



Social status strategy in early adolescent girls: Testosterone and value-based decision making



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ABSTRACT

There has been strong interest, spanning several disciplines, in understanding adolescence as a developmental period of increased risk-taking behavior. Our goals focus on one line of investigation within this larger developmental risk framework. Specifically, we examined levels of pubertal hormones in girls in relation to their willingness to take greater financial risks to gain social status. To this end, we tested the hypothesis that higher levels of testosterone during the ages of pubertal maturation are associated with a greater willingness to sacrifice money for social admiration. Sixty-three girls ages 10–14 ($M_{age} = 12.74$) participated in laboratory measures and completed at-home saliva sample collection. The Pubertal Development Scale (PDS) and basal hormone levels (testosterone, estradiol, DHEA) measured pubertal maturation. We made use of a developmentally appropriate version of an Auction Task in which adolescents could take financial risks in order to gain socially motivated outcomes (social status). PDS and testosterone were each associated with overall levels of financial risk taking over the course of the Auction Task. In hierarchical models, PDS and testosterone were predictors of the slope of overbidding over the course of the task. Results provide evidence for the role of testosterone and pubertal maturation in girls' motivations to engage in costly decision making in order to gain social status. Findings contribute to our understanding of the developmental underpinnings of some interesting aspects of adolescent risk behavior.

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1. Introduction

Puberty – the transition from childhood into adolescence – has been identified as a key maturational window of increased risk taking (Collado et al., 2014; Spielberg et al., 2014). Although several interacting theories seek to explain the ways in which pubertal development contributes to risk behavior, research in this area is in its early stages. One promising perspective highlights the hor-

monally influenced motivational underpinnings that contribute to the emergence of bold and risky behavior at this time of transition (e.g., Steinberg 2008). In particular, increases in testosterone associated with pubertal development, appear to predict an increased appetite for exciting affective experiences and an increased valuing of social admiration, which may interact with still-developing cognitive control systems in ways that can contribute to risk taking (Braams et al., 2015; Crone and Dahl, 2012).

During this developmental period of increased pubertal hormones, the salience of social status becomes more significant than at any other point in the life course (Gardner and Steinberg, 2005). A range of laboratory tasks, primarily focused on adults, has been used to explore the association between testosterone and deviations from purely rational strategic decision making. In particular, this research has demonstrated that higher testosterone levels in adults are associated with an individual's likelihood to prioritize increases in social status over increases in financial gain (van den

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Bos et al., 2013). In fact, the greater the salience of the opportunity to gain social status, the greater the deviations from strategic financial decision making that occur. For adolescents, this finding suggests that increasing social status may become more salient, rewarding, and strategic than prioritizing financial gains.

1.1. Puberty and risk taking

Neurodevelopmental changes occurring at puberty, including increased levels of gonadal hormones and dopaminergic reorganization, are thought to be strongly related to increases in risk taking in adolescence (Collado et al., 2014; Peper and Dahl, 2013). These hormonal and neural changes influence arousal, motivation, and emotion, resulting in a developmental period of particular vulnerability to sensation seeking and risk-taking behaviors (Forbes and Dahl, 2012).

Although the specific paths through which pubertal changes may affect risk taking have not been delineated, it is known that testosterone significantly influences dopaminergic neural transmission in the adolescent brain (Purves-Tyson et al., 2014; Sinclair et al., 2014). This has contributed to a wide range of theories, often conflicting, about how this development contributes to risk behavior. One hypothesis is that dopaminergic changes in the striatum and prefrontal cortex may increase reward sensitivity (Purves-Tyson et al., 2014; Sinclair et al., 2014). A contrasting hypothesis is that such changes may result in a “reward deficiency syndrome” (Forbes and Dahl, 2010; Steinberg 2008). Yet another line of investigation has focused on reward prediction errors as underlying these maturational changes (Cohen et al., 2010). Despite uncertainty in the specific mechanisms, these changes appear to increase sensation-seeking propensity and subsequently contribute to greater tendencies toward exploration and risk taking, especially in the presence of peers (Steinberg 2008). Indeed, reward-seeking behavior increases broadly at puberty (Braams et al., 2015; Spielberg et al., 2014) and this type of sensation seeking is tied to risk-taking behavior in children, adolescents, and adults (Chein et al., 2011). Still, despite key advances, the developmental underpinnings of adolescent risk taking associated with hormonal maturation have not been thoroughly explored.

