Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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To cite this article:
Burkhard C. Schipper (2015) Sex Hormones and Competitive Bidding. Management Science 61(2):249-266. http://dx.doi.org/10.1287/mnsc.2014.1959

MANAGEMENT SCIENCE
Vol. 61, No. 2, February 2015, pp. 249–266
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2014.1959

Sex Hormones and Competitive Bidding

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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.

Data, as supplemental material, are available at http://dx.doi.org/10.1287/mnsc.2014.1959.

Keywords: hormones; steroids; testosterone; estradiol; progesterone; cortisol; contraceptives; auctions; gender; competition; aggression; risk taking; endocrinological economics

History: Received May 1, 2012; accepted February 18, 2014, by Uri Gneezy, behavioral economics. Published online in *Articles in Advance* October 3, 2014.

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, Federal Communications Commission 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 bid.

There is independently replicated experimental evidence that, on average, women bid higher and earn lower profits than men in first-price auctions (Casari et al. 2007, Ham and Kagel 2006, Chen et al. 2013, Pearson and Schipper 2013).[1] 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 et al. (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 et al. (2013) report that women bid higher than men in *all* phases of their menstrual cycle, whereas 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 of estradiol, another sex hormone. To sum up, the existing evidence suggests that biological mechanisms such as sex hormones underlie some of the variations in bidding and profits observed in auctions. But the evidence is far from conclusive.

[1] More generally, gender differences have been demonstrated in a number of economically relevant domains, including investment (e.g., Barber and Odean 2011) and the labor market (for a review, see Blau and Kahn 2000). 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 (for surveys, see Croson and Gneezy 2009; Eckel and Grossman 2008a, b; Byrnes et al. 1999; Niederle and Vesterlund 2011). The biological mechanisms underlying many of the gender differences are still not understood.

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 to be positively correlated with "aggression" (see Archer 1991, Dabbs and Hargrove 1997, Mazur and Booth 1998, Mehta and Josephs 2006), which may be another channel through which basal testosterone affects bidding in auctions (see §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, or 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. To control for risk aversion, we measure risk preferences for gains and losses with a lottery choice task introduced by 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).[2] 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 4:00 P.M. 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 Supplementary Appendix A.2[3]) and a Styrofoam cup that contained a 4.5 ml sterile Nunc® CryoTube® vial. The cup functioned simply as a container to prevent the vial from

[2] 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 by 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.

[3] The supplementary appendix to this paper is provided as supplemental material at http://dx.doi.org/10.1287/mnsc.2014.1959.

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® Original Flavor—to stimulate saliva (see Dabbs 1991) as well as a sterilized plastic straw through which to drool about 2.5 ml of 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 Supplementary Appendix A.

2. *Holt–Laury Lottery Task*: Subjects received written instructions on the Holt–Laury lottery task (see Supplementary Appendix D). Each subject had five minutes to read the instructions. Then the experimenter 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.[4] 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 are used to control for risk aversion in the analysis of auction behavior.

3. *Auction Game*: Each subject received printed instructions for the auction game (see Supplementary Appendix E). Subjects were given five to seven 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 Supplementary 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 et al. (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 $\{1, 2, \ldots, 100\}$. The respective densities, l and h, are given by[5]

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

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

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

Each session consisted of eight subjects who were randomly rematched after each round. Subjects played 2 practice rounds that did not count for the final payoff, and then 30 "real" rounds.

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, and each subject was reminded of his valuation and bid, and informed whose bid was the winning bid, whether he received the object, and of his total payoff accumulated so far. (See Supplementary Appendix F for screenshots.)

4. *Questionnaire*: After the auction task, subjects completed a computerized questionnaire (see Supplementary Appendix G). This questionnaire elicited demographic information, menstrual cycle information, information relevant for assessing the quality of saliva, and 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, and race, such as the use of hormonal contraceptives, pregnancy, menstrual cycle phases, etc., may be correlated with salivary hormone levels. See Supplementary 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

[4] Laury and Holt (2008, p. 9) claim that the order of these tasks does 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.

