Title

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Pubertal Maturation, Sensation Seeking, and Socio-Affectively Motivated Behavior:
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By

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Abstract

Pubertal Maturation, Sensation Seeking, and Socio-Affectively Motivated Behavior:
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Doctor of Philosophy in Psychology

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This research examines some of the developmental processes that may help to explain risk-taking tendencies in adolescent girls. In particular, I investigated key aspects of a social and affective neuroscience theory of adolescence in which pubertal development predicts an increased appetitive drive for exciting affective experiences and for social admiration. Participants were 63 girls ages 10-14 (M_{age} = 12.74) who 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. Overbidding on a modified Auction Task for adolescents captured socio-affectively motivated behavior at the expense of strategic decision making. Sensation seeking, impulsivity, and resistance to peer influence were assessed via self-report. Covariates were age, verbal intelligence, and socioeconomic status. PDS predicted sensation seeking; PDS, testosterone, and sensation seeking each predicted overbidding on the Auction Task. Sensation seeking was least predictive of overbidding on the Auction Task at low levels of resistance to peer influence. In addition, PDS, testosterone, sensation seeking, and impulsivity were each associated with persistent overbidding over the course of the Auction Task. Results provide additional evidence for the association between pubertal development and sensation seeking, and highlight pubertal adolescent girls' drive for the affective experience of gaining social status. 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 contributes to our understanding of the developmental underpinnings of both prosocial and problematic real-world risk behavior.

Pubertal Development, Sensation Seeking, and Socio-Affectively Motivated Behavior: Investigating Developmental Contributors to Risk-Taking Tendencies

In adolescence, risky, often life-threatening behaviors are at a lifetime high (Steinberg, 2008). Indeed, even though adolescence is a time of unprecedented physical and cognitive prowess, a growing body of literature associates adolescence with increased mortality rates, accidental injuries, substance abuse, violence, risky sexual behavior, and suicide (Centers for Disease Control and Prevention, 2010; Resnick et al., 1997). Rates of risk taking are approximately 200-300% higher in adolescence than in childhood. Indeed, teens are more likely to binge drink, have casual sex partners, engage in violent behavior, commit crimes, and be involved in serious automobile accidents than either children (by definition) or adults (Chein, Albert, O'Brein, Uckert, & Steinberg, 2011; Steinberg, 2008). Results from the 2010 'Monitoring the Future' study suggest that levels of illicit drug, alcohol, and prescription medication abuse are of major concern during adolescence, at a life period when harm perception appears to be decreasing and availability for many substances is increasing (Johnston, O'Malley, Bachman, & Schulenberg, 2011).

Other risk-taking behaviors are also quite prevalent in adolescence. For example, as of 2009, fourteen percent of high school students reported more than four lifetime sexual partners, and 34% of sexually active high school students reported not using a condom during their last sexual intercourse (Centers for Disease Control and Prevention, 2010). Mortality rates are disproportionately high in adolescence, in part because of risky driving resulting in automobile accidents (Centers for Disease Control and Prevention, 1999). Such risk-taking behaviors have implications for individual long-term health, the safety of others, and the deployment of public resources.

Uncovering the contributors to the sharp increase in risk taking during adolescence is a priority. Puberty – the transition from childhood into adolescence – has been identified as a key maturational window of increased risk taking. 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 motivational underpinnings that contribute to the emergence of bold behavior at this time of transition (e.g., Steinberg, 2008). In particular, pubertal development appears to predict an increased appetite for exciting affective experiences and an increased value of social admiration, which may interact with still-developing cognitive control systems and contribute to either dangerous or prosocial risks, depending on the context (Crone & Dahl, 2012; Telzer, Fuligni, Lieberman, & Galvan, 2013). In this investigation, I examine the association between pubertal maturation and a form of bold behavior that overvalues the affective experience of social status at the expense of strategic decision making. I also seek to clarify the role of sensation seeking as similarly increasing at puberty and possibly contributing to such socio-affectively motivated behavior. Furthermore, I investigate the contributions of impulsivity and resistance to peer influence in this pathway.