1.2. Testosterone and social status

Although a growing body evidence suggests that increased social valuation in adolescence is linked to pubertal maturation, the specific hormonal changes that may underlie this reorientation to peers are not well understood. One proposed mechanism is the pubertal surge in testosterone in both boys and girls, which may amplify the motivational salience of social status and predict behavior that is consistent with the values of a particular context (Braams et al., 2015; Crone and Dahl, 2012). Testosterone predicts motivated dominance behavior in non-human and human primates, including both subtle behaviors (e.g. staring duration) and social forms of aggression (Eisenegger et al., 2011; van Honk et al., 2014). Indeed, testosterone levels correlate with risk taking and dominance in adolescents and adults (Apicella et al., 2014; Peper et al., 2013; van den Bos et al., 2013), and testosterone levels both predict and are modulated by social interactions (Eisenegger et al., 2011). In addition, to maintain high social status, sensitivity to social threat and dominance-challenging events is crucial, and evidence suggests that testosterone or its metabolite estradiol may increase reactivity to such threats (Carré et al., 2014; Eisenegger et al., 2011), possibly by inducing functional orbital frontal cortex (OFC) and amygdala decoupling (van Wingen et al., 2010).

Some evidence suggests that socially motivated behavior tied to testosterone occurs outside of awareness (Terburg et al., 2012) and may affect the relative value of differing behavioral approaches

even in the absence of consciously experienced motivational states. Given the importance of social status in adolescence as well as the clear connections between testosterone and socially motivated behavior, the focus herein is on the ways in which pubertal maturation may contribute to an overvaluation of the affective experience of social status at the expense of purely strategic behavior (that maximizes monetary gains).

1.3. The current project

We address some of the gaps in the adolescent risk-taking literature by directly investigating the developmental underpinnings of risk-taking propensities in girls. The goal is to measure, in a controlled environment, some of the first tendencies toward risk behavior that emerge in early adolescence and may interact with contextual factors to predict real-world risk taking. Specifically, we examine the association between pubertal maturation and socio-affectively motivated behavior, hypothesizing that higher levels of testosterone would be associated with increased willingness to pay (sacrifice financial gain) on the Auction Task, as well as more persistent financial risk-taking over the course of the task, as a reflection of adolescents prioritizing social status over financial gain.

2. Methods

2.1. Participants

Sixty-three developmentally normative preadolescent and adolescent girls ages 10–14 ($M = 12.74$; $SD = 1.09$), were primarily recruited via IRB-approved advertisements posted on online classified sites and in community centers, libraries, schools, and camps. Because participants also referred friends, snowball sampling was also used. The sample was ethnically diverse (52.4% White; 22.2% Mixed race/ethnicity; 11.1% Black/African American; 7.9% Hispanic/Latino; 4.8% Asian; 1.6% Other). Although participants tended to represent high socioeconomic status (mean SES Community Ladder = 6.83; 0–10 scale), our sample included families who received public assistance as well as those at intermediate income levels.

Participants had to meet age and gender criteria and be fluent in English. Exclusion criteria included hearing/vision difficulties that would interfere with their ability to complete tasks, evidence of intellectual disability, and use of medication that has shown to alter concentrations of sex steroids within 24 h of morning saliva sample collection. In addition, the Child Behavior Checklist (CBCL) (Achenbach and Rescorla, 2001), completed by each participant's parent, was used to assess for severe attention or thought problems that appeared to influence task performance. Participants with elevated scores on other CBCL syndrome/problem scales were included in this study in order to avoid the creation of a “supernormal” sample (Kendler, 1990).

2.2. Procedure

The procedure consisted of one laboratory visit and at-home salivary sample collection; it was fully approved by UC Berkeley's Committee for Protection of Human Subjects.

2.3. Laboratory visit

Parents consented and youth assented to participating in the study. Then, each youth participant completed a series of questionnaires and tasks, administered by a graduate student, postdoctoral fellow, or research assistant. Each parent also completed the Child Behavior Checklist (Achenbach and Rescorla, 2001), the MacArthur Scale of Subjective Social Status (Adler et al., 2000), and questions

regarding objective socioeconomic status. Participants were compensated \$20 for the 90 min laboratory visit, along with a small “prize” valued up to \$10 based on their performance on the Auction Task.

2.4. Salivary sample collection

Participants practiced collecting saliva samples during their lab visit and went home with detailed collection instructions and a brief diary to fill out after each at-home collection. Participants collected two basal samples (~1 ml) on two separate mornings, between seven and nine o'clock in the morning, in 2 ml cryovials by passive drool using a two-inch straw. Participants were instructed to rinse out their mouth with water 10 min before collecting each sample and were asked not to brush their teeth within one hour of saliva collection, take anything to produce saliva, eat a major meal or anything acidic or sugary within one hour of saliva collection, or eat anything at all within twenty minutes before saliva collection.