[5] The main reason for choosing this process of drawing values (as opposed to uniform distribution) is to be able to replicate Chen et al. (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 et al. 2007).

tasks were played out in front of the subjects. For each subject, a 10-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 second and fourth fingers 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 (for similar examples, see Schultheiss et al. 2005, Kivlighan et al. 2005, Edwards and O'Neal 2009, Saad and Vongas 2009).

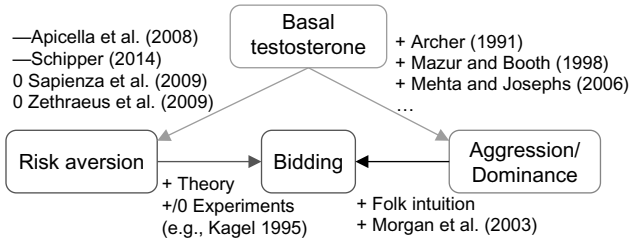
8. *Payment*: At the end of the experiment, subjects received, in private, their total cash payment from the show up fee, the auction task, and the lottery tasks. The average total earning was US$19.03 with a maximum of US$48.39 and a minimum of US$5.00. The entire procedure took about 1 hour and 20–30 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.[6] 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 (2014) 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 (2014) 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, Chap. 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.[7] Although the experimental evidence for risk aversion in first-price auctions with symmetric independent private values is at best mixed (for a survey, see 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.

Figure 1 Two Hypotheses on Basal Testosterone



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). 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

[6] We stress that the hypotheses outlined in this section were devised before the data were collected. We will introduce additional post hoc hypotheses in §5.

[7] We would like to point out, though, that various dispositions toward 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.

bidding and profits in first-price auctions, folk intuition suggests that bidding "more aggressively" 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.

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.[8] 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 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.

[8] In a companion study, Schipper (2014) found that cortisol in females is positively correlated with risk aversion, but the relationship is just marginally significant.

3.2. Hormone Responses

The second saliva samples collected after the behavioral task allow 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 the study by Jimenez et al. (2012), which shows a similar effect for both sexes, and that by Stanton et al. (2009), which shows 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 either 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 the study by 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 Supplementary Appendix A.6).

3.3. Statistical Approach

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

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

Table 1 Basal Salivary Hormones by Gender and Hormonal Contraceptive Use

	Naturally cycling females		Females using contraceptives		Male	
Salivary hormone	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

where $b_{i,t}$ is the bid of subject i at bidding period $t = 1, \ldots, 30$; β_0 is a constant; $v_{i,t}$ is the value[9] 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 et al. (2007), we control to some extent for learning by regressing on $\ell_t = 1/\ln(t+1)$. This term decreases nonlinearly in the number of bidding rounds.[10] The variable 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. Finally, $\varepsilon_{i,t}$ 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 the possibly degraded quality of saliva samples in earlier sessions 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, pp. 703–705).

Analogous to Equation (1), we estimate a model for total dollar profits (summed over all 30 time periods) in which we drop ℓ_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 the 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 (for a study of clustering in small samples, see Cameron et al. 2008,). 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 nonnormality.

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 provided in the supplemental material posted at http://dx.doi.org/10.1287/mnsc.2014.1959.

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 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 not only report 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 $\alpha/4 = 1.25\%$ (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 picograms per milliliter, whereas others, like progesterone or cortisol, are measured in nanomole per liter. Moreover, we see in Table 1 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 each basal hormone close to its mean and dividing that by its standard deviation. There are two caveats. First, because sex hormones differ by gender, this normalization could affect

[9] 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 et al. 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.

[10] 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.

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 ordinary least squares (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 data sets and Stata do-file that reproduce the entire analysis reported here and additional analysis are available in the supplemental material.

Table 2 presents the demographics of the data as elicited with the questionnaire (see Supplementary Appendix G).[11] We had 208 subjects in sessions of 8 subjects each. Out of the 208 subjects, 93 (45%) were female. Most of the subjects were Asian Americans (55%), followed by whites (38%).[12] 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 excluded 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 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	

Table 3 Gender and Hormonal Contraceptives

	(Bids1)	(Profits1)	(Bids2)	(Profits2)
Female	2.5173***	−4.2932***	1.7045**	−3.2075***
	(0.6955)	(0.9475)	(0.7128)	(1.0139)
Contraceptives			3.6679***	−5.0882**
			(1.1994)	(2.0759)
Demographics, majors, and GPA	Yes	Yes	Yes	Yes
Number of observations	6,060	202	6,060	202
R^2	0.8558	0.2599	0.8578	0.2873

Notes. Robust standard errors (clustered at the session level) are in parentheses. Coefficients of cubic polynomial in values and learning (bids), and the mean, standard deviation, and skewness of values drawn (profits) are not reported.
**Significant at the 5% level; ***significant at the 1% level.