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 drug addiction and teen pregnancy (National Center on Addiction and Substance Abuse at Columbia University, 2003). Processes concerning the affective/social underpinnings of risk-taking tendencies may differ for girls and boys (Hayward, 2003), especially because 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. In addition, differing cultural expectations and gender roles for boys and girls may interact with and amplify sex differences. Thus, this investigation focuses on the motivational underpinnings of bold and risky behavior specifically in adolescent girls, with implications for the prevention of substance abuse, sexual risk-taking, and other harmful behaviors, as well as for the optimization of healthy forms of risk behavior.

Puberty and Risk Taking

Recent research has debunked previous explanatory theories of risk taking contending that adolescents are irrational, feel invulnerable, or are less risk-averse than adults (Millstein & Halpern-Felsher, 2002; Reyna & Farley, 2006; Steinberg & Cauffman, 1996). One of the most exciting current theoretical frameworks for understanding risk taking in adolescence has emerged from social and affective neuroscience. This model focuses on pubertal changes in neural systems that underpin socio-emotional engagement and reward seeking as well as their interactions with the more gradual maturation of cognitive control systems in adolescence (Ernst, Pine, & Hardin, 2006; Somerville, Jones, & Casey, 2009). Neurodevelopmental changes occurring at puberty, including increased levels of gonadal hormones and dopaminergic reorganization, are thought to be more strongly related to increases in risk taking in adolescence than is age per se (Dahl, 2008; Spear, 2000). These hormonal and neural changes influence arousal, motivation, and emotion, resulting in a time of particular vulnerability to sensation seeking and risk-taking behaviors (Blakemore, Burnett, & Dahl, 2010; Forbes & Dahl, 2010; Silk, Steinberg, & Morris, 2003).

The specific paths through which pubertal changes may affect risk taking are largely unknown. For example, researchers have hypothesized that dopaminergic changes in the striatum and prefrontal cortex may increase reward sensitivity (Andersen, Rutstein, Benzo, Hostetter, & Teicher, 1997; Andersen, Thompson, Krenzel, & Teicher, 2002; Dumont, Andersen, Thompson, & Teicher, 2004; Ernst & Spear, 2008). Such changes may alternatively result in a "reward deficiency syndrome" (Forbes et al., 2010; Steinberg, 2008). Another line of investigation has focused on reward prediction errors as underlying these maturational changes (Cohen et al., 2010). Despite uncertainty in mechanism, these changes appear to increase sensation-seeking propensity and subsequently contribute to greater tendencies toward exploration and risk taking (Spear, 2000; Steinberg, 2008), especially in the presence of peers (see below). Indeed, reward-seeking behavior increases broadly at puberty (Dahl & Spear, 2004; Martin et al., 2002), and this type of sensation seeking is tied to risk-taking behavior in children, adolescents, and adults (Chein et al., 2011; Morrongiello & Matheis, 2004; Zuckerman, 1994). Still, despite key advances, the developmental underpinnings of adolescent risk taking have not been thoroughly explored.

The Importance of Peers

Increased sensation seeking appears to occur at puberty despite a simultaneous increase in fear reactivity (Quevedo, Benning, Gunnar, & Dahl, 2008). This process can lead to healthy versions of exploration as well as dangerous versions of risk taking. Puberty marks a time of increased independence and reproductive maturity, when taking risks is necessary for the ultimate goal of independence and creation of new families (Dahl, 2008). Still, in certain social contexts, such as in the presence of peers, adolescents may make especially risky or dangerous decisions. For example, peer substance use may be the single strongest predictor of an adolescent's own substance use (Chassin et al., 2004). Presence of peers in an automobile increases risk of a serious accident (Simons-Morton, Lerner, & Singer, 2005), and an individual’s sexual risk taking is tied to perceptions of peer sexual activity (Babalola, 2004; Brooks-Gunn & Furstenberg, 1989; Prinstein, Meade, & Cohen, 2003). In fact, the mere presence of peers predicts increased adolescent risk taking in a laboratory setting, even in the absence of peer interaction (Gardner & Steinberg, 2005). Such peer effects have not been found for adults and children.