With parental support as needed, participants filled out brief diary entries after each morning collection, to verify that the samples were collected at the appropriate time of day and under acceptable circumstances. Participants kept the samples in their home freezer until the time that they delivered the frozen samples to the laboratory. Parents were asked to return the samples and diary entries in person and were compensated an additional \$20 gift card payment for doing so. If requested, reminder calls or texts were made in order to increase compliance. In the lab, saliva samples were labeled with the participant's ID number and stored in a -20° C laboratory freezer and moved in regular intervals into -80° C freezer storage until they were analyzed.

2.5. Measures

2.5.1. Pubertal development scale (PDS)

We used the Pubertal Development Scale (PDS) (Petersen et al., 1988) to determine pubertal stage, a commonly used measure in the literature. The PDS is a self-report measure consisting of five items for girls, pertaining to the development of body hair, changes in complexion, the occurrence of a growth spurt, breast development, and the onset of menarche. All questions except the one concerning menarche (a dichotomy) are answered using a four-point scale. The PDS yields a gonadal score (growth spurt, breast development, and menarche) and an adrenal score (pubic/body hair and complexion changes); it can also be used to assign pubertal stages (Shirtcliff et al., 2009). The PDS was chosen because of its non-invasive nature, ease of completion, and good reliability and validity (Petersen et al., 1988; Shirtcliff et al., 2009). In this investigation, a mean PDS score was utilized as a measure of general pubertal maturation.

2.6. Hormone samples

Two morning saliva samples were assayed to determine testosterone, estradiol, and DHEA levels. Each saliva sample was thawed and assayed within 24 h in duplicate using well-established highly sensitive enzyme immunoassay kits (www.salimetrics.com). The average coefficient of variation (CV) based on hormone concentration was 8% for testosterone, 9% for DHEA, and 12% for estradiol. The two basal samples for each hormone were averaged to determine a mean basal testosterone level for each participant.

2.7. Airport Auction Task

The computerized Auction Task (van den Bos et al., 2008; van den Bos et al., 2013) was originally used to assess the relationship

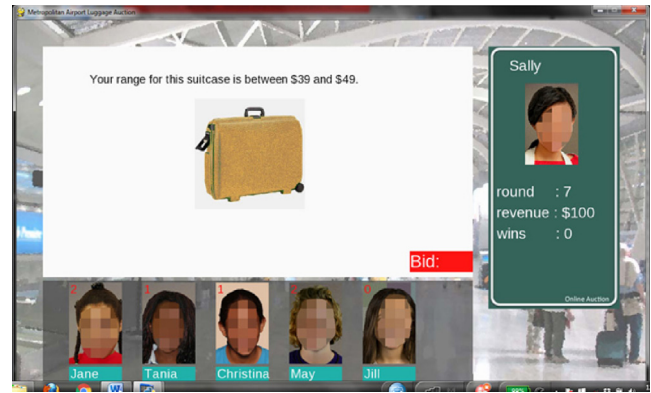


Fig. 1. Screen participant views during bidding.

between individual differences willingness to pay (sacrifice financial gain) for social status (van den Bos et al., 2008; van den Bos et al., 2013). The adapted version aims to assess whether pubertal testosterone in girls creates a similar prioritization of status (willingness to sacrifice financial gain for social status).

Before completing this task, the participant's photo was taken by an assessor. She was then given instructions for the Auction Task, completed “quiz” questions with corrective feedback, and played practice rounds to ensure comprehension. Next, the participant was shown pictures and brief profiles of nine girls and told that the girls were participating in the study at other sites. In reality, no other girls were playing the task: their participation was based on a computer-generated algorithm and the photos shown to the participant were stock photos. The participant was asked to rank order the other girls with whom she wanted to play with during the task. The participant's 1st, 2nd, 4th, 6th and 7th choices were selected by the computer to increase the believability of mutual rankings. As such, each participant believed she was playing against 5 competitors.

During the task, the participant's photo and the stock photos of the simulated competitors appeared at the bottom of the screen and the participant was assigned virtual funds of \$100. The participant was told that she was playing with the other girls in an auction, which involved bidding on luggage that had been lost by travelers in airports. The luggage in these auctions is never opened so one has to guess the value of its content. In each round of the auction task the participants were presented with a new piece of luggage, and each player was presented with a range of values that the contents could be worth (e.g. between \$10 and \$20; see Fig. 1). Participants were instructed that true value of the contents was always within the provided range. Next participant were asked to make a bid. Participants do not know each others bids, but the computer picks the winner by determining the highest bidder. When the participant wins a round, her name and picture is displayed to all other players, but the other players do not get any information about the winner's bid or the amount she gained (see Fig. 2) or lost (see Fig. 3). When a participant did not win the auction, she will just see who won but she will keep her money. Finally, the winner is informed about the real value of the luggage, if that is higher than her bid she earned money, but if it is lower than her bid she lost money on the bid. As such, lower bids theoretically had the potential for earning the highest amounts of money. However, only the highest bidder wins the auction. This presents a clear trade-off—bidding higher increases the participant's chance of winning the round, but also increases her chances of losing money. Each participant played 35 discrete rounds of this task and her total funds increased or decreased based on her winning bids. Each participant received a small gift (maximum value of \$10) upon completion of the study, contingent on her funds at the end of the task. Following partici-