Table 3 shows that we replicate gender differences in first-price auctions in the literature (see Casari et al. 2007, Ham and Kagel 2006, Chen et al. 2013, 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 et al. (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 study, GPA, and demographics. This difference is substantial since it is more than 28% of average total profits made in the auction in our sample.[13]

We also confirm the correlation with hormonal contraceptives observed by Pearson and Schipper (2013), here for a subsample of theirs. Women who use hormonal contraceptives bid on average 3.7 points higher

[11] 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.

[12] For comparison, the distribution of races among all University of California, Davis students is 42% white, 38% Asian, 3% black, 14% Hispanic, and 3% other (Budget & Institutional Analysis 2014). We do not know why we have a larger fraction of Asians in our sample. It could be that relatively more Asians are enrolled in majors that we reached with our advertisement. In particular, about 59% of economics students at University of California, Davis are Asian.

[13] Average earnings in the sample were \$15.02 for the auction game alone.

than white males ($p = 0.005$; specification (Bids2) in Table 3) 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 because it amounts to more than 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.

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 1 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 the supplementary 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 Supplementary 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 equilibrium bids.[14]

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.

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 that for 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 (specification (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 the previous round's profits in the specification for bids.[15] 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 using hormonal contraceptives (specifications

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

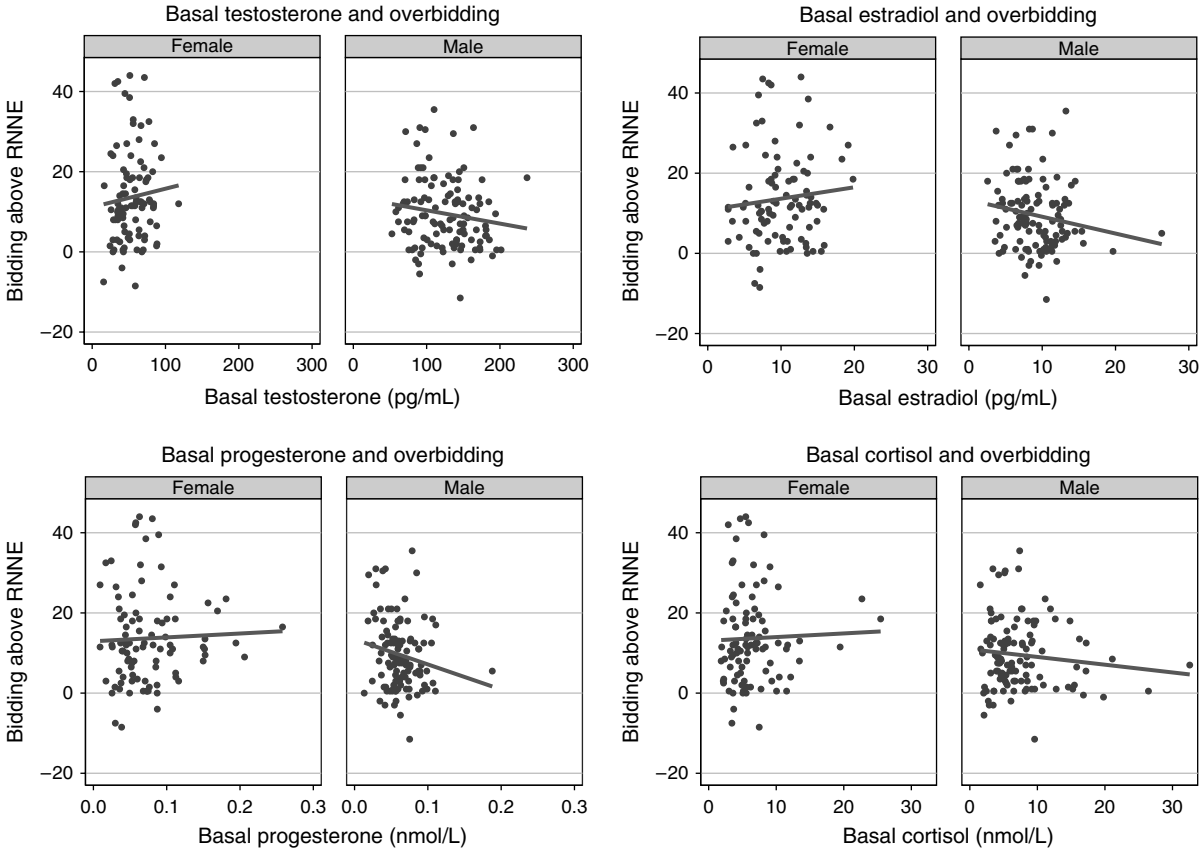
	(Bids3)	(Profits3)
Testosterone	0.0840	−0.3432
	(0.4055)	(0.6275)
Estradiol	−0.2711	−0.0401
	(0.3611)	(0.6439)
Progesterone	0.1275	−0.4749
	(0.3546)	(0.5623)
Cortisol	0.4135	−0.7438
	(0.4185)	(0.6886)
Demographics, majors, and GPA	Yes	Yes
Number of observations	3,330	111
R^2	0.8687	0.2862