One explanation for this phenomenon 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 (Dahl, 2008). Indeed, increasing levels of reproductive hormones characteristic of pubertal maturation have been tied to social information processing, social memory, and bonding (Nelson, Leibenluft, McClure, & Pine, 2005), and adolescence appears to be a period of significant social learning (Jones et al., 2011). 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 (Galvan et al., 2006; Knutson, Westdorp, Kaiser, & Hommer, 2000; Nelson et al., 2007). 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 (Crone & Dahl, 2012; Gunther Moor, van Leijenhorst, Rombouts, Crone, & Van der Molen, 2012; 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 there is a growing body evidence suggesting that increased social valuation 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 (Crone & 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, Haushofer, & Fehr, 2011). Indeed, testosterone levels correlate with risk taking and dominance in adolescents and adults (Carré, Putnam, & McCormick, 2009; Grant & France, 2001; Peper, Koolschijn, & Crone, 2013; Rowe, Maughan, Worthman, Costello, & Angold, 2004; Stanton, Liening, & Schultheiss, 2011; Vermeersch, T’Sjoen, Kaufman, Vinke, & Van Houtte, 2010), and testosterone levels both predict and are modulated by social interactions (e.g., Carré & Putnam, 2010). 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, Iseline, Welker, Hariri, & Dodge, 2014; Eisenegger et al., 2011; Goetz et al., 2014; Hermans, Ramsey, & van Honk, 2008), possibly by inducing functional OFC and amygdala decoupling (van Wingen, Mattern, Verkes, Buitelaar, & Fernández., 2010).

Although popular psychology suggests that testosterone-linked socially motivated behavior is necessarily 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, Naef, Snozzi, Heinrichs, & Fehr, 2010). Similarly, Bokesem and colleagues (2013) administered testosterone to adult women and found that it predicted decreased trust but increased generosity in *response* to trust. Even in non-human primates, aggressive dominance behavior has been linked to instability of the social hierarchy and scarcity of resources (Sapolsky, 1991; Sapolsky & Share, 2004). Thus, depending on the context, testosterone may encourage prosocial behavior and is most reliably tied to behavior that increases or secures social standing. Some evidence suggests that socially motivated behavior tied to testosterone occurs outside of awareness (Terburg, Aarts, & van Honk, 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 strategic behavior.

Interactions with Cognitive Control

As noted above, social and affective neuroscience theories of adolescent risk taking generally focus on the interaction of (a) relatively early pubertal changes in neural systems that underpin socio-emotional engagement and reward seeking and (b) the more gradual maturation of cognitive control systems in adolescence (Ernst, Pine, & Hardin, 2006; Somerville, Jones, & Casey, 2010). That is, the relative lag in cognitive capacities appears to contribute to increased risk-taking tendencies. Unlike sensation-seeking tendencies, which tend to surge at puberty, cognitive control abilities such as the increased capacity to inhibit impulses are thought to improve in a gradual linear trajectory from childhood through young adulthood (Steinberg, 2010). It is important to note that although impulsivity and sensation seeking are often conflated, they do not always co-occur. For example, as Steinberg and colleagues (2008) describe, an adolescent may impulsively end a friendship (impulsivity but not sensation seeking) or planfully take the steps to go skydiving (sensation seeking but not impulsivity).

In addition, some research suggests that resistance to peer influence is closely tied to the development of cognitive control systems (Grosbas et al., 2007) and increases linearly from ages 14 to 18, without much change in childhood and adulthood (Steinberg & Monahan, 2007). Still, the role of impulsivity and resistance to peer influence in adolescent risk taking are not well understood. For example, some evidence exists that ventral striatal activity to emotional faces in early adolescence is associated with increased resistance to peer influence and decreased risk taking (Pfeifer et al., 2011), but it is unclear to what extent resistance to peer influence may interact with pubertal processes. Thus, I aim to investigate not only sensation seeking, believed to be directly tied to pubertal development, but also to differentiate sensation seeking from impulsivity and to examine interactions between sensation seeking and (a) impulsivity and (b) resistance to peer influence.

