenez et al. (2012), who show a similar effect for both sexes, and Stanton et al. (2009), who show no significant effect for women. Bateup et al. (2002) find no significant effect between testosterone response and winning rugby competitions in females. Gonzalez-Bono et al. (1999) find a null result for testosterone responses and winning a basket ball game in males. Earlier, Mazur et al. (1997) reported that there is no significant increase of testosterone in both male or female winners of a video game contest. Nevertheless, we find it plausible that total profits in the auction game could be positively associated with testosterone responses especially in men.

The evidence on cortisol responses to winning competitions is more mixed. McCaul et al. (1992), Mazur et al. (1997), Gonzalez-Bono et al. (1999), and Booth et al. (1989) report null findings. In Bateup et al. (2002) cortisol declines in losing female rugby teams and increases with winning. In contrast, Jimenez et al. (2012) show that cortisol rises with defeat in both sexes. Since higher earnings are likely due to higher risk-taking and more risk-taking should be more stressful, we hypothesize that cortisol responds positively to total profits.

We have no hypotheses for responses of estradiol and progesterone to events in our auction game. Nevertheless, the collected ex post measures allow us to assess to a certain extent the measurement error of salivary hormones (see Appendix A.6).

### 3.3 Statistical Approach

We use regression analysis to estimate versions of the following parametric model for bids:

$$b_{i,t} = \beta_0 + \beta_1 v_{i,t} + \beta_2 v_{i,t}^2 + \beta_3 v_{i,t}^3 + \gamma \ell_t + \delta X_i + \zeta H_i + \eta C_i + \theta J_i + \varepsilon_{i,t}, \quad (1)$$

where  $b_{i,t}$  is the bid of subject  $i$  at bidding period  $t = 1, \dots, 30$ ;  $\beta_0$  is a constant,  $v_{i,t}$  is the value<sup>8</sup> of subject  $i$  at bidding period  $t$ ;  $X_i$  is a vector of demographic variables including gender, age, race, number of siblings, major of study, and GPA;  $H_i$  is a set of salivary hormone variables of subject  $i$ ; and  $C_i$  is a dummy indicating the use of hormonal contraceptives by subject  $i$ . As in Casari, Ham, and Kagel (2007), we control to some extent for learning by regressing on  $\ell_t = \frac{1}{\ln(t+1)}$ . This term decreases non-linearly in the number of bidding rounds.<sup>9</sup>  $J_i$  denotes a set of subject-specific terms interacting the use of contraceptives with salivary hormones etc. These interaction terms will sometimes be used to focus our analysis on various subsamples.  $\varepsilon_{i,t}$  is the unobserved error term of subject  $i$  in period  $t$  (clustered at the session level). For robustness checks, we will also add in some specifications session dummies to control for session effects (e.g., the sex ratio of the session or possibly degraded quality of saliva samples in earlier sessions as compared to later sessions). As a baseline, we estimate the models using ordinary least squares but as robustness checks we will also use the between estimator and random effects estimator (see Cameron and Trivedi, 2005, p. 703–705).

Analogous to equation (1), we estimate a model for total dollar profits (summed over all thirty time periods) in which we drop  $\ell_t$  and the cubic polynomial in the value, but add the mean, the variance, and the skewness of the subject’s empirical distribution of values as dependent variables. These models are estimated with ordinary least squares method.

In all regressions, we fix four features. First, to control for correlations across time and subjects, we cluster standard errors at the session level. Recall that subjects play 30 rounds. Hence, their decisions in each round may be correlated due to learning. Moreover, subjects are randomly rematched each round within the session of only eight subjects. Hence, their interaction may affect each other’s decisions. By clustering at the session level, we control for *both* types of correlations (see Cameron et al., 2008, for a study of clustering in small samples). Since we have 208 subjects in sessions of eight subjects, we have 26 clusters and thus 26 independent observations. Clustering standard errors using `cluster` in Stata also takes care of potential heteroscedasticity and non-normality.

Second, for lack of space we suppress the reporting of coefficients for the polynomial in value, the mean, standard deviation, and skewness of the subjects’ empirical distribution of values, basic demographics (control for age, Asian or other race) and academic information (GPA and major of study). The estimates are available on request and can be reproduced using the Stata do-file and data sets available from the author’s website.

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<sup>8</sup>We include a cubic polynomial in order not to force bids to be a (piecewise) linear function of values as for instance under assumptions of risk neutrality or constant relative risk aversion (see for instance Cox, Smith, and Walker, 1988). However, we should mention that estimated coefficients for the quadratic and cubic terms are zero and our results do not change in any substantial way when omitting the quadratic and cubic terms.

<sup>9</sup>In an earlier version we controlled more flexibly for learning by using a set of bidding period dummies instead. Our results remain qualitatively unchanged. The current specification was adopted on the recommendation of a reviewer.

Third, our analysis of the correlation between salivary hormones and bidding or profits involves *multiple testing* of four hormones. The chance of falsely observing one hormone to be significantly correlated with bidding or profits is much higher when four hormones are analyzed as compared to when, from the beginning, just one hormone is analyzed. Thus, the use of  $p$ -values may lead to errors of inference, and in particular to the underestimation of false positives. We will report not just individual  $p$ -values but also point out whether or not results are significant when we account for multiple testing using the Bonferroni correction, which is a conservative method to correct for multiple testing. If the desired significance level is  $\alpha = 5\%$ , then the Bonferroni corrected significance level for each hormone is  $\frac{\alpha}{4} = 1.25\%$  (since there are four hormones). Thus, any hormone that is significant at the 1.25% level is Bonferroni corrected significant at the 5% level.

Fourth, some hormones like salivary testosterone or estradiol are measured in pg/ml while others like progesterone or cortisol are measured in nmol/L. Moreover, we see in Table 3 that their absolute levels differ quite a bit. To be better able to interpret the regression results, we use standard scores or z-scores by centering basal hormones close to their mean and dividing them by their standard deviation. There are two caveats. First, as sex hormones differ by gender, this normalization could affect gender specific results. To circumvent this problem, we compute z-scores for each gender separately. Second, since there is typically no subject whose hormone level corresponds exactly to the mean, this normalization may lead to collinearity especially when interaction terms are included. To avoid this problem, we use the observation that is nearest to the mean in place of the mean. That is, we normalize each hormone by

$$z_i := \frac{h_i - \mu_{g(i)}^*}{\sigma_{g(i)}},$$

where  $h_i$  is subject  $i$ 's basal salivary hormone level,  $g$  is a function that assigns to each subject  $i$  its gender  $g(i)$ , and  $\sigma_{g(i)}$  is the standard deviation of basal salivary hormone levels of subjects with gender  $g(i)$ . Finally,  $\mu_{g(i)}^*$  is the basal hormone level of the subject whose gender is closest to the gender-specific mean for that hormone. That is,  $\mu_{g(i)}^* = h_j$  such that  $j = \arg \min_{k \in N_{g(i)}} \{|h_k - \mu_{g(i)}|\}$ , where  $N_{g(i)}$  is the set of subjects with gender  $g(i)$ , and  $\mu_{g(i)}$  is the mean of the basal salivary hormone levels of subjects with gender  $g(i)$  for that hormone. For instance, in OLS regressions of profits, the coefficient for any basal hormone measures the effect in terms of dollars when the basal hormone level increases by one standard deviation above the basal hormone level of the subject with the same gender who is closest to the gender-specific mean (keeping everything else constant).

## 4 Results on Basal Hormones

The datasets and Stata do-file that reproduce the entire analysis reported here and additional analysis are available from <http://www.econ.ucdavis.edu/faculty/schipper/>.

Table 1 presents the demographics of the data as elicited with the questionnaire (see Appendix G).<sup>10</sup> We had 208 subjects in sessions of 8 subjects each. Out of the 208 subjects, 93 (45%) are female. Most of the subjects are asian-americans (55%) followed by whites (38%).<sup>11</sup> Six subjects (three females and three males) did not provide their GPA. One woman reported that she was pregnant. Since circulating levels of various steroids change substantially during pregnancy, we exclude her from our analysis of salivary hormones. Six females and eight males reported to be homo- or bisexual. We do not find robust significant correlations between sexual preferences and salivary hormones.

Table 2 shows that we replicate gender differences in first-price auctions in the literature (see Casari, Ham, and Kagel, 2007, Ham and Kagel, 2006, Chen, Katuščák, and Ozdenoren, 2013, and Pearson and Schipper, 2013). Women bid on average 2.5 points higher ( $p = 0.001$ , specification “Bids1”) than white males when using the same controls as in prior studies by Chen, Katuščák, and Ozdenoren (2013) and Pearson and Schipper (2013). Similarly, specification “Profits1” reveals that women earn on average \$4.29 less than white males ( $p < 0.001$ ) when controlling for major of studies, GPA, and demographics. This difference is substantial since it is more than 28% of average total profits made in the auction in our sample.<sup>12</sup>

We also confirm the correlation with hormonal contraceptives observed in Pearson and Schipper (2013); here for a subsample of theirs. Women who use hormonal contraceptives bid

Table 1: Basic Demographics

Variable	Number	Mean	Std. Dev.
Subjects	208		
Female	93	0.45	
Age	208	20.36	2.24
White	79	0.38	
Asian	116	0.55	
Hispanic	13	0.06	
Black	5	0.02	
Others	8	0.04	
GPA	202	3.17	0.52
Math	5	0.02	
All Sciences	61	0.29	
Economics	103	0.50	
Other Social Sciences	65	0.31	
Humanities	20	0.10	
Pregnant	1		
Homo- or Bisexual	14	0.07	

<sup>10</sup>Subjects were allowed to select multiple majors and ethnic backgrounds. Thus, the means do not add up to unity. In our sample all math majors happened to be male.

<sup>11</sup>For comparison, the distribution of races among all UC Davis students is 42% white, 38% asian, 3% black, 14% hispanic, and 3% other. See <http://facts.ucdavis.edu/studentheadcountethnicity.lasso>. We don’t know why we have a larger fraction of asians in our sample. It could be that relative more asians are enrolled in majors that we reached with our advertisement. In particular, about 59% of economics students at UC Davis are asian.

<sup>12</sup>Average earnings in the sample were \$15.02 for the auction game alone.

on average 3.7 points higher than white males ( $p = 0.005$ , specification “Bids2” in Table 2) and earn on average \$5.09 less than white males ( $p = 0.022$ , specification “Profits2”) when controlling for major of study, GPA, and demographics. Again, this difference is substantial as it amounts to more than  $\frac{1}{3}$  of total earnings. We cannot claim this is a causal effect since it may be due to selection. In particular, women who decide to take hormonal contraceptives may also differ systematically in their bidding behavior from women who decide not to take any hormonal contraceptives. It is not clear whether a priori more risk averse women are more likely to use hormonal contraceptives or whether women with more risky sexual behavior are more likely to take hormonal contraceptives.

Table 2: Gender and Hormonal Contraceptives

	(Bids1)	(Profits1)	(Bids2)	(Profits2)
Female	2.5173*** (0.6955)	-4.2932*** (0.9475)	1.7045** (0.7128)	-3.2075*** (1.0139)
Contraceptives			3.6679*** (1.1994)	-5.0882** (2.0759)
Demographics, Majors & GPA	Yes	Yes	Yes	Yes
<i>Number of Observations</i>	6060	202	6060	202
R <sup>2</sup>	0.8558	0.2599	0.8578	0.2873

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Not reported: Coefficients of cubic polynomial in values and learning (bids), and mean, standard deviation, and skewness of values drawn (profits).

We now turn to hormones from saliva collected before any behavioral task (i.e., “basal hormones”). For one male subject, the amount of saliva we collected was not sufficient to assay progesterone and cortisol, so he is excluded from the analysis of salivary hormones. Table 3 provides summary statistics for salivary hormones by gender and the use of hormonal contraceptives. Not surprisingly, gender differences in sex hormones become visible, especially with respect to testosterone. Figure 7 in the appendix shows histograms and kernel distributions of all four hormones by gender. Since the biological functions of sex hormones differ between males and females, our analysis will be gender-specific. All hormonal contraceptives contain some versions of progesterone and often ethinyl estradiol (see Appendix B for more details on hormonal contraceptives). It is known that these exogenous progestins and estradiol are not captured in saliva but some endogenous hormones are suppressed in women using hormonal contraceptives (e.g., Schultheiss et al., 2003). Thus, in our analysis we distinguish further between naturally cycling females and females using hormonal contraceptives.