Notes. Robust standard errors (clustered at the session level) are in parentheses. Coefficients of cubic polynomial in values and learning (bids), and the mean, standard deviation, and skewness of values drawn (profits) are not reported.

[14] In Nash equilibrium, a risk-neutral bidder would bid 1/2 of his value. Using overbidding relative to risk-neutral Nash equilibrium in Figure 2 allows us to present bids, values, and hormones in two-dimensional graphs.

[15] We do not 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.

Figure 2 Overbidding and Basal Salivary Hormones by Gender



Note. RNNE, risk-neutral Nash equilibrium.

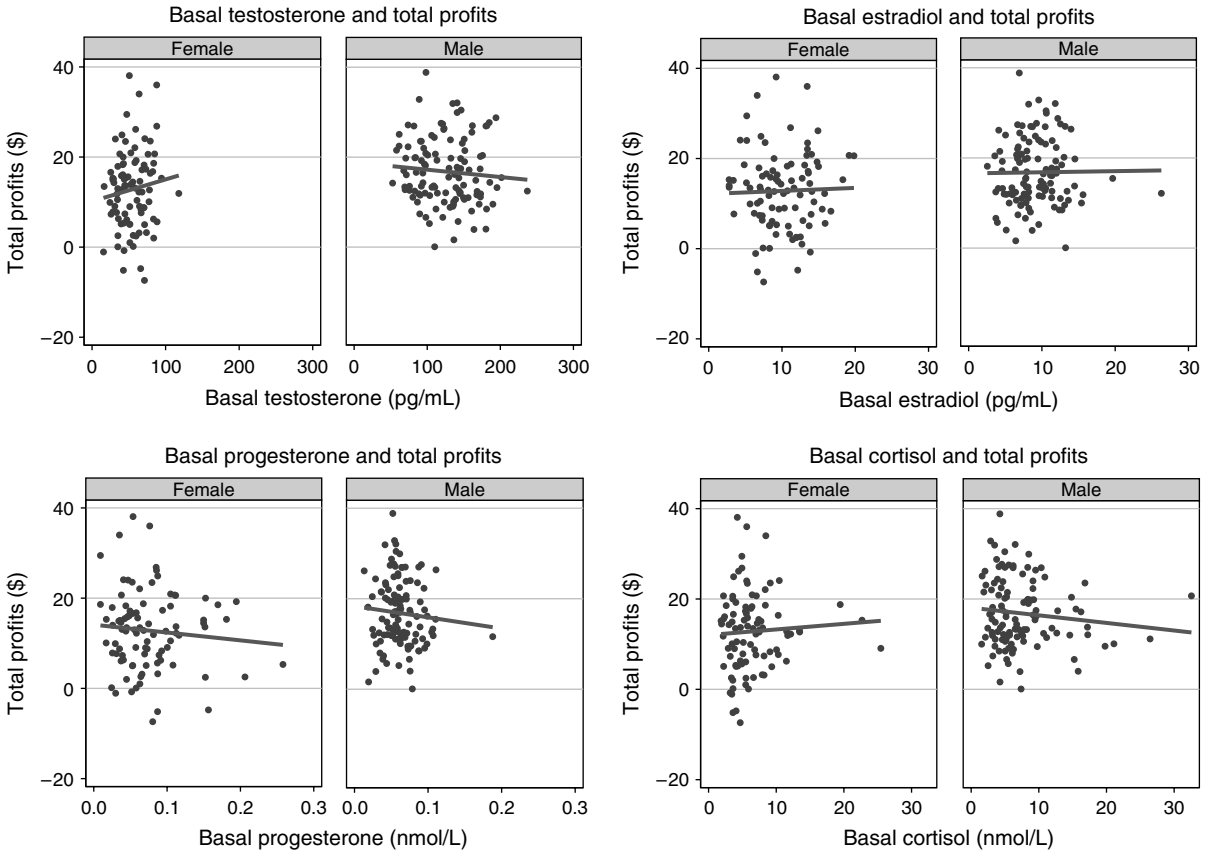
Table 5 Basal Salivary Hormones, Bidding, and Profits for Females