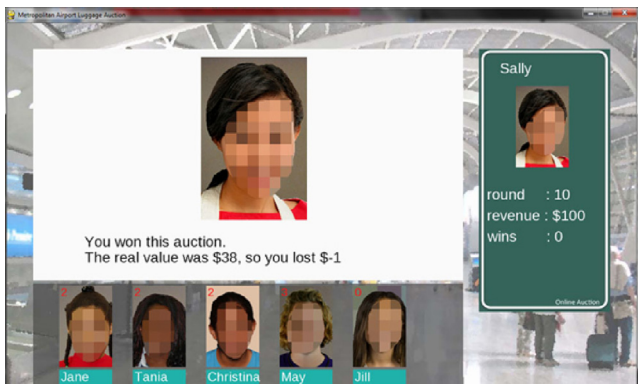


Fig. 2. Screen participants viewed when winning a round.

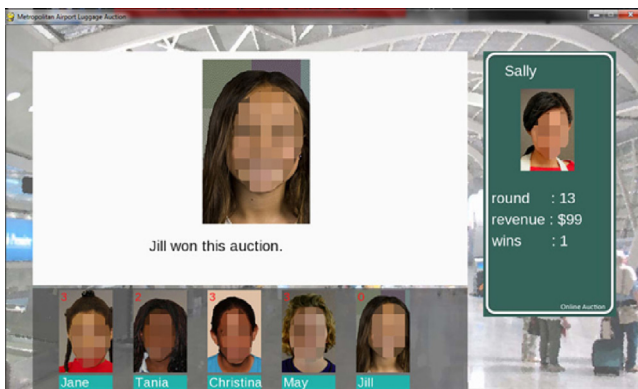


Fig. 3. Screen participants viewed when losing a round.

pation, trained staff briefly evaluated the participant's grasp of the Auction Task and trust in the paradigm. In order to avoid participant pool contamination, we employed a delayed debriefing strategy. Following the completion of this study, participants and their parents were sent a letter explaining the mild deception employed in the Auction Task. The parent/guardian was encouraged to contact the research team with any questions or concerns.

2.8. Risk neutral strategy and overbidding

If a participant wanted to complete the task and be sure not to lose any money, she could simply bid at the lowest value provided in estimate. For example, in one round a participant could be shown a picture of a piece of luggage with a range of \$10 to \$20. In this round, this strategy suggests to bid \$10. This strategy is called risk neutral because the participant does not risk losing any money; the worst-case scenario is that the true value is \$10. However, this strategy leads to a small chance of ever winning an auction, particularly if others play more competitive strategies. In previous experiments we have shown that, if they were explicitly instructed how it works, people can, and will, play this strategy when playing against computer opponents, but not if they played against other humans (van den Bos et al., 2008, 2013).

For the purposes of analysis, the amount of money a participant is willing to wager above this risk-neutral bid is conceptualized as overbidding. Overbidding increases one's chance of winning a round in the auction but in the long-term will result in loss of money. Thus, this task assessed the participant's willingness to take financial risks (losing money) for the experience of gaining social status associated with winning the auction and having her picture shown to the other players, which we conceptualize as a largely affective process (van den Bos et al., 2013). Note again that the

other players only learn who wins, but not the potential gains or losses associated with that win.

Auction Task data were utilized in two ways: (a) a mean overbidding score (see van den Bos et al., 2013 for a description) was used to measure the participant's average overbidding throughout the task and entered into regression analyses, and (b) mean overbidding scores for five consecutive bins of six rounds each were used to measure the slope of overbidding in hierarchical linear modeling analyses.

2.9. Additional covariates

A range of additional measures was collected, including the MacArthur Scale of Subjective Social Status (Adler et al., 2000); the vocabulary subtest of the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV) (Wechsler 2003); body mass index (BMI); and use of any medication within 24 h of basal saliva sample collection.

3. Results

3.1. Preliminary analyses

Descriptive information and correlations among all variables of interest and covariates are presented in Table 1. Several variables were considered for inclusion as covariates, including age, race/ethnicity, vocabulary, BMI, use of medication, and multiple measures of sociometric status. Age and vocabulary each emerged as significant predictors in at least some of the primary analyses; these variables were retained as covariates in each of the following analyses. SES Community Ladder (hereafter referred to as SES) was also retained as a covariate for both theoretical reasons and because it emerged as a marginal predictor in some analyses. For ease of interpretation, only these utilized covariates are included in Table 1. Descriptive information on the other potential covariates is available upon request from the corresponding author.