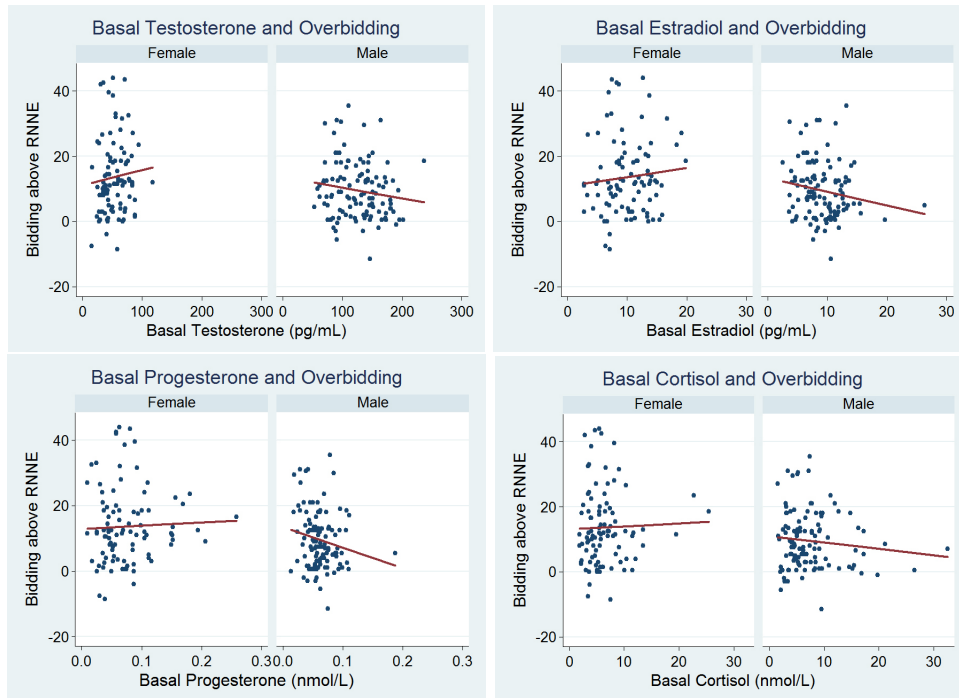
The relationship between basal salivary hormones and bidding behavior is preliminarily explored in Figure 2 in which we print a scatter plot for each hormone by gender and fit a linear regression between hormone levels and differences between observed bids and risk neutral Nash

Table 3: Basal Salivary Hormones by Gender and Hormonal Contraceptive Use

Salivary Hormone	Natur. Cycling Females		Fem. on Contraceptives		Male	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Testosterone (pg/mL)	57.9536	19.0284	42.0580	17.5637	125.7049	37.9870
Estradiol (pg/mL)	10.1028	3.8498	9.9486	3.6519	9.1036	3.4890
Progesterone (nmol/L)	0.0779	0.0481	0.0648	0.0382	0.0623	0.0242
Cortisol (nmol/L)	6.8084	4.3430	5.1743	2.2237	7.4268	5.0665

equilibrium bids.<sup>13</sup>

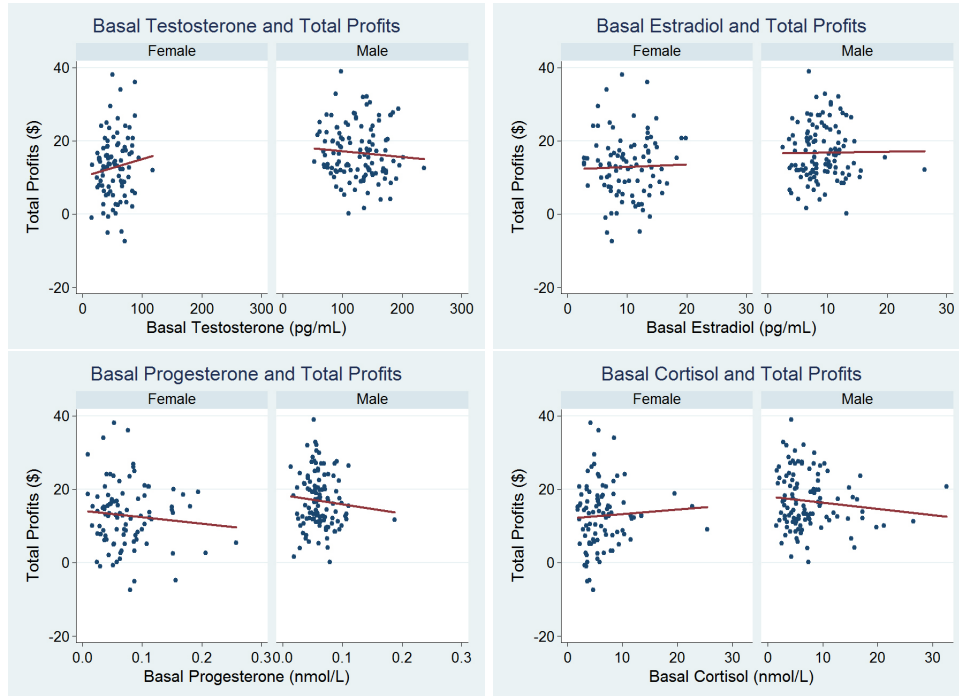
Figure 2: Overbidding and Basal Salivary Hormones by Gender



In the upper left panel we observe that testosterone may be positively correlated with overbidding, i.e., bidding above risk neutral Nash equilibrium bids, in females but negatively correlated with overbidding in males, suggesting that different channels, if any, are at work for males and females. Similar relationships may hold for estradiol (upper right panel), progesterone (lower left panel), and cortisol (lower right panel) but if there is a relationship, then it appears to be much weaker for females than for males.

<sup>13</sup>In Nash equilibrium, a risk neutral bidder would bid  $\frac{1}{2}$  of his/her value. Using overbidding relative to risk neutral Nash equilibrium in Figure 2 allows us to present bids, values, and hormones in two-dimensional graphs.

Figure 3: Total Profits and Basal Salivary Hormones by Gender



When we turn to total profits in Figure 3, the upper left panel suggests that profits are positively correlated with testosterone in females but negatively correlated in males. No relationship appears for estradiol (upper right panel). A negative correlation between progesterone and profits is observed for both females and males in the lower left panel. Finally, the relationship for cortisol appears to be similar to testosterone. There is a positive correlation between cortisol and profits in females but a negative correlation in males.

We seek to corroborate these preliminary observations with multivariate regressions that can control also for the use of hormonal contraceptives, gender, and further demographics. Table 4 restricts the analysis to the male subsample. Clearly, for both bids (specification “Bids3”) and total profits (“Profits3”) we observe null results for each hormone. The null results are robust to dropping demographic variables, using the between estimator or the random effects estimator (for the bid specification), or including previous round’s profits in the specification for bids.<sup>14</sup> Thus, we reject the hypothesis that basal testosterone or cortisol is correlated with bidding and profits in males.

In Table 5 we restrict our analysis to the female subsample. We use interaction terms to focus on naturally cycling females (specifications “Bids4” and “Profits4”) or females on

<sup>14</sup>We don’t find significant associations between hormones and race except for testosterone in asian versus white males. Redoing the analysis for asian and white males, respectively, yields null results as well.

Table 4: Basal Salivary Hormones, Bidding, and Profits for Males

	(Bids3)	(Profits3)
Testosterone	0.0840 (0.4055)	-0.3432 (0.6275)
Estradiol	-0.2711 (0.3611)	-0.0401 (0.6439)
Progesterone	0.1275 (0.3546)	-0.4749 (0.5623)
Cortisol	0.4135 (0.4185)	-0.7438 (0.6886)
Demographics, Majors & GPA	Yes	Yes
<i>Number of Observations</i>	3330	111
R <sup>2</sup>	0.8687	0.2862

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Not reported: Coefficients of cubic polynomial in values and learning (bids), and mean, standard deviation, and skewness of values drawn (profits).

hormonal contraceptives (specifications “Bids5” and “Profits5”), respectively. For instance, in specification “Bids4” we interact each hormone with the dummy variable for the use of hormonal contraceptives. The coefficient for each hormone now measures the correlation between the hormone and bids of naturally cycling females (i.e., when the dummy variable “Contraceptives” takes on the value zero). For naturally cycling females we observe null results for all hormones except for progesterone. An increase of progesterone by one standard deviation above the mean of the female subsample is associated with an increase of 1.4 bid points ( $p = 0.016$ ) and a decrease of 1.64 dollars ( $p = 0.059$ ) in profits controlling for demographics, major of study, and GPA. We find this economically significant as it translates into more than 10% of average total profits in the auction. The finding for bids remains marginally significant when we take into account multiple testing using Bonferroni correction. The association between bidding and progesterone is qualitatively robust to dropping demographic variables and major of studies ( $\beta = 1.113$ ,  $p = 0.063$ ), using the between estimator ( $\beta = 1.446$ ,  $p = 0.055$ ) or the random effects estimator ( $\beta = 1.431$ ,  $p = 0.010$ ), or when restricting to the subsample of naturally cycling women only ( $\beta = 1.51$ ,  $p = 0.011$ ). The association is also significant if we focus on the subsample of Asian naturally cycling females.<sup>15</sup>

Specifications “Bids5” and “Profits5” of Table 5 are analogous, but for females using hormonal contraceptives (i.e., when the dummy for “naturally cycling” takes on the value zero). We obtain null results for all hormones except for basal estradiol, which is only marginally significant ( $p = 0.081$  in “Bids5” and  $p = 0.089$  in “Profits5”). This association is not robust as it becomes

<sup>15</sup>We have 49 asian naturally cycling females in our sample. We do not find a significant association for white naturally cycling females. We suspect that this is due to the small sample size (16 white naturally cycling females). We do not find significant associations between hormones and race in females.



Table 5: Basal Salivary Hormones, Bidding, and Profits for Females

	(Bids4)	(Profits4)	(Bids5)	(Profits5)
Testosterone	-0.5108 (0.7763)	1.0281 (1.1357)	2.9181 (2.0404)	-3.8861 (3.7491)
Estradiol	0.0197 (0.6105)	-0.2384 (1.0437)	-2.4265* (1.3358)	4.5979* (2.5967)
Progesterone	1.4313** (0.5533)	-1.6442* (0.8322)	-0.1113 (2.8049)	-0.3814 (4.8301)
Cortisol	0.3703 (0.4278)	0.1171 (0.8282)	0.2091 (1.3566)	-0.3901 (2.2486)
Contraceptives	5.4246*** (1.6937)	-6.4417* (3.4554)		
Naturally Cycling			-5.4246*** (1.6937)	6.4417* (3.4554)
Hormones x Contraceptives	Yes	Yes	No	No
Hormones x Naturally Cycling	No	No	Yes	Yes
Demographics, Majors & GPA	Yes	Yes	Yes	Yes
<i>Number of Observations</i>	2670	89	2670	89
R <sup>2</sup>	0.8563	0.3656	0.8563	0.3656

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Not reported: Coefficients of cubic polynomial in values and learning (bids), and mean, standard deviation, and skewness of values drawn (profits).

insignificant when dropping demographics and major of studies or when using the between estimator in the bid specification. It is clearly insignificant when adjusting for multiple testing using Bonferroni correction. That is why we consider it to be a null-finding.

**Observation 1 (Basal Salivary Hormones)** *Bids are significantly positively correlated and profits marginally significantly negatively correlated with basal salivary progesterone in females who do not use hormonal contraceptives. This observation for bids remains marginally significant when Bonferroni corrections are made for multiple testing of four hormones. No other robust significant correlations between basal salivary hormones and bidding and profits are observed in males or females.*

## 5 Post Hoc Analysis of the Basal Progesterone Effect

Among the hypotheses proposed in Section 3, we found evidence only for the positive (negative, respectively) association between bidding (profits, respectively) and progesterone in naturally cycling females. In this section we follow up with the analysis of two hypotheses on possible mechanisms. We emphasize again that these hypotheses have been formulated only after the experiment.

## 5.1 Does Basal Progesterone Affect Bidding through Risk Aversion?

To our surprise, we found no association with respect to testosterone or cortisol. Originally, we hypothesized that risk aversion is one of the pathways through which testosterone or cortisol could affect bidding and profits. This was one of the reasons why in our experiment we elicited risk preferences for gains and losses through lottery choice tasks introduced by Holt and Laury (2002) and Laury and Holt (2005), respectively. We can now use elicited risk preferences to investigate whether progesterone could affect bidding and profits through risk aversion. There is evidence that increases in progesterone during the luteal phase are positively associated with women’s avoidance of infections as reflected in behavior in public bathrooms (Fleischman and Fessler, 2011). Increases in progesterone during the luteal phase are also associated with increased accuracy in decoding facial expressions and increased attention to social stimuli (Maner and Miller, 2014) as well as non-conscious needs to have close, friendly relationships with others (Schultheiss, Wirth, and Stanton, 2004, Wirth and Schultheiss, 2006, Brown et al., 2009). Since increases in progesterone in the luteal phase prepare the body for pregnancy, it makes sense from an evolutionary point of view to minimize the risk to a potential fetus from a challenging social environment. Thus we hypothesize that progesterone is positively associated with bidding through a positive correlation with risk aversion in the Holt-Laury lottery task.