	(Bids4)	(Profits4)	(Bids5)	(Profits5)
Testosterone	−0.5108	1.0281	2.9181	−3.8861
	(0.7763)	(1.1357)	(2.0404)	(3.7491)
Estradiol	0.0197	−0.2384	−2.4265*	4.5979*
	(0.6105)	(1.0437)	(1.3358)	(2.5967)
Progesterone	1.4313**	−1.6442*	−0.1113	−0.3814
	(0.5533)	(0.8322)	(2.8049)	(4.8301)
Cortisol	0.3703	0.1171	0.2091	−0.3901
	(0.4278)	(0.8282)	(1.3566)	(2.2486)
Contraceptives	5.4246***	−6.4417*		
	(1.6937)	(3.4554)		
Naturally cycling			−5.4246***	6.4417*
			(1.6937)	(3.4554)
Hormones × Contraceptives	Yes	Yes	No	No
Hormones × Naturally cycling	No	No	Yes	Yes
Demographics, majors, and GPA	Yes	Yes	Yes	Yes
Number of observations	2,670	89	2,670	89
R^2	0.8563	0.3656	0.8563	0.3656

Notes. Robust standard errors (clustered at the session level) are in parentheses. Coefficients of cubic polynomial in values and learning (bids), and the mean, standard deviation, and skewness of values drawn (profits) are not reported.
*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

(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 an decrease of 1.64 dollars ($p = 0.059$) in profits, controlling for demographics, major of study, and GPA. We find this economically significant because 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 the Bonferroni correction. The association between bidding and progesterone is qualitatively robust to dropping demographic variables and major of study ($\beta = 1.113$, $p = 0.063$), 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

Figure 3 Total Profits and Basal Salivary Hormones by Gender



if we focus on the subsample of Asian naturally cycling females.[16]

Specifications (Bids5) and (Profits5) of Table 5 are analogous, but for females using hormonal contraceptives (i.e., when the dummy for *naturally cycling* takes 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 because it becomes insignificant when dropping demographics and major of study or when using the between estimator in the bid specification. It is clearly insignificant when adjusting for multiple testing using the 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 §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 were 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 (2008), respectively.

[16] 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.

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 nonconscious needs to have close, friendly relationships with others (Schultheiss et al. 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 Supplementary 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, and 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., less often) than group Y.[17]

Not all subjects may display a unique cutoff 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 1; see Tables 14 and 15 in Supplementary Appendix D). The information obtained from subjects who switch several times or choose the dominated option is limited. That is why we call those subjects' risk preferences inaccessible and will focus the analysis on subjects with accessible risk preferences by including appropriate interactions between our measure of risk aversion and a dummy indicating the inaccessibility of risk preferences. In our sample, 178 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 (2014). 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 a control in the analysis of bidding and profits in the auctions.