Extreme values for two hormones (testosterone and estradiol) and four Auction Task overbidding bins (bins 2, 3, 4, and 5; not bin 1 or overall mean Auction Task overbidding), were winsorized to 3SD above/below the median with ordering preserved. For each of these variables, two values at most were winsorized. These adjustments are reflected in Table 1. For other variables, winsorizing was not needed.

As expected, all hormone values were significantly intercorrelated but still shared under half of their variance with one another. Thus, in subsequent analyses they are examined individually. In addition, PDS score was significantly correlated with all hormones, but again shared under half of its variance with these variables. Age and vocabulary were associated with overbidding on the Auction Task in the expected direction, with increasing age and verbal ability predicting less overbidding.

Because the Auction Task has not been used with adolescents in the past, Auction Task data were inspected for evidence of rational bidding consistent with task comprehension. As expected, in general, these adolescent participants overbid more than adults (M overbidding = 0.72) (e.g., see van den Bos et al., 2013), but their overbidding tended to decrease as the task progressed, consistent with principles of learning.

3.2. Regression analyses

3.2.1. Prediction of Auction Task

To determine the developmental predictors of Auction Task performance, we utilized hierarchical regression, with prediction by PDS and the three hormones each examined in a separate model. PDS and testosterone, but not estradiol or DHEA, significantly predicted overbidding on the Auction Task, adjusting for covariates

Table 1
Study Variable Descriptives and Correlations.

	1	2	3	4	5	6	7	N	M	SD
1. Age								63	12.74	1.09
2. Vocab	−0.11							63	13.87	2.61
3. SES	0.06	0.05						63	6.83	1.47
4. PDS	0.56***	−0.08	0.13					62	2.68	0.65
5. Testo.	0.13	−0.08	−0.05	0.29*				60	54.01	21.43
6. Est.	0.31*	−0.22†	−0.14	0.45***	0.58***			60	1.24	0.54
7. DHEA	0.35**	−0.14	−0.04	0.39**	0.66***	0.43***		60	173.14	110.68
8. AT	−0.26*	−0.24†	−0.23†	0.09	0.28*	0.05	0.11	63	0.72	0.26

Note: Vocab = WISC-IV Vocabulary, SES = Socioeconomic Status (Community Ladder), PDS = Pubertal Development Scale, Testo = testosterone, Est. = estradiol, AT = Auction Task. Valid N listwise = 59.

† $p < 0.10$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 2
Prediction of Auction Task Overbidding from Self-Reported Pubertal Development, and Pubertal Hormones.

Predictor Variable	β	R	ΔR^2
Step 1		0.42	0.18*
Age	−0.28*		
Vocab	−0.24*		
SES	−0.20†		
Step 2		0.50	0.09*
PDS	0.37**		
Step 1		0.41	0.17*
Age	−0.28*		
Vocab	−0.24†		
SES	−0.21†		
Step 2A		0.50	0.08*
Testo	0.29*		
Step 2B		0.41	0.00
Est.	0.07		
Step 2C		0.45	0.03
DHEA	0.19		

Note: Target predictors (PDS; Testo.; Est., DHEA) were each entered in a separate model. Data are presented for the step on which the variable was first entered. Vocab = WISC-IV Vocabulary, SES = Socioeconomic Status (Community Ladder), PDS = Pubertal Development Scale, Testo = testosterone, Est. = estradiol.

† $p < 0.10$.
* $p < 0.05$.
** $p < 0.01$.

(Table 2). It is notable that age and vocabulary were associated with Auction Task performance in the opposite direction. That is, the type of socio-affectively motivated behavior that occurs at the expense of strategic decision making *decreases* with age and verbal intelligence but *increases* in relation to pubertal maturation.

To verify the association between our measure of overbidding and financial outcome on the Auction Task, we re-conducted analyses with final earnings as the variable of interest. As predicted, in bivariate correlations, overbidding was significantly negatively correlated with final earnings in the task ($r = -0.84, p < 0.001$). The final earnings variable was marginally negatively correlated with testosterone ($r = -0.24, p = 0.069$) and significantly positively correlated with age ($r = 0.33, p = 0.008$) and vocabulary ($r = 0.27, p = 0.030$) but was not significantly associated with DHEA, estradiol, or PDS. When our final earnings variable was substituted for overbidding in regression analyses, PDS and testosterone (but not estradiol or DHEA) were significantly negatively associated with smaller final sums of money (PDS: $\beta = -0.30, R = 0.61, \Delta R^2 = 0.06, p = 0.021$; Testosterone: $\beta = -0.24, R = 0.61, \Delta R^2 = 0.06, p = 0.029$). Age and vocabulary were significantly positively associated with increased earnings in regression analyses (Age: $\beta = 0.34, p = 0.004$; Vocabulary: $\beta = 0.32, p = 0.006$).