For both the gain and loss domains, the lottery choice task consists of a menu of 10 decisions between pairs of binary lotteries named “option A” and “option “B” (see Tables 14 and 15 in Appendix D). Each subject has to make choices between these pairs of lotteries. The probability of outcomes varies systematically across the list of lottery pairs. In both the loss and gain domains, the tasks are designed such that risk neutrality implies choosing option A five times in sequence, sufficient risk aversion implies choosing option A more than five times in sequence, while sufficient risk seeking implies choosing option A fewer than five times in sequence. Thus as a matter of terminology, we say that a group X of subjects is *more risk averse* (*resp. more risk seeking*) than a group Y if on average it chooses option A more often (*resp. loss often*) than group Y.<sup>16</sup>

Not all subjects may display a unique cut-off for switching between the options, but may switch several times between options A and B. Moreover, a subject may not respect dominance (as tested with Decision No. 1, see Tables 14 and 15 in Appendix D). The information obtained from subjects who switch several times or choose the dominated option is limited. That is why we call those subject’s risk preferences inaccessible and will focus the analysis on subjects with accessible risk preferences by including appropriate interactions between our measure of risk

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<sup>16</sup>It is possible to fit for subjects with accessible risk preferences, for each domain, and for each number of choices of option A the corresponding interval of risk parameters for popular utility functions such as constant relative risk aversion (see Holt and Laury, 2002, Laury and Holt, 2008, Harrison and Ruthström, 2008). However, we believe that in this study it adds nothing beyond our behavioral definitions of risk aversion and risk seeking above.

aversion and a dummy indicating the inaccessibility of risk preferences. In our sample, 178 out of 208 subjects have accessible risk preferences both in gain and loss domains. A detailed analysis of the role of salivary sex hormones for risk aversion, reflection (i.e., risk aversion in the gain domain and risk seeking in the loss domain), and accessibility of risk preferences is contained in Schipper (2012). Here we will just use the number of choices of option A of subjects with accessible risk preferences as a measure of risk aversion as controls in the analysis of bidding and profits in the auctions.

Table 6: Risk Aversion and Basal Progesterone

	(Bids6)	(Profits6)
Testosterone	-0.9764 (0.7874)	1.6170 (1.3750)
Estradiol	0.4041 (0.6312)	-0.7922 (1.1894)
Progesterone	1.4493** (0.6046)	-1.6458* (0.8874)
Cortisol	0.1290 (0.4864)	0.2886 (1.1267)
Contraceptives	6.1707*** (1.6852)	-7.5755** (3.6435)
Risk Aversion Gains	0.9243* (0.4813)	-1.0613 (0.9427)
Risk Aversion Losses	0.7052 (0.4754)	-0.9310 (0.9659)
Hormones x Contraceptives	Yes	Yes
Risk Preferences Inaccessible	Yes	Yes
Risk Aversion x Inaccessible Preferences	Yes	Yes
Demographics, Majors, & GPA	Yes	Yes
<i>Number of Observations</i>	2670	89
R <sup>2</sup>	0.8626	0.4299

Robust standard errors (clustered at the session level) in parentheses.  
Significance levels: \*10%; \*\* 5%; \*\*\* 1%. Not reported: Coefficients of cubic polynomial in values and learning (bids), and mean, standard deviation, and skewness of values drawn (profits).

Motivated by the finding in the previous section, we restrict our analysis to the female subsample and focus on naturally cycling females using interaction terms. Specifications “Bids6” in Table 6 reveals that when controlling for risk aversion the coefficient for progesterone remains significant ( $p = 0.024$ ) and its magnitude is not reduced compared to specification “Bids4”. The finding is qualitatively robust to dropping demographic variables and major of studies ( $\beta = 1.213$ ,  $p = 0.066$ ), using the between estimator ( $\beta = 1.420$ ,  $p = 0.056$ ) or random effects estimator ( $\beta = 1.450$ ,  $p = 0.017$ ), or restricting to only the subsample of naturally cycling females ( $\beta = 1.465$ ,  $p = 0.019$ ). For profits, the coefficient for progesterone in specification “Profits6” in Table 6 is of the same magnitude as in specification “Profits4” and remains marginally significant

( $p = 0.075$ ). Our impression is that progesterone does not affect bidding and profits through risk aversion since the size of the coefficient is not reduced when introducing risk aversion as a potential mediator. Further evidence for this claim is provided in Schipper (2014) who shows that there is no significant correlation between basal progesterone and risk aversion.

**Observation 2 (Risk Aversion and Basal Progesterone)** *Basal progesterone does not affect bidding and profits through risk aversion as elicited with Holt-Laury lottery tasks.*

## 5.2 Does Basal Progesterone Affect Bidding through Mistakes?

The second post hoc hypothesis on the effect of progesterone is based on a biological explanation. It is known in the literature that progesterone may have a sedating effect (see Pluchino et al., 2006, van Broeckhoven et al., 2006).<sup>17</sup> Throughout the human brain, there are neurons secreting the neurotransmitter GABA. When GABA interacts with other neurons they are inhibited, which means that they are less likely to “fire”. Well-known benzodiazepines drugs like Valium, Librium, and Xanax enhance the inhibitory effect of GABA, thus reducing anxiety and having a calming and sedating effect. The same as been observed for some metabolites of progesterone, i.e., substances converted from progesterone in the body. This sedating effect of progesterone should translate into more “mistakes”. A mistake in the context of first-price auctions with symmetric independent private values is a bid that results in a loss when the object is won. Any bid above the bidder’s valuation results in a loss if the bid is the winning bid. Such a bid is weakly dominated by bids below the bidder’s valuation. This implies that on average more “mistakes” increase bidding. We hypothesize that progesterone is positively correlated with bidding through weakly dominated bids (see Figure 4).

Figure 4: A Hypothesis for Basal Progesterone

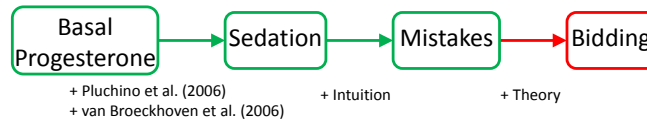


Figure 5 presents some preliminary evidence for this hypothesis. The left panel shows a scatter plot of bids above value by gender. The red circle-shaped dots belong to females, while the blue triangle-shaped dots indicate bids by males. The x-axis indicates the value for the object, while the y-axis denotes the bid. Any bid above the 45° line is a bid above value. It is a weakly dominated bid. We see more red circles above the 45° line than blue triangles suggesting

<sup>17</sup>We thank Coren Apicella (private communication) for drawing our attention to the connection between progesterone and GABA<sub>A</sub>.

that more females use weakly dominated bids than males. In our sample, 23 out of 93 females (25%) play a weakly dominated bid at some point during the auction, while only 20 out of 114 males (17.5%) do so. The right panel of Figure 5 shows histograms and densities of total dollar profits by gender. Again, we see that a larger fraction of females than males earn negative profits, which of course must be due to weakly dominated bids.

Figure 5: Bids above Value and Profits by Gender

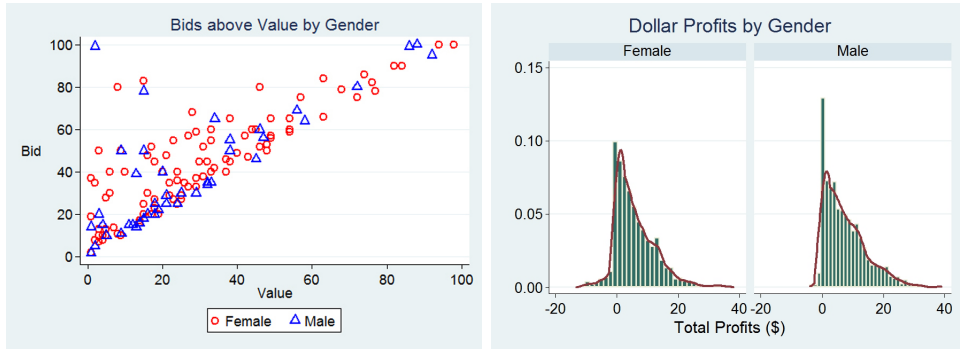


Table 7: Basal Progesterone and Mistakes

	(Bids7)	(WD)	(Bids8)
Testosterone	-0.2776 (0.6873)	-0.2802 (0.2024)	-0.4116 (0.6993)
Estradiol	-0.0421 (0.4678)	0.0708 (0.1645)	0.0089 (0.4896)
Progesterone	1.1011** (0.4143)	0.1081 (0.1424)	1.3534*** (0.4675)
Cortisol	0.6227 (0.4145)	-0.3198* (0.1938)	0.5851 (0.4097)
Contraceptives	4.6079*** (1.3346)	0.0008 (0.2740)	4.2937*** (1.3304)
Weakly Dominated Bid	20.6809*** (2.5726)		17.7756*** (2.2053)
Contraceptives x W.D. Bid			-9.5404** (3.5858)
Hormones x Contraceptives	Yes	Yes	Yes
Hormones x Weakly Dominated Bid	No	No	Yes
Hormones x Contracept. x W.D. Bid	No	No	Yes
Demographics, Majors & GPA	Yes	Yes	Yes
<i>Number of Observations</i>	2670	2670	2670
$R^2$	0.8807		0.8840

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Not reported: Coefficients of cubic polynomial in values and learning.

We seek to illuminate the hypothesis of mistakes through regression analysis in Table 7. As before we restrict our analysis to the female subsample and focus on naturally cycling females using interaction terms. Specification “Bids7” is analogous to specification “Bids4” but we add a dummy indicating a weakly dominated bid. We observe that the coefficient for progesterone in females who do not use hormonal contraceptives is reduced by about 23% (compared to “Bids4”) but it remains significant ( $p = 0.014$ ). This suggests that some but not all of the effect that progesterone has on bidding might be due to weakly dominated bids. Further we check whether progesterone is a significant predictor of weakly dominated bids. If weakly dominated bids are not associated with progesterone, then progesterone could not affect bidding through weakly dominated bids. The probit regression of weakly dominated bids on hormones and further controls in specification “WD” reveals no significant association between progesterone and weakly dominated bids. We conclude that progesterone affects bidding not solely through mistakes. In fact, the association between progesterone and bidding for specification “Bids8” focusing on undominated bids (i.e., if the dummy for a weakly dominated bid is zero) of naturally cycling females is as large as in “Bids4” and significant ( $p = 0.008$ ). Our conclusions remain unchanged when we use the random effects estimator instead of OLS in “Bids7” or “Bids8”, add lagged profit as a control, or restrict to the subsample of naturally cycling females.

**Observation 3 (Mistakes and Basal Progesterone)** *Basal Progesterone does not affect bidding and profits through mistakes.*

## 6 Hormone Responses

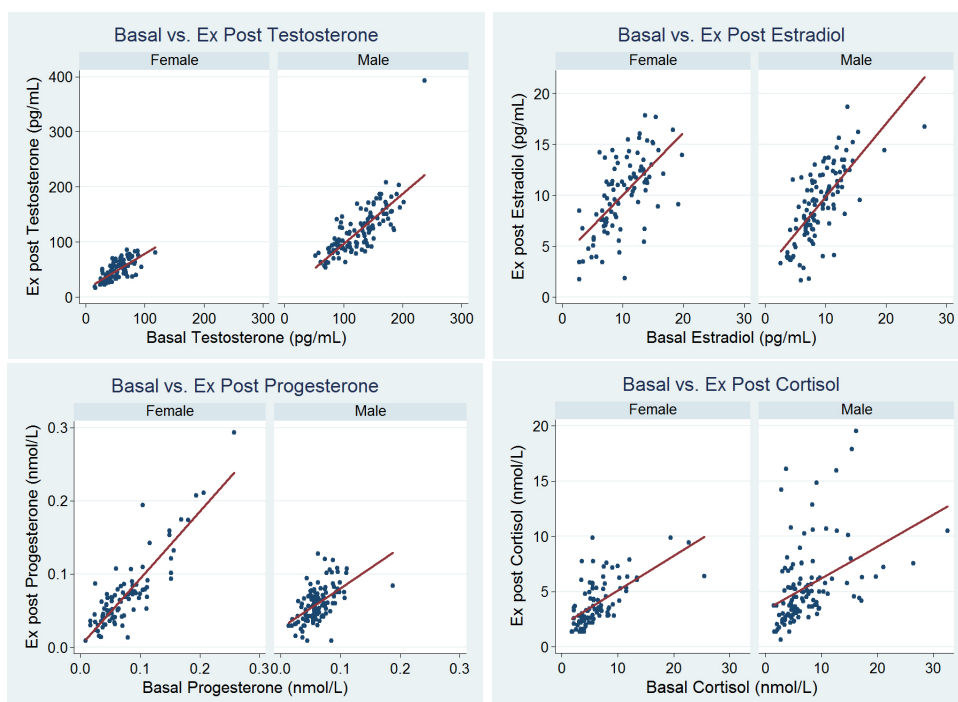
In this section we turn to the analysis of how hormones respond to profits in the auction game. The summary statistics of ex post salivary hormones is presented in Table 8. We observe that, compared to the samples collected at the beginning of the experiment, most hormones are slightly decreased. This may not come as a surprise, especially for testosterone and cortisol, as they follow a circadian cycle and decline during the day. Figure 6 shows scatter plots correlating basal salivary hormones with ex post salivary hormones by gender. We do not recognize any obvious changes in salivary hormones except for cortisol in males. In some male subjects, cortisol seems to respond positively while in others cortisol declines over the duration of the experiment. The question now becomes what pushed cortisol up for some male subjects.