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. Specification (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 study ($\beta = 1.213$, $p = 0.066$), 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

Table 6 Risk Aversion and Basal Progesterone

	(Bids6)	(Profits6)
Testosterone	−0.9764	1.6170
	(0.7874)	(1.3750)
Estradiol	0.4041	−0.7922
	(0.6312)	(1.1894)
Progesterone	1.4493**	−1.6458*
	(0.6046)	(0.8874)
Cortisol	0.1290	0.2886
	(0.4864)	(1.1267)
Contraceptives	6.1707***	−7.5755**
	(1.6852)	(3.6435)
Risk aversion gains	0.9243*	−1.0613
	(0.4813)	(0.9427)
Risk aversion losses	0.7052	−0.9310
	(0.4754)	(0.9659)
Hormones × Contraceptives	Yes	Yes
Risk preferences inaccessible	Yes	Yes
Risk aversion × Inaccessible preferences	Yes	Yes
Demographics, majors, and GPA	Yes	Yes
Number of observations	2,670	89
R^2	0.8626	0.4299

Notes. Robust standard errors (clustered at the session level) are in parentheses. Coefficients of cubic polynomial in values and learning (bids), and the mean, standard deviation, and skewness of values drawn (profits) are not reported.
*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

[17] 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 as a potential mediator. Further evidence for this claim is provided by 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.

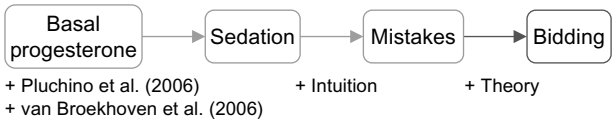
5.2. Does Basal Progesterone Affect Bidding Through Mistakes?

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 Broekhoven et al. 2006).[18] 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 5 presents some preliminary evidence for this hypothesis. The left panel shows a scatter plot of bids above value by gender. The circle-shaped dots indicate bids by females, whereas the triangle-shaped dots indicate bids by males. The x-axis indicates the value for the object, whereas 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 circles above the 45° line than triangles, suggesting that more females use weakly dominated bids than males. In our sample, 23 of 93 females (25%) play a weakly dominated bid at some point during the auction, whereas only 20 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.

[18] We thank Coren Apicella (private communication) for drawing our attention to the connection between progesterone and $GABA_A$.

Figure 4 A Hypothesis for Basal Progesterone



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. Furthermore, 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) reveal 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

Table 7 Basal Progesterone and Mistakes

	(Bids7)	(WD)	(Bids8)
Testosterone	−0.2776	−0.2802	−0.4116
	(0.6873)	(0.2024)	(0.6993)
Estradiol	−0.0421	0.0708	0.0089
	(0.4678)	(0.1645)	(0.4896)
Progesterone	1.1011**	0.1081	1.3534***
	(0.4143)	(0.1424)	(0.4675)
Cortisol	0.6227	−0.3198*	0.5851
	(0.4145)	(0.1938)	(0.4097)
Contraceptives	4.6079***	0.0008	4.2937***
	(1.3346)	(0.2740)	(1.3304)
Weakly dominated bid	20.6809***		17.7756***
	(2.5726)		(2.2053)
Contraceptives × *Weakly dominated bid*			−9.5404**
			(3.5858)
Hormones × *Contraceptives*	Yes	Yes	Yes
Hormones × *Weakly dominated bid*	No	No	Yes
Hormones × *Contraceptives* × *Weakly dominated bid*	No	No	Yes
Demographics, majors, and GPA	Yes	Yes	Yes
Number of observations	2,670	2,670	2,670
R^2	0.8807		0.8840

Notes. Robust standard errors (clustered at the session level) are in parentheses. Coefficients of cubic polynomial in values and learning are not reported.