3.3. Multilevel modeling

We used Hierarchical Linear Modeling (HLM v6.05; Raudenbush, 2004) to examine the persistence of overbidding over the course of the Auction Task. Thus, overbidding was the outcome of interest. The equation for HLM modeling was as follows:

Level 1 Model:

$$Y_{\text{Overbidding}} = \beta_0(\text{Intercept}) + \beta_1(\text{BinSlope})$$

Level 2 Model:

$$\beta_0(\text{Intercept}) = \gamma_{00}(\text{Intercept}) + \gamma_{01}(\text{Covariates, PDS, Hormones})$$

$$\beta_1(\text{BinSlope}) = \gamma_{10}(\text{Intercept}) + \gamma_{11}(\text{Covariates, PDS, Hormones})$$

The participants' bids during the Auction Task trials were grouped into "bins," and the base model (level 1; repeated measures) included a dummy coded variable that modeled the average of each bin across the 5 bins (Bin 1 = trials 1–6; Bin 2 = trials 7–12; Bin 3 = trials 13–18; Bin 4 = trials 19–24, Bin 5 = trials 25–30). The bin average was significantly predicted by the slope of overbidding across bins ($\beta = -0.07; p < 0.001$), as well as the intercept ($\beta = 0.91; p < 0.001$). In HLM, once a level-1 (within-individual) equation is established, level-1 predictors can become outcomes-of-interest at level 2 (between-individual). Cross-level interactions are used to capture how difference factors influence level-1 associations, specifically changes in overbidding across the task.³

Age, race/ethnicity, vocabulary, BMI, medication status, and multiple measures of sociometric status were examined first to assess their impact on the course of overbidding. Vocabulary was significant predictor ($\beta = -0.01; p = 0.003$), and age was a marginal predictor ($\beta = -0.01; p = 0.100$), so they were included in the final model. Two measures of SES were significant predictors; for consistency with previous analyses, the Community Ladder ($\beta = -0.02; p < 0.001$) was retained in the final model. The negative coefficient for each of these covariates is indicative of a decrease in overbidding over the course of the task.

Next, we examined predictors of interest after adjusting for covariates. Hormones and PDS were each examined in separate models. As expected, PDS significantly predicted the slope of overbidding over the course of the Auction Task ($\beta = 0.03; p = 0.032$), in that more pubertal maturation predicted more persistent overbidding. A similar effect emerged for testosterone ($\beta = 0.001$;

³ In order to achieve best model fit, covariates and predictors of interest that did not significantly predict a parameter in the model were dropped from that parameter.

$p=0.005$). Neither estradiol nor DHEA significantly predicted the persistence of overbidding over the course of the task.

4. Discussion

We examined the relationship between testosterone and willingness to take greater financial risks in exchange for increased social status. After adjusting for covariates, self-reported pubertal development predicted mean overbidding on the Auction Task, as did testosterone. Although popular psychology suggests that testosterone-linked socially motivated behavior is aggressive, testosterone administration in adult women also predicts fair bargaining behavior that increases the efficiency of social interactions, prevents rejection, and secures access to resources (Eisenegger et al., 2010). Similarly, Boksem et al. (2013) administered testosterone to adult women and found that it predicted decreased trust but increased generosity in response to trust. Thus, depending on the context, testosterone may encourage prosocial behavior and is most reliably tied to behavior that increases or secures social standing.

This pattern is indicative of a developmentally influenced affective motivation for the experience of social status, even at the expense of performing more poorly on a decision-making task and obtaining a lower reward. This effect was not simply age-related; in fact, increased age and verbal intelligence were associated with less overbidding on the Auction Task. This pattern highlights the importance of the bold, socio-affectively motivated behavior that emerges with pubertal maturation in contrast to the more rational decision making that is associated with increased age and verbal intelligence. It is consistent with research contending that social admiration is a particularly salient reward in itself (e.g., Zink et al., 2008), and provides additional evidence of the importance of social status as particularly rewarding with increased pubertal maturation (e.g., Crone and Dahl, 2012). In this, task social status replaced financial gain as a strategically motivated strategy. Furthermore, the association between testosterone and Auction Task performance is in line with research by van den Bos et al. (2013) showing a similar effect in male adults, and links to research largely conducted with adults suggesting that testosterone predicts status-relevant behavior (i.e., overbidding) when an individual's status is threatened or unstable (e.g., Josephs et al., 2003).