Recall that we hypothesize a positive association between hormone response and total profits, both for testosterone and cortisol. We had no hypotheses on estradiol and progesterone responses. To follow up on the hypotheses we compute for each subject and hormone, the *relative hormone response* as the ratio of the difference between ex post salivary and basal hormone levels to the basal hormone level. We then regress the relative hormone response on total auction profits and further controls. Results for relative testosterone responses are presented in Table 9 by

Table 8: Ex Post Salivary Hormones by Gender and Hormonal Contraceptive Use

Salivary Hormone	Natur. Cycling Females		Fem. on Contraceptives		Male	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Testosterone (pg/mL)	52.5303	17.1496	39.3447	13.8502	120.0368	44.6956
Estradiol (pg/mL)	10.1630	3.6535	9.8751	3.8467	9.1907	3.4975
Progesterone (nmol/L)	0.0739	0.0520	0.0596	0.0312	0.0598	0.0241
Cortisol (nmol/L)	4.0264	2.0886	3.8623	1.8239	5.4496	3.5363

Figure 6: Basal vs. Ex Post Salivary Hormones



gender and the use of hormonal contraceptives. Specification “TMale” shows results for the male subsample. We use interaction terms to focus on naturally cycling females (specification “TNCFemales”) and females on hormonal contraceptives (specification “TPill”), restricting to the female subsample in both specifications. We clearly observe null results on the correlation between total profits and testosterone responses.

In Table 10 we turn to cortisol responses. Again we observe null results for cortisol responses to total profits in both naturally cycling females (specification “CNCFemales”) and females using hormonal contraceptives (specification “CPill”). However, cortisol responds positively to total profits in males (specification “CMales”). An increase of total profits by one dollar

Table 9: Response of Testosterone by Gender and Use of Contraceptives

	(TMale)	(TNCFemale)	(TPill)
Total Profit in US Dollars	0.0011 (0.0020)	-0.0010 (0.0029)	-0.0024 (0.0077)
Contraceptives		0.0969 (0.1190)	
Naturally Cycling			-0.0969 (0.1190)
Total Profit x Contraceptives		-0.0014 (0.0086)	
Total Profit x Nat. Cycling			0.0014 (0.0086)
Demographics, Majors & GPA	Yes	Yes	Yes
<i>Number of Observations</i>	111	89	89
R <sup>2</sup>	0.0629	0.1086	0.1086

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

increases cortisol in males by almost 3% on average when controlling for demographics, major of study, and GPA. While this increase is significant ( $p = 0.024$ ), we consider its magnitude to be small.

Table 10: Response of Cortisol by Gender and Use of Contraceptives

	(CMale)	(CNCFemale)	(CPill)
Total Profit in US Dollars	0.0278** (0.0116)	0.0049 (0.0044)	0.0057 (0.0067)
Contraceptives		0.1523 (0.1102)	
Naturally Cycling			-0.1523 (0.1102)
Total Profit x Contraceptives		0.0008 (0.0080)	
Total Profit x Nat. Cycling			-0.0008 (0.0080)
Demographics, Majors & GPA	Yes	Yes	Yes
<i>Number of Observations</i>	110	89	89
R <sup>2</sup>	0.1973	0.1568	0.1568

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

**Observation 4 (Hormone Responses)** *Testosterone does not respond to total profits in the auction game. We observe a significant but small positive cortisol response to total profits in males only.*



## 7 Discussion

The null finding for basal testosterone in males is surprising given the prior evidence on the association with both risk-taking (Apicella et al, 2008, Schipper, 2014) and aggression (Archer, 1991, Dabbs and Hargrove, 1997, Mazur and Booth, 1998, Mehta and Josephs, 2006).<sup>18</sup> One reason may be that the evidence in the literature for the presence of risk aversion in first-price auctions is mixed (see Kagel, 1995). The null finding may also be due to the presence of both risk-taking and aggressions in auctions. One feature of the first-price auction is that the effects of risk-taking and aggression oppose each other. They may cancel each other out.

The null finding for basal estradiol in females is also surprising given that it plays a prominent role in the menstrual cycle and also given earlier results on the association between menstrual cycle information and bidding (Pearson and Schipper, 2013). The finding of a positive association between basal progesterone and bidding in naturally cycling females was hypothesized from this earlier menstrual cycle study. Progesterone is the steroid hormone whose change is most pronounced during the menstrual cycle (see for instance, Chatterton et al., 2005). Exogenous administration of versions of progesterone through hormonal contraceptives suppresses the endogenous secretion of progesterone (e.g. Fleischman et al., 2010). Large amounts of progesterone are secreted in naturally cycling women by the corpus luteum that is formed after ovulation from the dominant follicle. Since hormonal contraceptives effectively prevent the development of a dominant follicle, they also prevent the development of the corpus luteum. Thus we are not surprised to have a null finding for women on hormonal contraceptives.

Our finding with respect to basal progesterone is also consistent with substantial gender differences in bidding in first-price auctions (Casari, Ham, and Kagel, 2007, Ham and Kagel, 2006, Chen, Katusčák, and Ozdenoren, 2013, Pearson and Schipper, 2013) that we also replicate in our sample. We suggest that to some extent this gender difference may be due to differing basal levels of progesterone in men and women. Our finding with respect to basal progesterone is also consistent with findings on the use of hormonal contraceptives. Pearson and Schipper (2013) already observed that women who use hormonal contraceptives bid significantly higher and earn significantly lower profits than men. This correlation may be due to a selection effect or due to the action of hormonal contraceptives. All hormonal contraceptives contain a synthetic version of progesterone. One may reasonably expect that hormonal contraceptives would have a similar effect as endogenous progesterone on bidding and profits in auctions.

In a post hoc analysis, we study whether the positive association between basal progesterone and bidding could be due to either risk aversion or mistakes. Interestingly, we observe that progesterone does not seem to correlate with bidding via risk aversion, despite the fact that

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<sup>18</sup>As mentioned earlier, Stanton et al. (2011b) report a u-shaped relationship between risk attitudes and salivary testosterone. Allowing for a quadratic relationship between progesterone and testosterone in regressions analogous to specifications “Bids3” to “Bids5” yields null-results as well.

there is a literature on gender differences in risk aversion (for surveys, see Croson and Gneezy, 2009, Eckel and Grossman, 2008a, Byrnes, Miller, and Schafer, 1999). However, our claim of the irrelevance of risk aversion relies crucially on the assumption that the Holt-Laury lottery task is a valid measure of risk aversion. Recently, Lönnqvist et al. (2011) observed a poor test-retest correlation when both repeating the Holt-Laury lottery task and comparing it to other elicitation methods (see Deck et al., 2010, for related evidence). Thus, our irrelevance claim should be read with caution as measurement error in the elicitation of risk preferences may likely attenuate any relationship (see Beauchamp, Cesarini, and Johannesson, 2012, for a discussion). Moreover, we speculate that attitudes towards risks in a broader sense may be context-specific rather than universal. Previously, positive associations between progesterone and mitigating “social risks” have been reported in the literature (Fleischman and Fessler, 2011, Maner and Miller, 2014, Schultheiss, Wirth, and Stanton, 2004, Wirth and Schultheiss, 2006, Brown et al., 2009). Individual behavior in Holt-Laury lottery tasks may not be well-suited to measure risk attitudes in our strategic context.

Progesterone has a slight sedating effect (see Pluchino et al., 2006, van Broeckhoven et al., 2006) and may lead to more mistakes and thus higher bids on average. Although we observe that women on average make more mistakes in the sense of selecting weakly dominated bids more frequently, we find that basal progesterone is positively associated with higher bids in naturally cycling females when restricting to undominated bids. Moreover, basal progesterone is uncorrelated with selecting weakly dominated bids in naturally cycling females. This suggests that the effect of basal progesterone on bidding in naturally cycling females is *not* mediated through mistakes. Perhaps the sedating effect of progesterone does not manifest itself in mistakes per se but in the speed of learning to choose undominated bids. In Appendix C we show that this is not the case. We observe that the number of rounds till a subject learns to choose undominated bids is not significantly correlated with basal progesterone. Moreover, basal progesterone is significantly positively associated with bids both in the first and last 15 rounds of the auction game.

Our null finding for basal cortisol is not surprising given the mixed evidence on the association of cortisol and aggression (van Bokhoven et al., 2005, Alink et al., 2009, Poustka et al., 2010), the weak evidence on cortisol and risk aversion (Schipper, 2014), and the mixed evidence for risk aversion in first-price auctions (Kagel, 1995).

With respect to hormone responses, we find the lack of a response of testosterone to profits in auctions, especially in males, surprising given that testosterone responses to outcomes in various competitions have been documented (Booth et al., 1989, Mazur et al., 1992, McCaul et al., 1992, Jimenez et al., 2012). Two possible reasons may be that profits slowly accumulated over 30 rounds of the game and were only privately known to the subject itself. The private profits may not constitute a sufficiently strong stimulus for a testosterone burst. This is somewhat similar

to the null finding in Mazur et al. (1997), who also suspected that the absence of a significant testosterone increase in winners of a video game contest may be due to the inability to create differences in mood with the video game. It would be interesting to analyze whether hormone responses become measurable when total auction profits are made public.

The significant but small cortisol response in males is not unexpected but still somewhat surprising given the mixed evidence in the literature. It is not entirely clear, though, why we see such a response in males only. One reason is that males on average bid lower than females. Thus, they take more “risks”, which could create more stress. This difference in stress may cause the difference in cortisol responses in males and females.

We hope that we have presented a careful study of steroid hormones and competitive bidding in auctions. We would like to caution the reader that our finding of a positive association between basal progesterone and bidding remains only marginally significant when correcting for multiple testing of four hormones using the Bonferroni method. Cautioning against possible false positives is very relevant in the field of endocrinological economics. Typically, multiple relationships of differing directions between many hormones and many types of behaviors can be a priori hypothesized. Most studies are conducted with small samples and, often, effect sizes are small. Moreover, positive findings are exciting and have received a fair amount of attention in the popular press. As arguments outlined in Ioannidis (2005) suggest, these factors may make the field prone to false positives. It is therefore important to conduct and publish replication studies. In our case, Shachat and Wei (2012) present findings on progesterone and first-price auctions that are consistent with ours. They collected salivary testosterone, estradiol, and progesterone in an experiment with first-price auctions and reverse first-price auctions. They reported that a group of women that includes women with higher progesterone has lower profits in the first-price auction than males. Their analysis focuses on the heterogeneity of bidding heuristics.

Our paper is related to an increasing literature on endocrinological economics. Pearson and Schipper (2012) show a null result for the correlation between the digit ratio (2D:4D), a putative measure of prenatal exposure to testosterone and estrogen, and competitive bidding and profits in first-price auctions. Wozniak, Harbaugh, and Mayr (2014) and Buser (2012) study the correlation between self-reported menstrual cycle information and the selection into tournaments with either piece-rate and winner-take-all compensation à la Gneezy, Niederle, and Rustichini (2003) and Niederle and Vesterlund (2007). Several studies correlate economically relevant behavior with direct measurements of circulating hormones, mostly testosterone and oxytocin. See Burnham (2007) for results using the ultimatum game, Zak, Kurzban, and Matzner (2004, 2005) for the trust game, Sanchez-Pages and Turiegano (2011) for the prisoners’ dilemma, and Johnson et al. (2006) for a “war” game. Outside the lab, Coates and Herbert (2008) show that salivary morning testosterone levels are positively correlated with daily profits in 17 male

financial traders in the City of London studied over 8 days. These traders were trading in competitive financial markets with trades ranging from £100,000 to £500,000,000, including trades in risky financial products like interest rate futures. Coates and Herbert (2008) also show that traders' salivary cortisol levels rise with both the variance of trading results and the volatility of the market. There is also a related literature on social preferences using placebo-controlled administration of hormones. See Kosfeld et al. (2005), Baumgartner et al. (2008), Zak, Stanton, and Ahmadi (2007) on oxytocin, Zethraeus et al. (2009) on estrogen and testosterone, and Zak et al. (2009) and Eisenegger et al. (2010) on testosterone. It should be pointed out, though, that to further our understanding of how hormones effect economic behavior requires both careful correlation studies and placebo-controlled experiments. In order to establish causalities with placebo-controlled studies, it is necessary to know whether exogenously administered hormones actually act similar to endogenous hormones, to establish knowledge about doses administered, effect sizes and their relation to endogenous levels, as well as to elaborate the interaction between exogenous and endogenous hormones. For most hormones of interest to behavioral studies, this knowledge is extremely preliminary.