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

Figure 5 Bids Above Value and Profits by Gender

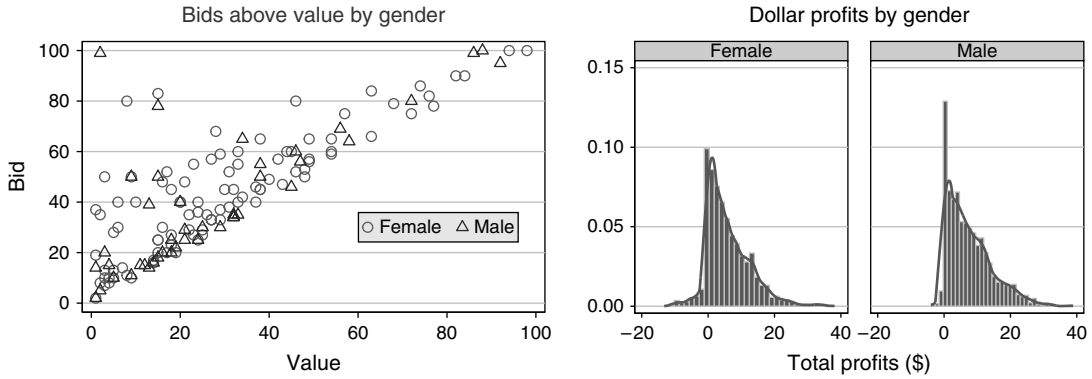


Table 8 Ex Post Salivary Hormones by Gender and Hormonal Contraceptive Use

	Naturally cycling females		Females using contraceptives		Male	
Salivary hormone	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

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, because 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, whereas in others cortisol declines over the duration of the experiment. The question now becomes what pushed cortisol up for some male subjects.

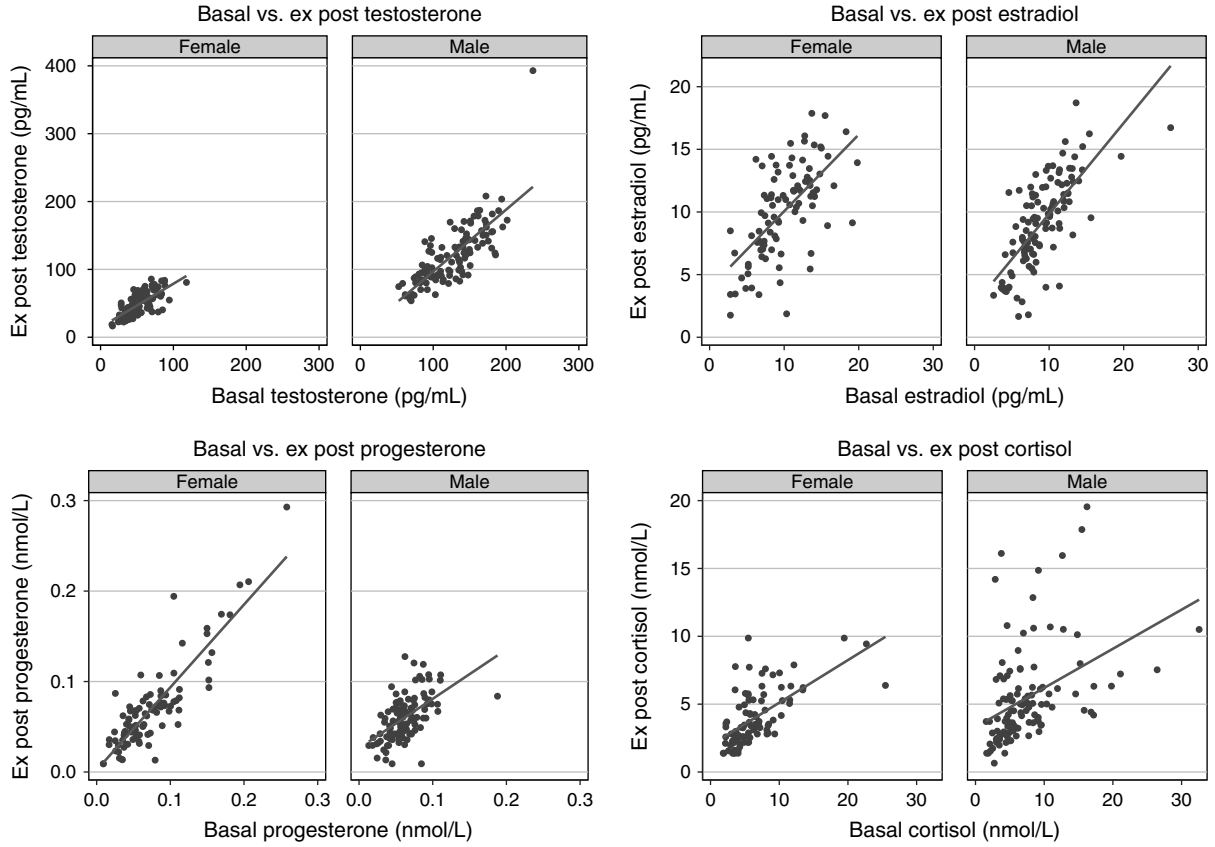
Recall that we hypothesize a positive association between hormone response and total profits, both for testosterone and cortisol. We had no hypotheses on estradiol and progesterone responses. To follow up on the hypotheses, we compute for each subject and hormone the *relative hormone response* as the 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 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 using hormonal