In multilevel modeling, PDS and testosterone predicted the slope of overbidding over the course of the Auction Task. This finding suggests that participants with higher levels of basal testosterone did not correct their bidding behavior as drastically as those with lower levels of testosterone, and their bidding decisions continued to be motivated by the affective value of social status at the expense of strategic decision making. For participants with more advanced pubertal maturation, the experience of having their picture shown to the other girls as “winner” of the round appears to have been reinforcing enough that this behavior persisted despite the feedback that funds were decreasing. Learning may have been shaped by this motivational process of social reinforcement, rather than by cognitive processes, for those who found it especially rewarding (Jones et al., 2011).

4.1. Focus on girls

Given the breadth of biological, social, cultural, and environmental factors that influence development associated with risk-taking behavior, we chose to focus on a narrow age range of girls. Based on evidence that neurodevelopmental and social processes leading to risk taking may differ for boys and girls, this cross-sectional design allowed us to explore the relationship between pubertal development, testosterone, and risk-taking

behavior. Girls are understudied in the risk-taking literature even though they may be particularly vulnerable to the negative implications of risk-taking behaviors, such as smoking, self-harm, physical inactivity (MacArthur et al., 2012), and sexually transmitted infections (Centers for Disease Control and Prevention, 2014). Many biological, social, and cultural factors differ for boys and girls, arguing for examination of the developmental affective and social underpinnings of risk-taking tendencies separately by sex.

Specifically, processes concerning the affective/social underpinnings of risk-taking tendencies may differ for girls and boys. Girls undergo pubertal changes an average of one to two years earlier than boys and hormonal changes associated with puberty are different for girls and boys. Girls and boys both experience marked increases in testosterone during puberty—although increases in boys are much greater (Braams et al., 2015). Other changes in sex hormones also differentially influence girls. Increased levels of estrogen have been shown to augment the reactivity of the reward system in women (Dreher et al., 2007), and menarche has been associated with earlier initiation and greater frequency of a range of unhealthy behaviors including substance use (Westling et al., 2008) and delinquent behavior (Harden and Mendle, 2012). Although evidence is mixed, some research suggests that sex steroids (estradiol, testosterone) may be differentially associated with risk behavior and social processing in adolescent girls and boys (e.g., Castellanos-Ryan et al., 2013). In addition, hormone administration has been found to have distinct neural and behavioral effects on men and women (Rilling et al., 2014). In future research, it will be important to investigate parallel processes in boys, to begin to clarify the ways in which pubertal development similarly and/or differentially contributes to risk behavior across sexes.

4.2. The importance of peers

The presence of peers and desire for social status among peers has significant implications for adolescent risk taking. Association with deviant peers has been shown to be a significant predictor of adolescent substance use (van Ryzin et al., 2012), presence of peers in an automobile increases risk of a serious accident (Centifanti et al., 2014), and an adolescent's sexual risk taking is tied to perceptions of peer sexual activity (Akers et al., 2011). In addition, the presence of peers predicts increased adolescent risk taking in a laboratory setting, even in the absence of peer interaction (Gardner and Steinberg, 2005). Importantly, such peer effects on this laboratory task have not been found for either adults or children.

One explanation is that in potentially dangerous situations that occur in the presence of peers, the opportunity to demonstrate bravery and increase social status may lead pubertal adolescents to interpret the feeling of fear in some contexts as thrilling (Spielberg et al., 2014). Areas of the brain associated with reward processing overlap significantly with socio-emotional circuits, and evidence suggests that peer acceptance in adolescence may be processed similarly to other rewards (Chein et al., 2011). In recent research comparing children, adolescents, and adults in their tendency to take risks, the presence of peers was shown to activate reward circuitry (ventral striatum; orbitofrontal cortex) specifically for adolescents, resulting in increased risk-taking behavior (Chein et al., 2011). Adolescents have also demonstrated greater rejection-related distress and associated subgenual anterior cingulate activation than adults in the presence of peers (Masten et al., 2009). In short, the presence of peers at this time of increased social valuation may sensitize adolescents to the reward value of risky choices, resulting in more risk taking.

Although pubertal maturation and socio-affectively motivated behavior have implications for risk-related behavior, it is important to clarify that the relevant processes are not necessarily negative or problematic. Just as pubertal-dependent increases in drive for

social status may contribute to risky driving in the presence of peers, in other contexts these processes can contribute to healthy forms of bold exploration and prosocial risk taking, such as performing as the lead in a school play or playing sports. In addition, peer influence can be powerfully positive in certain contexts. For example, in one study, overweight and lean adolescents were more likely to engage in physical activity when in the presence of peers or close friends than when not (Salvy et al., 2007). Further, it is especially likely that sensation seeking and a motivation for social admiration may contribute to healthy outcomes in contexts that offer scaffolding and supports that encourage the ability to recruit still-developing cognitive control networks (Crone and Dahl, 2012).