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# Supplementary Appendix for “Sex hormones and competitive bidding” by Burkhard C. Schipper

## A Salivary Hormone Methodology

### A.1 Steroid Hormones

Sex differences in brain and behavior are to a large extent influenced by sex steroids. According to the classic organizational-activational hypothesis of sexual differentiation (see Phoenix et al, 1959), a transient rise in testosterone during prenatal or early postnatal development masculinizes the brain in males, while the absence of testosterone leads to female neural structures. During puberty, testicular and ovarian hormones act on previously sexually differentiated circuits to facilitate expression of sex-typical behaviors in particular social contexts (see Schultz et al., 2009, Arnold and Breedlove, 1985, and Kelly et al., 1999). Thus, sex steroids are thought to have both organizational effects and activational effects. Organizational effects refer to more permanent influences that often occur prenatally, early after birth, or during puberty. An example is the prenatal organization of tissues of male adult reproductive behavior. Activational effects are temporary effects and often they depend on prior organizational effects. For instance, a male does not display mating behavior facilitated by the prenatally organized tissues unless adequate sex hormones are produced at puberty (see Baron-Cohen et al. 2006).

Often, exogenous hormones are distinguished from endogenous hormones. The latter are hormones released by glands in the body, while exogenous hormones are hormones administered orally, transdermally, intranasally, or by various types of injections. Exogenous hormones may have effects different from endogenous hormones of the same type depending on absorption, metabolism, and the presence of prior organizational effects mentioned above. For instance, orally administered steroids are subject to the first-pass effect, i.e., the metabolic reduction of the steroid in the liver, and not all of the administered dose becomes available in the blood for binding on receptors.

We focus on four endogenous steroid hormones: testosterone, estradiol, progesterone, and cortisol (for overviews, see Nelson, 2011). Testosterone,  $C_{19}H_{28}O_2$ , belongs to the androgen group. It is derived via some intermediated steps from cholesterol and secreted in the testis, ovaries, and adrenal gland. Some of it is aromatized into estradiol. Since it is observed in most vertebrates, it must have had a long evolutionary history (Mechoulam et al., 1984). Testosterone has anabolic effects such as stimulating the bone density and muscle mass as well as androgenic effects such as the maturation of sex organs and secondary sex characteristics especially in males. It is necessary for sperm development. In humans, various behavioral correlations with testosterone have been reported mostly pertaining to aggression (e.g. Archer, 1991) and dominance (e.g. Mazur and Booth, 1998, Mehta and Josephs, 2006).

Estradiol,  $C_{18}H_{24}O_2$ , sometimes also named E2 or  $17\beta$ -estradiol, is a member of the estrogen group. It is also derived via some intermediated steps from cholesterol and secreted in the testis, ovaries, and the adrenal cortex. It changes over the menstrual cycle, peaking shortly before ovulation and again in the second half of the cycle (see Fritz and Speroff, 2011). However, in blood plasma, estradiol is bound to globulin and albumin, and only a small fraction is free and biologically active. This fraction is constant over the menstrual cycle (Wu et al., 1976). Estradiol enters cells relatively freely. Its anabolic effects include effects on the bone structure and its androgenic effects are on the maturation of female sex organs and secondary sex characteristics. Wu et al. (2009) suggest that the aromatization of testosterone into estradiol is important for the organization and activation of neural circuits that control male territorial

behaviors in mice.

Progesterone,  $C_{201}H_{300}O_{200}$ , sometimes denoted by P4, belongs to the progesten group. It is derived from cholesterol, secreted in the ovaries, especially the corpus luteum, the adrenal glands, and during pregnancy in the placenta. It is also contained in milk. Progesterone is stored in fat tissue. It can be metabolized (via some intermediate steps) into cortisol, testosterone, and estradiol. Progesterone changes over the menstrual cycle, rising after ovulation and declining before menstruation (see Fritz and Speroff, 2011). As its name suggests, it plays a prominent role during pregnancy (“pro-gestation”). Progesterone is a neurosteroid that can be synthesized within the central nervous system. There is a surprisingly small literature on behavioral effects in humans; see Fleischman and Fessler (2011), Maner and Miller (2014), Schultheiss, Wirth, and Stanton (2004), Wirth and Schultheiss (2006), and Brown et al. (2009).

Cortisol,  $C_{21}H_{30}O_5$ , is a steroid hormone belonging to glucocorticoid group. It is secreted in adrenal glands and controlled by the hypothalamus. It is considered to be the “stress hormone” since it is released in response to stress. It increases blood sugar, suppresses the immune system, and is aiding fat, protein, and carbohydrate metabolism. As the other steroid hormones, it is derived from cholesterol via some intermediated steps. Massage (Field et al. 2005), intimacy (Ditzen et al., 2007, 2008), and sexual arousal (Hamilton and Meston, 2011) reduce cortisol levels. Caffeine (Lovallo et al., 2006) and sleep deprivation (Leproult et al, 1997) can increase cortisol levels. Cortisol follows a typical circadian cycle. On average it is lowest at 4:00 am and peaks at 8:00 am. In terms of behavioral effects, cortisol may interact with testosterone. For instance, Mehta and Josephs (2010) report that testosterone is positively correlated with dominance in low cortisol males while negatively correlated in high cortisol males.

## A.2 Instruction for Saliva Collection

### Instructions for Saliva Collection

Terminal: \_\_

In this experiment we are collecting saliva from the participants (you). The saliva is analyzed for the hormones it contains. You have received a collection tube. We need it about half full. Please do not eat, drink or chew any chewing gum other than provided by the experimenter during the experiment, as this will affect your saliva.

### How to collect saliva?

1. Chew one piece of Trident original sugarless chewing gum to stimulate saliva.
2. After half a minute, spit the gum out into a tissue.
3. Uncap the collection tube.
4. A short straw is provided for you. Please place it in the tube.
5. Drool saliva through the straw into the tube until it is approximately half full.
6. Remove the straw onto a tissue.
7. Recap the tube.

The experimenters will collect the tubes during the experiment.

The used chewing, straws and tissues should be deposited into the rubbish bin at the end of the experiment.

If you have any questions, please raise your hand and an experimenter will attend to your question.

## A.3 Further Details on Saliva Collection and Storage

All sessions were run between February 8 and March 16, 2010, at the same time of the day in the afternoon. This is important as some hormones such as cortisol follow a circadian cycle (Van Cauter and Turek, 1995). The starting time of each session, 16:00, was scheduled such as to have sufficient time passed after lunch and to complete the session before dinner time. This is because salivary testosterone or cortisol may respond to meals 30 to 60 minutes before saliva collection (e.g. Al-Dujaili and Bryant, 2005). For testosterone, late-afternoon collections represented samples with physiologically relevant “low” hormone concentrations (Granger et al., 2004).

We must mention that the switch to Daylight Saving Time occurred on March 14, 2010. Although we were not able to find studies analyzing the effect of Daylight Saving Time on cortisol or other steroid hormones, it is known from Valdez et al. (2003) and Kantermann et al. (2007) that the switch to Daylight Saving Time may affect the circadian cycle. Thus, salivary hormones from subjects in sessions on March 15 and 16 may be affected by Daylight Saving Time. We will analyze this issue below.

Saliva samples were stored immediately after collection at  $-20^{\circ}\text{C}$  till the end of March 2010 and then at  $-80^{\circ}\text{C}$  till May 2010 when they were assayed. Granger et al. (2004) study testosterone concentration in stored saliva samples. They found no associations between testosterone levels and storage duration for samples stored at  $-80^{\circ}\text{C}$  over a period of 36 months. The same applies for samples collected in the late

afternoon and stored at  $-20^{\circ}\text{C}$  over a period of 24 months.

## A.4 Assays

Assays were conducted by the Endocrine Core Laboratory of the California National Primate Research Center at the University of California, Davis. Prior to assay of cortisol, progesterone, estradiol and testosterone, saliva samples were centrifuged at 3000 rpm for 20 min to separate the aqueous component from mucins and other suspended particles.

Salivary concentrations of testosterone were estimated in duplicate using the salivary testosterone enzyme immunoassay kit (Salimetrics LLC, State College, PA). Assay procedures were run in accordance to manufacturer’s protocol salivary testosterone enzyme immunoassay kit insert revision 2-2010. The salivary testosterone assay has a least detectable dose of 1.0 pg/mL, and intra- and inter-assay coefficients of variation were 4.44 and 7.96, respectively.

Salivary concentrations of estradiol were estimated in duplicate using the high sensitivity salivary  $17\beta$ -estradiol enzyme immunoassay kit (Salimetrics LLC, State College, PA). Assay procedures were run in accordance to manufacturer’s protocol HS Salivary  $17\beta$ -Estradiol EIA Kit Insert, revision date 2-22-10. The salivary estradiol assay has a least detectable dose of 0.1 pg/mL, and intra- and inter-assay coefficients of variation were 3.43 and 6.01, respectively.

Salivary concentrations of progesterone were estimated in duplicate using commercial radioimmunoassay kits (Siemens Healthcare Diagnostics, Inc., Los Angeles, CA). Assay procedures were modified to accommodate overall lower levels of progesterone in human saliva relative to plasma as follows: (1) standards were diluted to concentrations ranging from 0.05–4.0 ng/mL, and (2) sample volume was increased to 200  $\mu\text{l}$ . The salivary progesterone assay has a least detectable dose of 0.00914 ng/ml, and intra- and inter-assay coefficients of variation were 4.15 and 5.84, respectively.

Salivary concentrations of cortisol were estimated in duplicate using commercial radioimmunoassay kits (Siemens Healthcare Diagnostics, Inc., Los Angeles, CA). Assay procedures were modified to accommodate overall lower levels of cortisol in human saliva relative to plasma as follows: (1) standards were diluted to concentrations ranging from 2.76 to 345 nmol/L, (2) sample volume was increased to 200  $\mu\text{l}$ , and (3) incubation times were extended to 3 h. Serial dilution of samples indicates that the modified assay displays a linearity of 0.98 and a least detectable dose of 1.3854 nmol/L. Intra- and inter-assay coefficients of variation are 5.44 and 6.12, respectively.

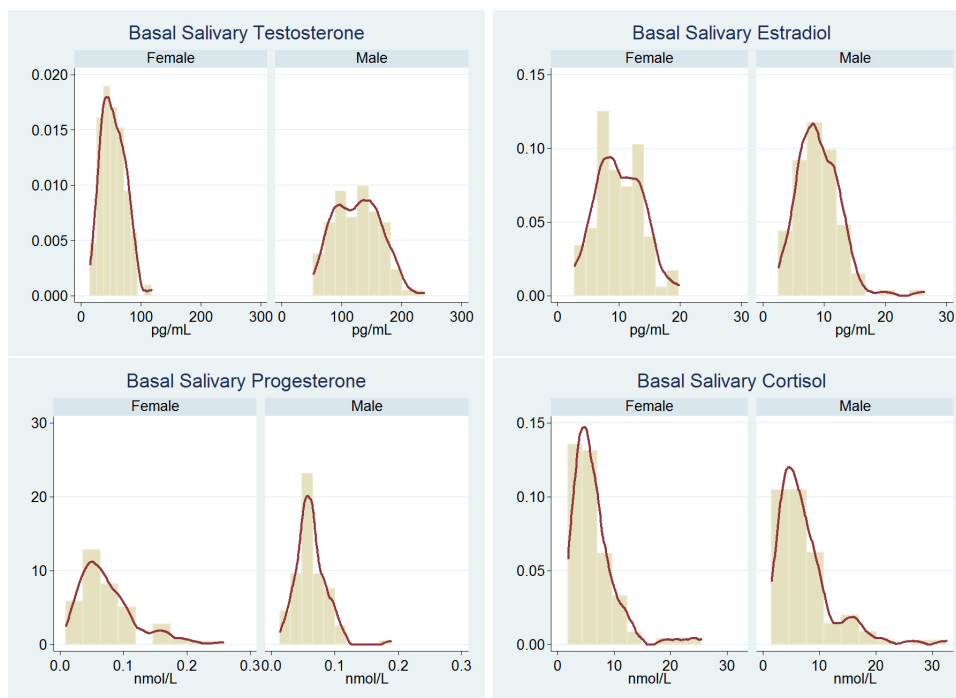
Figure 7 shows histograms and densities of basal salivary hormones by gender.