Table 9 Response of Testosterone by Gender and Use of Contraceptives

	(TMale)	(TNCFemale)	(TPill)
Total profit in U.S. dollars	0.0011	−0.0010	−0.0024
	(0.0020)	(0.0029)	(0.0077)
Contraceptives		0.0969	
		(0.1190)	
Naturally cycling			−0.0969
			(0.1190)
Total profit × Contraceptives		−0.0014	
		(0.0086)	
Total profit × Naturally cycling			0.0014
			(0.0086)
Demographics, majors, and GPA	Yes	Yes	Yes
Number of observations	111	89	89
R^2	0.0629	0.1086	0.1086

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

Figure 6 Basal vs. Ex Post Salivary Hormones



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 increases cortisol in males by almost 3% on average when controlling for demographics, major of study, and GPA. Although 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 U.S. dollars	0.0278**	0.0049	0.0057
	(0.0116)	(0.0044)	(0.0067)
Contraceptives		0.1523	
		(0.1102)	
Naturally cycling			−0.1523
			(0.1102)
Total profit × Contraceptives		0.0008	
		(0.0080)	
Total profit × Naturally cycling			−0.0008
			(0.0080)
Demographics, majors, and GPA	Yes	Yes	Yes
Number of observations	110	89	89
R^2	0.1973	0.1568	0.1568

Note. Robust standard errors (clustered at the session level) are in parentheses.
**Significant at the 5% level.

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).[19]

[19] 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.

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 aggression 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 et al. 2007, Ham and Kagel 2006, Chen et al. 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 there is a literature on gender differences in risk aversion (for surveys, see Croson and Gneezy 2009, Eckel and Grossman 2008a, Byrnes et al. 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 (for related evidence, see Deck et al. 2013). Thus, our irrelevance claim should be read with caution because measurement error in the elicitation of risk preferences may likely attenuate any relationship (for a discussion, see Beauchamp et al. 2012). Moreover, we speculate that attitudes toward 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 et al. 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 Broekhoven 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 Supplementary Appendix C we show that this is not the case. We observe that the number of rounds till a subject learns to chose undominated bids is not significantly correlated with basal progesterone. Moreover, basal progesterone is significantly positively associated with bids in both 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. 2008, 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 privately known

only to the subjects themselves. The private profits may not constitute a sufficiently strong stimulus for a testosterone burst. This is somewhat similar to the null finding of Mazur et al. (1997), who also suspected that the absence of a significant testosterone increase in winners of a video game contest may have been 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 et al. (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 in the manner of Gneezy et al. (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 et al. (2004, 2005) for the trust game, Sanchez-Pages and Turiegano (2010) 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 eight 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), and Zak et al. (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 furthering our understanding of how hormones effect economic behavior requires both careful correlation studies and placebo-controlled experiments. To establish causalities with placebo-controlled studies, it is necessary to know whether exogenously administered hormones actually act similarly 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.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2014.1959.

Acknowledgments

The author thanks Michel Grosz, Gabriel Mathy, Wen Yong Tang, and Nick Zolas for excellent research assistance. Moreover, he thanks Coren Apicella, David Cesarini, Anna Dreber, Nikolaos Georgantzis, and Gabriel Mathy, as well as audiences at New York University, Hong Kong University of Science and Technology, the University of Heidelberg, the 2013 Xiamen University International Workshop on Experimental Economics, the conference on "New Challenges for Economic Decision-Making: Biology, Neuroscience, and Economic Models" at the University of Southern California 2011, and the MOVE Workshop on Gender Differences in Competitiveness and Risk Aversion, Barcelona 2010, for helpful comments. Financial support through the University of California, Davis Hellman Fellowship is gratefully acknowledged.

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