4.3. Strengths & limitations

Strengths of this study include (a) the inclusion of multiple measures of pubertal development, including a self-report measure and hormone samples, (b) the use of a unique behavioral measure that directly measures socio-affectively motivated behavior at the expense of strategic decision making, and (c) the flexible utilization of statistical techniques to investigate multiple aspects of these data. Despite these strengths, several limitations are noteworthy. First, in addition to measurement of hormones, the study utilized only a self-report measure of puberty. Despite some concerns with the limited reliability of self-report data, there is some evidence that self-reported pubertal development on the PDS is reliable and valid (Petersen et al., 1988; Shirtcliff et al., 2009). A related issue concerns our measure of pubertal hormones, as mentioned above in the results section. Without a longitudinal design, one cannot parse developmental (i.e., pubertal maturation) from non-developmental individual differences in hormone levels, which may have complicated this investigation and conflated two important factors. A similar challenge is that, for logistical reasons, we were unable to control for several factors that may have contributed to some noise in our hormonal measures, including circadian and sleep influences and menstrual cycle timing. Further, it should be noted that recent research suggests that enzyme immunoassays (EIA) demonstrate weak correlations with liquid chromatography tandem mass spectrometry when it comes to testosterone, and particularly overestimate lower testosterone estimates in women (Welker et al., 2016). Similarly, research has shown that the serum-saliva correlation is reduced in females compared to males (Granger et al., 2004). Thus, while our testosterone concentrations were commensurate with other studies using testosterone hormone concentrations assessed via enzyme immunoassay, the Welker et al. study suggests that studies using EIA to estimate testosterone in women may be inflated due to use of EIA methodology. While Welker et al. suggested that the systematic error in enzyme immunoassays may inflate type 2 errors in women by obscuring behavioral and psychological effects of testosterone typically found in men, it should be noted that the current study found a significant relationship between testosterone levels and bidding behavior in women despite this likelihood.

As noted above, an additional limitation is in the generalizability of our findings. The participants, though fairly ethnically diverse, tended to be from higher income families and to have very strong verbal abilities. In the future, a priority will be to recruit a more socioeconomically and educationally diverse sample. This diversity is especially important given the associations between future-oriented time perspective and decreased likelihood of risk behavior (e.g., McDade et al., 2011), and evidence suggesting that persons of higher socioeconomic status may be more likely to be future oriented than people of lower socioeconomic status (e.g. Guthrie et al., 2009).

In addition to providing further evidence for the association between pubertal development and pubertal girls' drive for the

affective experience of social status, these results also suggest an association between pubertal maturation and the *persistence* of socio-affectively motivated behavior (perhaps due to social reinforcement learning), with patterns of nonstrategic decision making that otherwise would appear irrational. This research has implications for the developmental underpinnings of both prosocial and problematic adolescent risk taking. While many socially-motivated behaviors in which adolescents engage (e.g., drinking at a party, reckless driving, attempting a dangerous skateboarding stunt, posting a sexually suggestive video on the internet) result in negative health outcomes, prosocial programs and efforts to positively engage youth can also leverage this willingness to increase social status. Creating competitive social environments to reward youth who engage in prosocial activities such as achieving high grades, engaging in volunteer activities, or helping out friends and family, could also serve to motivate youth as they enter into the developmental period of increased social salience. Next steps include the mapping of these processes onto real-world risk and prosocial behaviors as well as the investigation of sex differences.

5. Conclusion

We examined the developmental underpinnings of risk-taking tendencies in adolescent girls by examining pubertal contributions to socio-affectively motivated behavior to increase social status at the expense of losing money. These cross-sectional data are consistent with our a priori predictions that individuals with higher testosterone and more advanced pubertal maturation would be associated greater tendency to prioritize status-seeking at the expense of monetary loss. These findings provide additional evidence for the association between pubertal development and pubertal girls' drive for the affective experience of social status. Although a longitudinal design is needed to determine whether these effects are truly due to developmental differences occurring with puberty (rather than individual differences between subjects), this is an important step to understanding motivations underlying adolescent risk behavior.

The current findings invite further investigation of the development of risk taking. Additional research is needed to delineate the specific pathway from pubertal development and pubertal hormones to socio-affectively motivated behavior, which may ultimately lead to real-world risk behavior such as substance abuse, early sexual debut, or risky driving. Particular focus is needed to explore this relation among the highest-risk youth, given the reciprocal relationship between context, hormones, neural development and risk taking behavior.

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