## A.5 Factors Affecting Salivary Hormones

As mentioned above, the quality of saliva samples may be compromised by food intake prior to collection. To control for such effects, we asked subjects in the questionnaire to report whether or not they had lunch today, when they had lunch today, about the time they ate last, what they ate last, about the time they drank last, and what they drank last. From this we construct variables “When lunch today” that is zero if lunch was skipped and monotonically increases with the lunch time of the day. Similarly, we construct variables “Time last eaten” and “Time last drank” that monotonically increase with the time since last eaten (resp. drank).

Granger et al. (2004) and Kivlighan et al. (2004) show that salivary testosterone may be increased

Figure 7: Densities of Basal Salivary Hormones by Gender



by blood contamination through microinjuries in the mouth or teeth brushing. Similarly, Kivlighan, Granger, and Schwartz (2005) observed decreased levels of salivary estradiol and increased levels of salivary progesterone due to microinjuries in the mouth or teeth brushing. Kivlighan et al. (2004) found that cortisol is irresponsive to microinjuries in the mouth or teeth brushing. To control for potential blood contamination, we asked subjects in the questionnaire to report on their daily dental care, the last time they brushed their tooth and whether they know of any injuries in their mouth. From this information we construct a dummy variable for “Mouth injuries”, and variables “Freq. toothbrush.” and “Time last toothbrush.”, respectively.

Smoking may impact the endocrine system (Kapoor and Jones, 2005) but the evidence is mixed. Zumoff et al. (1990) show an association of smoking on serum levels of progesterone and estradiol but Thomas et al. (1993) were unable to find significant effects of smoking on salivary progesterone, plasma testosterone, and urinary estradiol. The use of tobacco can affect salivary testosterone levels (Attia et al., 1989). We don’t know whether smoking could change the endocrine system or just measurable levels of salivary hormones. Anyway, we asked in the questionnaire to self-report the frequency of smoking and created a variable “Smoking” that is monotonically increasing in the frequency of smoking.

As mentioned above the switch to Daylight Saving Time on March 14, 2010, may affect our data collected on March 15 and 16. Although, we were not able to find studies analyzing the effect of Daylight Saving Time on cortisol or other steroid hormones, it is know from Valdez et al. (2003) and Kantermann et al. (2007) that the switch to Daylight Saving Time may affect the circadian cycle. We created a dummy variable “Daylight Sav. Time” that is one for sessions March 15 and 16 and zero otherwise.

In the questionnaire (see Appendix G) we collected further information on factors that may affect

salivary hormones. Ellison and Lager (1986) report that moderate recreational running may be associated with lower salivary progesterone levels in females. Thus, we collect information on physical exercise scheduled. Brown et al. (2009) indicate that “social closeness” may effect progesterone. We asked for dating activities, whether students live alone, with family etc. Hooper et al. (2009) report associations between soy consumption and endocrinological factors. While they did not find an effect of soy consumption on estradiol, they found significantly reduced FSH and LH and increased menstrual cycle length. Our sample contains a large fraction of Asians and soybean protein is relatively common in ethnic asian food. Besides race, we also collect data on dietary preferences. Obesity has been linked to abnormal menstrual cycles and deficient progesterone secretion (Jain et al. 2007). Therefore we collect information on height and weight. While all those factors may affect hormones, they may not necessarily affect the quality of the assays. Thus, we do not include them in the analysis of quality. Yet, the analysis is available from the author on request and can be produced from the datasets and the Stata do-file available from <http://www.econ.ucdavis.edu/faculty/schipper/>.

In Table 11, we present results from OLS regressions of salivary hormone levels normalized by their standard deviation on above-mentioned variables and session dummies by gender. “T”, “E”, “P”, and “C” refer to testosterone, estradiol, progesterone, and cortisol, respectively. “F” and “M” refer to female and male, respectively. We use robust standard errors to adjust for potential heteroscedasticity and non-normality. We observe that whenever a variable is significant, then the coefficient is close to zero with four exceptions. Testosterone and cortisol of males (specifications TM and CM, respectively) where “When lunch today” on average decreases testosterone by 0.07 of its standard deviation and cortisol by 0.13 of its standard deviation, respectively. Moreover, for estradiol in males we find that the frequency of smoking is positively correlated with salivary estradiol (specification EM). Finally, the frequency of brushing teeth is positively correlated with cortisol in males only (specification CM). This is somewhat surprising given that Kivlighan et al. (2004) found that cortisol is irresponsive to microinjuries in the mouth or teeth brushing. Some of the variables we used in robustness checks of our results.

## A.6 Assessing Measurement Errors in Salivary Hormones

Measurement error cannot be avoided in salivary hormones measurements. Our results may be downward biased (i.e., attenuation bias). It is possible that our null findings are due to measurement error. It is also possible that we underestimate the size of the association between bidding (or profits) and progesterone in naturally cycling females. In this section we study to what extent we can use the ex post salivary hormone measures to assess the measurement error of the basal salivary hormone measures.

Let  $H_i^t$  denote the hormone measure of subject  $i$  at  $t = 1, 2$ , where  $t = 1$  stands for the basal measure and  $t = 2$  for the ex post measure. We assume that the basal measure  $H_i^1$  is noisy but related to the true underlying hormone level  $H_i$  by  $H_i^1 = H_i + \varepsilon_i^1$ , where  $\varepsilon_i^1$  is the measurement error of the basal measure. Similarly, the ex post measure  $H_i^2 = H_i + \Delta_i + \varepsilon_i^2$ , where  $\Delta_i$  is the response of the hormone to events in the auction and  $\varepsilon_i^2$  is the measurement error of the ex post measure. We assume  $Cov(H_i, \varepsilon_i^1) = Cov(H_i, \varepsilon_i^2) = Cov(\Delta_i, \varepsilon_i^2) = 0$ .

When we regress  $H_i^1$  on  $H_i^2$ , the coefficient is given by

$$\beta_{12} = \frac{Cov(H_i^2, H_i^1)}{Var(H_i^2)} = \frac{Var(H_i) + Cov(H_i, \Delta_i) + Cov(\varepsilon_i^1, \Delta_i) + Cov(\varepsilon_i^1, \varepsilon_i^2)}{Var(H_i) + Var(\Delta_i) + Var(\varepsilon_i^2) + 2Cov(H_i, \Delta_i)}.$$

Table 11: Quality of Salivary Hormones

	(TF)	(TM)	(EF)	(EM)	(PF)	(PM)	(CF)	(CM)
When lunch today	-0.0099 (0.0211)	-0.0703** (0.0295)	-0.0588 (0.0727)	0.0150 (0.0370)	-0.0901 (0.0660)	-0.0220 (0.0210)	-0.0529 (0.0421)	-0.1341** (0.0567)
Time last eaten	-0.0005 (0.0005)	0.0017* (0.0009)	-0.0015 (0.0017)	-0.0002 (0.0009)	-0.0022 (0.0016)	-0.0019*** (0.0007)	-0.0019** (0.0008)	-0.0029* (0.0015)
Time last drank	-0.0024** (0.0012)	-0.0023 (0.0017)	-0.0046 (0.0029)	0.0013 (0.0017)	-0.0044 (0.0040)	-0.0003 (0.0011)	-0.0035 (0.0022)	0.0007 (0.0020)
Mouth injuries	-0.0571 (0.0963)	0.2321 (0.2340)	-0.2568 (0.3165)	0.0989 (0.2223)	0.1947 (0.4825)	-0.0797 (0.1793)	0.1736 (0.2256)	-0.0773 (0.2193)
Freq. toothbrush.	0.1487 (0.1082)	0.0585 (0.1168)	0.1030 (0.2610)	0.1236 (0.1182)	-0.5213 (0.3491)	0.1655* (0.0974)	-0.0380 (0.1452)	0.3596** (0.1580)
Time last toothbrush.	-0.0026 (0.0044)	-0.0047* (0.0024)	0.0020 (0.0054)	-0.0088** (0.0040)	-0.0027 (0.0040)	-0.0047*** (0.0017)	-0.0116 (0.0070)	0.0003 (0.0029)
Smoking	0.0495 (0.1096)	0.1046 (0.1305)	0.4001 (0.2703)	0.4167** (0.1969)	0.1090 (0.2889)	0.0999 (0.1124)	-0.0564 (0.2054)	0.1444 (0.2353)
Daylight Sav. Time	0.2276 (0.2136)	-0.1032 (0.2632)	0.3933 (0.6583)	0.1314 (0.3033)	0.3975 (0.8050)	0.0109 (0.1330)	1.5397* (0.8122)	-0.1674 (0.2983)
<i>Number of Observations</i>	93	115	93	115	93	114	93	114
<i>R<sup>2</sup></i>	0.0980	0.1630	0.0763	0.1814	0.0738	0.2009	0.2684	0.1605

Robust standard errors in parentheses; Significance levels: \*10%; \*\* 5%; \*\*\* 1%.



Likewise, when we regress  $H_i^2$  on  $H_i^1$ , the coefficient is

$$\beta_{21} = \frac{Cov(H_i^2, H_i^1)}{Var(H_i^1)} = \frac{Var(H_i) + Cov(H_i, \Delta_i) + Cov(\varepsilon_i^1, \Delta_i) + Cov(\varepsilon_i^1, \varepsilon_i^2)}{Var(H_i) + Var(\varepsilon_i^1)}.$$

Thus, if  $\Delta_i = 0$  for all  $i$ , then  $\beta_{12} \leq \beta_{21}$  if and only if  $Var(\varepsilon_i^1) \leq Var(\varepsilon_i^2)$ . That is, in the absence of a hormone response, the coefficients  $\beta_{12}$  and  $\beta_{21}$  allow us to assess the measurement error of the basal hormone measurement relative to the ex post measurement. If there is a hormone response,  $\Delta_i \neq 0$ , then in order to assess measurement error further information on the variance of the hormone response and the covariance of the underlying hormone level and the hormone response would be required. This information is typically not available.

Table 12: Regressing Basal on Ex Post Measures and Vice Versa

	(E12)	(E21)	(P12)	(P21)
Ex Post Estradiol	0.6980*** (0.0520)			
Basal Estradiol		0.6721*** (0.0501)		
Ex Post Progesterone			0.7762*** (0.0410)	
Basal Progesterone				0.8229*** (0.0434)
<i>Number of Observations</i>	206	206	205	205
<i>R</i> <sup>2</sup>	0.4691	0.4691	0.6387	0.6387

Standard errors in parentheses. Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Recall from Section 3.2 that we do not expect estradiol or progesterone to respond to events in the auction. If we assume this hypothesis to hold, then for those hormones we can use the ex post salivary measures to assess the measurement error in the salivary measures of those basal hormones. Table 12 shows the results from regressing basal estradiol on ex post estradiol (specification “E12”), ex post estradiol on basal estradiol (specification “E21”), basal progesterone on ex post progesterone (specification “P12”), and ex post progesterone on basal progesterone (specification “P21”). The coefficients for estradiol are of very similar magnitude. The coefficient of ex post progesterone in “P12” is slightly smaller than the coefficient of basal progesterone in “P21” suggesting that basal progesterone has a slightly smaller measurement error. We conclude that our measurements of basal estradiol and progesterone do not have larger measurement errors than our ex post measurements. Nevertheless, we emphasize again that some degree of measurement error is unavoidable in endocrinological economics. This may lead to the underestimation of the size of the true association between behavior and hormones.

## B Further Details on Hormonal Contraceptives

Hormonal contraceptives may influence endogenous basal hormone levels. Schultheiss et al. (2003) report that users of oral contraceptives show suppressed levels of salivary testosterone and estradiol.

Roughly 25.6% of women in our sample administer hormonal contraceptives. This number is

reasonable given the age of women and their ethnic background.<sup>19</sup> From 21 females using hormonal contraceptives, 10 females reported the name of the contraceptive. This enabled us to evaluate their typical administration schedules and active ingredients.

Contraceptives can be classified into three categories (see Fritz and Speroff, 2011, Section III, for an extensive overview): First, there are injections like Depo Provera. This is a long-acting reversible contraceptive acting over 12 weeks containing as the active ingredient only a progestin. Second, there are oral birth control pills. While some of the pills available may contain as the active ingredient a progestin only, all the pills reported in the experiments contained both a progestin as well as ethinyl estradiol. Ethinyl estradiol is not converted into estradiol in the body but can bind to estrogen receptors. There are oral contraceptives that contain the active ingredient for three weeks and an inert ingredient (i.e., placebo) for one week during which a withdrawal bleeding usually occurs (e.g. Avian, Desogen, Junel, Microgestin, Ortho-Tri-Cyclen, Sprintec, and Yasmin). Then there are oral contraceptives that contain the active ingredient for 24 days after which an inert ingredient is taken for 4 days during which withdrawal bleeding usually occurs (e.g. Yaz). For some oral contraceptives like Ortho-Tri-Cyclen, the concentration of active ingredient varies across the cycle (i.e., biphasic or triphasic oral contraceptives). Third, there are extended cycle oral contraceptives that contain an active ingredient for 84 days after which an inert ingredient is used for 7 days during which withdrawal bleeding usually occurs (e.g. Seasonale). Fourth, there is the NuvaRing, a flexible vaginal ring that when placed in the vagina releases both a progestin as well as estradiol over a period of three weeks, after which it is removed for a one-week break during which a withdrawal bleeding occurs. Compared to oral contraceptives, whose active ingredients peak about two hours after intake and then decline for the rest of the day, the NuvaRing releases the active ingredients more constantly. Except for Depo Provera, all hormonal contraceptives reported involve a regular break/placebo during which circulating levels of progesterone are expected to be lower than when active ingredients are taken. This break may affect behavior. Not all women may observe the break but skip the placebo or break in order to avoid the inconvenience of withdrawal bleeding.

Different hormonal contraceptives contain different progestins, and different progestins have different effects on the brain. Not all progestins can be converted into the GABA<sub>A</sub> receptor-active metabolites (Pluchino et al., 2009). Thus, not all hormonal contraceptives may have the same slight sedating effect that we alluded to in the main text. While we find the progesterone-GABA<sub>A</sub>-sedation explanation for the correlation with the use of hormonal contraceptives quite attractive, we cannot claim a causal effect since it may be a selection effect. In particular, women who decide to take hormonal contraceptives may also differ systematically in their bidding behavior from women who decide not to take any hormonal contraceptives. It is not clear whether a priori more risk averse women are more likely to use hormonal contraceptives or whether women with more risky sexual behavior are more likely to take hormonal contraceptives. Conclusive evidence could be obtained in an experiment in which oral contraceptives and a placebo are blindly and randomly assigned to women. Obviously, such an experiment would be rather difficult to conduct. Moreover, women who would agree to participate in such a “risky” experiment may systematically differ in their risk preferences from the rest of the population.

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<sup>19</sup>The United States Department of Health and Human Services (2010) estimates that in the US roughly over 11% of asian, hispanic, and black women between 15 to 44 years of age use the pill compared to over 21% of white women. The use of the pill varies also with age. In the age group 15 to 19, it is slightly over 15%, while it increases to 26% in the age group 20 to 24. Note that the mean age of women in our sample is 20.1 years old. Another study, Collins and Hershbein (2011), finds higher percentages of users among college women but that study contains only about 10% of Asian women. The use of hormonal contraceptives is less common in Asian women compared to white.

Table 13: Learning

	(Learning)	(FirstRounds)	(LastRounds)
Testosterone	0.0417 (1.2013)	-0.8922 (0.7060)	-0.3187 (0.7309)
Estradiol	-1.7126 (1.2730)	0.5268 (0.6368)	-0.2365 (0.6486)
Progesterone	1.3063 (1.4839)	1.3263** (0.4937)	1.6859** (0.6686)
Cortisol	-0.6505 (0.8028)	0.1310 (0.4912)	0.5968 (0.5137)
First 15 Rounds			2.0506*** (0.4667)
Last 15 Rounds		-2.0506*** (0.4667)	
Hormones x Last 15 Rounds	No	Yes	No
Hormones x First 15 Rounds	No	No	Yes
Demographics, Majors & GPA	Yes	Yes	Yes
<i>Number of Observations</i>	68	2040	2040
R <sup>2</sup>	0.2069	0.8519	0.8519

Robust standard errors (clustered at the session level) in parentheses.

Significance levels: \*10%; \*\* 5%; \*\*\* 1%

Not reported: Coefficients of cubic polynomial in values and dummies for bidding rounds (FirstRounds, LastRounds) and mean, standard deviation, and skewness of values drawn (Learning).

## C Learning

In Section 5.2 we hypothesized that the positive association between basal progesterone and bids in naturally cycling women may be mediated through mistakes because progesterone has a slight sedating effect. Our evidence did not support this hypothesis. Perhaps the slight sedating effect of progesterone does not manifest itself in mistakes per se but in the speed of learning to choose undominated bids. We investigate this post hoc hypothesis in this section.

For each naturally cycling female, we count the number of rounds until she does not play anymore weakly dominated bids. In Table 13, specification “Learning”, we regress this number on basal salivary hormones and further controls restricting the data to the subsample of naturally cycling females. We observe that the number of rounds until a subject learns to play undominated bids is not significantly correlated with basal progesterone in naturally cycling females (e.g.,  $p = 0.387$  for progesterone).

We also analyze whether the positive association between basal progesterone and bidding in naturally cycling women is present only in early rounds, when learning may be still limited, and disappears in later rounds of the auction game. To this extent, we compare the first and last 15 rounds. In Table 13, specification “FirstRounds” we regress bids on controls and interaction terms with the last 15 rounds restricting to the subsample of naturally cycling women. The coefficient for hormones now applies to the association between hormones and bidding in the first 15 rounds (when the dummy “last 15 rounds” is zero) in naturally cycling females. We observe that progesterone is significantly positively associated with bidding in the first 15 rounds ( $p = 0.013$ ), where the magnitude of the coefficient is similar to the one in specification “Bids4” of Table 5. Specification “LastRounds” is analogous but instead we focus

on bids in the last 15 rounds of naturally cycling women. We observe that progesterone is significantly positively associated for bidding in the last 15 ( $p = 0.018$ ) rounds. Again, the coefficient is similar to the one in specification “Bids4” in Table 5.

**Observation 5** *In naturally cycling females, basal progesterone is not associated with learning to choose undominated bids. Basal progesterone is significantly positively associated with bidding both in the first 15 and last 15 rounds of the auction game.*

Playing weakly dominated bids in our first-price auction sometimes results in a loss and thus strong feedback information for learning. Thus, while higher basal progesterone may per se lead to slower learning via the sedation hypothesis, this may be countered by faster learning through stronger feedback information about negative profits. These two countering effects may be a reason why we do not observe an association between basal progesterone and learning. This is reminiscent of Casari, Ham, and Kagel (2007), who report that initially women bid significantly higher than men and thus are more prone to the winner’s curse in common value first-price auctions. However, because of experiencing the winner’s curse more frequently, women also learn bidding much faster than men, thus eventually their earnings may slightly surpass those of the men.

## D Instructions for the Holt-Laury Lottery Task

### Instructions for the Lottery Experiment

Terminal: \_\_

Along with these instructions, you have received two decision sheets. Each of them shows ten decisions listed on the left. Each decision is a paired choice: either "Option A" or "Option B." On each sheet, you will make ten choices and record these in the final column, but only one of them from each sheet will be used in the end to determine your earnings. Before you start making your ten choices, please let me explain how these choices will affect your earnings for this part of the experiment.

There is a ten-sided die that will be used to determine payoffs in front of your eyes; the faces are numbered from 1 to 10 (the "0" face of the die will serve as 10). After you have made all of your choices, we will throw this die twice for each decision sheet, once to select one of the ten decisions of the sheet to be used, and a second time to determine what your payoff is for the option you chose, A or B, for the particular decision selected. Even though you will make ten decisions on each sheet, only one of these from each sheet will end up affecting your earnings, but you will not know in advance which decisions will be used. Obviously, each decision has an equal chance of being used in the end.

Now, please look at Decision 1 at the top of the first sheet. Option A yields a sure gain of \$3.20 (320 cents), and option B yields a sure gain of \$0.20 (20 cents). Next look at Decision 2 in the second row. Option A yields \$4.00 if the throw of the ten sided die is 1, and it yields \$3.20 if the throw is 2-10. Option B yields \$7.70 if the throw of the die is 1, and it yields \$0.20 if the throw is 2-10. The other decisions on the sheet are similar, except that as you move down the table, the chances of the better payoff for each option increase.

The second decision sheet is identical to the first one except for one difference: all payoffs are negative. For instance look at Decision 1 at the top of the second sheet. Option A yields a sure loss of \$3.20 (minus 320 cents), and option B yields a sure loss of \$0.20 (minus 20 cents). Payoffs for this choice are negative and will be subtracted from your previous earnings.

To summarize, on each decision sheet you will make ten choices: for each decision row you will have to choose between Option A and Option B. You may choose A for some decision rows and B for other rows, and you may change your decisions and make them in any order. When you are finished, we will come to your desk and collect both decision sheets. Then the market experiment will be run. After the market experiment we will throw the ten-sided die for each decision sheet to select which of the ten Decisions will be used. Then we will throw the die again for each decision sheet to determine your payoff for the Option you chose for that Decision. Payoffs for your choices and will be added/subtracted to/from your previous earnings from the market experiment, and you will be paid the sum of all earnings in cash when we finish.

So now please look at the empty boxes on the right side of the record sheet. You will have to write a decision, A or B in each of these boxes, and then the die throw will determine which one is going to count. We will look at the decision that you made for the choice that counts, and circle it, before throwing the die again to determine your earnings for this part. Then you will write your earnings in the blank at the bottom of the page. Please note that these gains/losses will be added/subtracted to/from your previous earnings up to now.

Are there any questions? Now you may begin making your choices. Please do not talk with anyone while we are doing this; raise your hand if you have a question.

### D.1 Additional Details on the Lottery Task

Tables 14 and 15 show the lottery pairs for the gain and loss domains, respectively. The first column numbers the decisions. The second and third columns present the pairs of lotteries, named "option A"

Table 14: Decision Sheet (Gains)

Decision No.	Option A	Option B	Your Choice	Exp. Payoff A - Exp. Payoff B (not shown to subjects)
1	\$3.20 if throw of die is 1 to 10	\$0.20 if throw of die is 1 to 10		\$3.00
2	\$4.00 if throw of die is 1 \$3.20 if throw of die is 2 to 10	\$7.70 if throw of die is 1 \$0.20 if throw of die is 2 to 10		\$2.33
3	\$4.00 if throw of die is 1 or 2 \$3.20 if throw of die is 3 to 10	\$7.70 if throw of die is 1 or 2 \$0.20 if throw of die is 3 to 10		\$1.66
4	\$4.00 if throw of die is 1 to 3 \$3.20 if throw of die is 4 to 10	\$7.70 if throw of die is 1 to 3 \$0.20 if throw of die is 4 to 10		\$0.99
5	\$4.00 if throw of die is 1 to 4 \$3.20 if throw of die is 5 to 10	\$7.70 if throw of die is 1 to 4 \$0.20 if throw of die is 5 to 10		\$0.32
6	\$4.00 if throw of die is 1 to 5 \$3.20 if throw of die is 6 to 10	\$7.70 if throw of die is 1 to 5 \$0.20 if throw of die is 6 to 10		-\$0.35
7	\$4.00 if throw of die is 1 to 6 \$3.20 if throw of die is 7 to 10	\$7.70 if throw of die is 1 to 6 \$0.20 if throw of die is 7 to 10		-\$1.02
8	\$4.00 if throw of die is 1 to 7 \$3.20 if throw of die is 8 to 10	\$7.70 if throw of die is 1 to 7 \$0.20 if throw of die is 8 to 10		-\$1.69
9	\$4.00 if throw of die is 1 to 8 \$3.20 if throw of die is 9 or 10	\$7.70 if throw of die is 1 to 8 \$0.20 if throw of die is 9 or 10		-\$2.36
10	\$4.00 if throw of die is 1 to 9 \$3.20 if throw of die is 10	\$7.70 if throw of die is 1 to 9 \$0.20 if throw of die is 10		-\$3.03

and “option B”, respectively. For each of the 10 choices, each subject had to decide between option A and B, and indicate it in the fourth column. The last column is not shown to subjects in the experiment but printed here for convenience of the reader. It shows for each decision the difference of the expected payoffs between options A and B.

Table 15: Decision Sheet (Losses)

Decision No.	Option A	Option B	Your Choice	Exp. Payoff A - Exp. Payoff B (not shown to subjects)
1	-\$3.20 if throw of die is 1 to 10	-\$0.20 if throw of die is 1 to 10		-\$3.00
2	-\$4.00 if throw of die is 1 -\$3.20 if throw of die is 2 to 10	-\$7.70 if throw of die is 1 -\$0.20 if throw of die is 2 to 10		-\$2.33
3	-\$4.00 if throw of die is 1 or 2 -\$3.20 if throw of die is 3 to 10	-\$7.70 if throw of die is 1 or 2 -\$0.20 if throw of die is 3 to 10		-\$1.66
4	-\$4.00 if throw of die is 1 to 3 -\$3.20 if throw of die is 4 to 10	-\$7.70 if throw of die is 1 to 3 -\$0.20 if throw of die is 4 to 10		-\$0.99
5	-\$4.00 if throw of die is 1 to 4 -\$3.20 if throw of die is 5 to 10	-\$7.70 if throw of die is 1 to 4 -\$0.20 if throw of die is 5 to 10		-\$0.32
6	-\$4.00 if throw of die is 1 to 5 -\$3.20 if throw of die is 6 to 10	-\$7.70 if throw of die is 1 to 5 -\$0.20 if throw of die is 6 to 10		\$0.35
7	-\$4.00 if throw of die is 1 to 6 -\$3.20 if throw of die is 7 to 10	-\$7.70 if throw of die is 1 to 6 -\$0.20 if throw of die is 7 to 10		\$1.02
8	-\$4.00 if throw of die is 1 to 7 -\$3.20 if throw of die is 8 to 10	-\$7.70 if throw of die is 1 to 7 -\$0.20 if throw of die is 8 to 10		\$1.69
9	-\$4.00 if throw of die is 1 to 8 -\$3.20 if throw of die is 9 or 10	-\$7.70 if throw of die is 1 to 8 -\$0.20 if throw of die is 9 or 10		\$2.36
10	-\$4.00 if throw of die is 1 to 9 -\$3.20 if throw of die is 10	-\$7.70 if throw of die is 1 to 9 -\$0.20 if throw of die is 10		\$3.03

In Decision No. 1 of Table 14 the choice is between a gain of \$3.20 (option A) and \$0.20 (option B). A subject respecting dominance should choose option A. Observe that the two payoffs for lotteries under option A have roughly the same magnitude. Thus, this lottery is relatively “safe”. The lower the decision in Table 14, the higher becomes the probability for the best outcome \$4.00 for option A and \$7.70 for option B. The optimal choice of a risk neutral individual is to choose option A for the first five

decisions and then switch to option B for decisions 6 to 10 as the expected value is higher for A than B in the first five decisions, while the expected value for B is higher than A for decisions 6 to 10 (see last column). A sufficiently risk averse individual tends to switch to option B before Decision No. 6, while a sufficiently risk seeking individual switches to option B after Decision No. 6.

The lottery choice task for the gain domain in Table 15 is analogous to Table 14 except that gains are replaced with corresponding losses and thus the signs of differences in expected payoffs of the last column are reversed. A risk neutral individual will start out in Decision No. 1 with option B and switch to option A from Decision No. 6 onward. A sufficiently risk averse individual will switch to option A after choosing option B for more than the first five decisions, while a sufficiently risk seeking individual will switch to option A before Decision No. 6.

## E Instructions for the Auctions

### Introduction

You are about to participate in a decision process in which an imaginary object will be auctioned off for each group of participants in each of 30 rounds. This is part of a study intended to provide insight into certain features of decision processes. If you follow the instructions carefully and make good decisions you may earn a bit of money. You will be paid in cash at the end of the experiment.

*During the experiment, we ask that you please do not talk to each other.* If you have a question, please raise your hand and an experimenter will assist you.

You may refuse to participate in this study. You may change your mind about being in the study and quit after the study has started.

### Procedure

In each of 30 rounds, you will be *randomly* matched with one other participant into a group. Each group has two bidders. You will not know the identity of the other participant in your group. Your payoff each round depends ONLY on the decisions made by you and the other participant in your group.

In each of 30 rounds, each bidder's value for the object will be randomly drawn from 1 of 2 distributions:

**High value distribution:** If a bidder's value is drawn from the high value distribution, then

- with 25% chance it is randomly drawn from the set of integers between 1 and 50, where each integer is equally likely to be drawn.
- with 75% chance it is randomly drawn from the set of integers between 51 and 100, where each integer is equally likely to be drawn.

For example, if you throw a four-sided die, and it shows up 1, your value will be equally likely to take on an integer value between 1 and 50. If it shows up 2, 3 or 4, your value will be equally likely to take on an integer value between 51 and 100.

**Low value distribution:** If a bidder's value is drawn from the low value distribution, then

- with 75% chance it is randomly drawn from the set of integers between 1 and 50, where each integer is equally likely to be drawn.



- with 25% chance it is randomly drawn from the set of integers between 51 and 100, where each integer is equally likely to be drawn.

For example, if you throw a four-sided die, and if it shows up 1, 2 or 3, your value will be equally likely to take on an integer value between 1 and 50. If it shows up 4, your value will be equally likely to take on an integer value between 51 and 100.

Therefore, if your value is drawn from the high value distribution, it can take on any integer value between 1 and 100, but it is three times more likely to take on a higher value, i.e., a value between 51 and 100.

Similarly, if your value is drawn from the low value distribution, it can take on any integer value between 1 and 100, but it is 3 times more likely to take on a lower value, i.e., a value between 1 and 50.

In each of 30 rounds, each bidder's value will be randomly and independently drawn from the high value distribution with 30% chance, and from the low value distribution with 70% chance. You will not be told which distribution your value is drawn from. The other bidders' values might be drawn from a distribution different from your own. In any given round, the chance that your value is drawn from either distribution does not affect how other bidders' values are drawn.

Each round consists of the following stages:

Bidders are informed of their private value, and then each bidder will simultaneously and independently submit a bid, which can be any integer between 1 and 100, inclusive.

The bids are collected in each group and the object is allocated according to the rules of the auction explained in the next section.

Bidders will get the following feedback on their screen: your value, your bid, the winning bid, whether you got the object, and your payoff.

The process continues.

## Rules of the Auction and Payoffs

In each round,

- if your bid is greater than the other bid, you get the object and pay your bid:

$$\mathbf{Your\ Payoff = Your\ Value - Your\ Bid;}$$

- if your bid is less than the other bid, you don't get the object:

$$\mathbf{Your\ Payoff = 0.}$$

- if your bid is equal to the other bid, the computer will break the tie by flipping a fair coin. Such that:

with 50% chance you get the object and pay your bid:

$$\mathbf{Your\ Payoff = Your\ Value - Your\ Bid;}$$

with 50% chance you don't get the object:

**Your Payoff = 0.**

There will be 30 rounds. There will be 2 practice rounds. From the first round, you will be paid for each decision you make.

Your total payoff is the sum of your payoffs in the 30 “real” rounds.

The exchange rate is \$1 for 13 points.

We encourage you to earn as much cash as you can. Are there any questions?

**Review Questions:** Please raise your hand if you have any questions. After 5 minutes we will go through the answers together.

1. Suppose your value is 60 and you bid 62.  
If you get the object, your payoff = .  
If you don't get the object, your payoff = .
2. Suppose your value is 60 and you bid 60.  
If you get the object, your payoff = .  
If you don't get the object, your payoff = .
3. Suppose your value is 60 and you bid 58.  
If you get the object, your payoff = .  
If you don't get the object, your payoff = .
4. In each of 30 rounds, each bidder's value will be randomly and independently drawn from the high value distribution with % chance.
5. Suppose your value is drawn from the low value distribution. With what % chance is the other bidder's valuation also drawn from the low distribution?
6. True or False:  
If a bidder's value is 25, it must have been drawn from the low distribution.  
If a bidder's value is 60, it must have been drawn from the high distribution.  
You will be playing with the same two participants for the entire experiment.  
A bidder's payoff depends only on his/her own bid.

## F Screen Shots

Period: 1 of 1 Remaining time (sec): 25

Your value is **51**.  
Please submit a bid (1 - 100):

Round	Value	Your Bid	Buy?	Payoff	Total Payoff
1	51	23	No	0.0	0.0

Period: 1 of 1

**You did get the item.**

Your value was: **51**

Your bid was: **23**

The winning bid was: **Your bid**

Your profit is: **28**

## G Questionnaire

### **SURVEY (collected on the subject's computer terminal)**

We are interested in whether there is a correlation between participants' bidding behavior and some socio-psychological and biological factors. It is an extremely important part of our research. This information will be strictly confidential.

1. What is your (biological) sex?

- Male
- Female

2. What is your sexual orientation?

- Heterosexual
- Homosexual
- Bisexual
- Transsexual

3. Are you currently in a relationship?

- No
- Married
- Boyfriend/girlfriend

4. How many people did you date within the last year? (drop down menu)

- None
- 1 person
- 2 persons
- 3 persons
- 4 persons
- 5 persons
- 6 persons
- 7 persons
- 8 persons
- 9 persons
- 10 persons
- More than 10 persons

5. Do you have children? (drop down menu)

- No
- 1 child
- 2 children
- 3 children
- 4 children
- More than 4 children

6. What is your ethnic origin? (You may choose several.)
- White
  - Asian/Asian American
  - African American
  - Hispanic/Latino
  - Native American
  - Other
7. What is your age (in years)? \_\_\_\_\_
8. What is your weight (in pounds)? \_\_\_\_\_
9. What is your height (in inches)? \_\_\_\_\_ (*Remark: We helped them to calculate if known only in feet or cm*)
10. How many siblings do you have?  
I have \_\_\_ younger siblings.  
I have \_\_\_ older siblings.
11. How often do you exercise in an average week?
- Never
  - At least once a week
  - At least twice a week
  - At least three times a week
  - Four or more times a week
12. Have you ever broken a finger on your right hand?
- No
  - Yes
13. If yes, was it the pointer or ring finger?
- Yes
  - No
14. Would you describe your personality as (please choose one)
- optimistic
  - pessimistic
  - neither
15. Which of the following emotions did you experience during the experiment?  
(You may choose any number of them.)
- anger
  - anxiety

- confusion
- contentment
- fatigue
- happiness
- irritation
- mood swings
- withdrawal

16. Do you live
- alone
  - with your parents
  - with your partner/boyfriend/girlfriend/spouse
  - with a roommate?

For female participants only:

17. Are you pregnant?
- No
  - Yes
  - May be
18. How many days ago was the first day of your **last** menstrual period? \_\_\_\_\_
19. What is your best guess on how many days until your **next** menstrual cycle? \_\_\_\_\_
20. On average, how many days are there between your menstrual periods?
- less than 25 days
  - 25 days
  - 26 days
  - 27 days
  - 28 days
  - 29 days
  - 30 days
  - 31 days
  - 32 days
  - 33 days
  - 34 days
  - 35 days
  - more than 35 days
21. Do you often experience changes in the length of your menstrual cycle?
- No, it is quite regular and almost always takes the same number of days.
  - The length is irregular.

22. Do you keep a menstrual cycle calendar?
- Yes
  - No
23. Do you usually experience any symptoms of PMS? (please choose one)
- None
  - Mild**
  - Severe
24. Are you currently experiencing any symptoms of PMS (please choose one)
- None
  - Mild
  - Severe
25. Do you currently use a hormone-based contraceptive (birth control pill, IUD, contraceptive patch [OrthoEvra], vaginal ring [Nuvaring], Norplant, IUS, injection [DepoProvera, Lunelle], etc.)?
- Yes
  - No
26. If yes, what type? \_\_\_\_\_

For all participants:

27. Do you smoke?
- Daily
  - Occasionally
  - Never
28. Do you regularly take dietary supplements that help you perform better in sports?
- No
  - Yes
29. If yes, what type? \_\_\_\_\_
30. Are you vegetarian or vegan?
- No
  - Yes
31. Do you regularly eat soybean-based food like tofu, soymilk etc.?
- Not at all
  - Not very often
  - Yes, daily

- Yes, several times a week
32. When did you have lunch today?
- I skipped lunch
  - 11.00 am
  - 12.00 pm
  - 1.00 pm
  - 2.00 pm
  - 3.00 pm
33. Before arriving at the experiment, how long has it been since you last ate?
- 30 min
  - 1 hour
  - 2 hours
  - 3 hours
  - 4 hours
  - More than 4 hours ago
34. What did you eat last? \_\_\_\_\_
35. Did you drink coffee/tee/other drinks in the past two hours before arriving at the experiment?
- Yes, within 30 min before the experiment
  - Yes, within 1 hour before the experiment
  - Yes, within 1.5 hours before the experiment
  - Yes, within 2 hours before the experiment
36. What did you drink last? \_\_\_\_\_
37. Do you currently have any small injuries in your mouth or gums (cuts, sores, bleeding)?
- Yes
  - No
38. How many times a day do you brush your teeth?
- Never
  - Once a day
  - Twice a day
  - Three times a day
  - More than three times a day
39. When was the last time you brushed your teeth?
- 30 minutes ago
  - 1 hours ago



- 2 hours ago
  - 3 hours ago
  - More than 3 hours ago
40. What was your SAT score? \_\_\_\_\_
41. What is your major field of study?
- Economics
  - Mathematics
  - Other Social Science
  - English
  - Other Arts/Humanities
  - Chemistry/Biology/Physics
  - Other Natural Science
  - Engineering
42. What is your current GPA? \_\_\_\_\_
43. If you are student, how many quarters have you completed? \_\_\_\_\_

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