The Importance of Considering Sex and Gender Differences

There are many biological, social, and cultural factors that differ for boys and girls and argue for examining the developmental affective and social underpinnings of risk-taking tendencies separately by sex and/or gender, at least initially. For example, the earlier initiation of pubertal maturation and differing hormonal/brain changes for girls versus boys may contribute to different mechanistic pathways that ultimately result in risk-taking propensities. Indeed, increased levels of estrogen have been shown to augment the reactivity of the reward system in women (Dreher, Schmidt, Kohn, Furman, Rubinow, & Berman, 2007), and menarche has been associated with earlier initiation and greater frequency of smoking and drinking in adolescent girls (Dick, Rose, Viken, & Kaprio, 2000). Although evidence is mixed, some research suggests that sex steroids (estradiol, testosterone) may be differentially associated with risk behavior in adolescent girls and boys (see Costello, Sung, Worthman, & Angold, 2007; de Water et al., 2012; Eriksson, Kaprio, Pulkkinen, & Rose, 2005; Martin, Mainous, Curry, and Martin, 1999; Vermeersch, T'Sjoen, Kaufman, & Vinke, 2008).

Some evidence from animal models suggests that dopamine reorganization is more salient for males than for females, but both sexes undergo this process at puberty. Investigators have suggested that the proportional change in several areas of the brain may be more important than the magnitude of change in any one area (Andersen, Rutstein, Benzo, Hostetter, & Teicher, 1997; Sisk & Foster, 2004; Steinberg, 2008). In fact, similar rates of risk taking in girls and boys have been found in rigorous laboratory studies, including those involving brain imaging (e.g., Chein et al, 2011, Galvan, Hare, Voss, Glover, & Casey, 2007; Gardner & Steinberg, 2005). Pubertal maturation has been tied to real-world risk behaviors such as substance use in boys and girls (de Water, Braams, Crone, & Peper, 2012), and early pubertal onset predicts substance use/abuse and sexual risk-taking in both boys and girls (Downing & Bellis, 2009). Thus, sex differences in real-world risk taking may be more related to societal expectations and social context than to biological processes (Steinberg, 2008).

In addition, cultural values, gender roles, and social context may interact with maturational processes and contribute to specific patterns of risk for boys and girls. For example, Downing and Bellis (2009) found that boys and girls with early pubertal timing may be at risk of some similar behaviors (e.g., early substance use) and other differing ones (e.g., males: fighting and aggressive responses to emotional upset). Furthermore, in certain contexts, early pubertal timing has been shown to predict girls' association with older, more normbreaking friends (Stattin, Kerr, & Skoog, 2011), in which peer socialization effects or deviancy training (e.g., Dishion, Capaldi, Spracklen, & Li, 1995) may be especially likely to lead to risky behavior. Based on evidence that neurodevelopmental and social processes leading to risk taking may differ for boys and girls, and in an effort to design a feasible yet rigorous study, I focus herein on girls, with future plans for the investigation of sex differences.

The Current Project

The proposed project seeks to 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. As described above, I examine the association between pubertal development and behavior that overvalues the affective experience of social status at the expense of strategic decision making. The role of sensation seeking, as well as impulsivity and resistance to peer influence, is also investigated.

An adolescent version of the Auction Task (van den Bos, Golka, Effelsberg, & McClure, 2013) is used to capture socio-affectively motivated behavior. The Auction Task is a computer task that measures a participant's bidding on an auction item with an expected value (e.g., $10 ± $2). The participant who wins the auction (i.e., makes the highest bid) tends to lose money as a result of overbidding, but has her name and picture shown to the other participants as the "winner." In this way, the Auction Task can uniquely measure the participant's tendency behave in such a way as to maximize the feeling of social status at the expense of strategic decision making (i.e., overbid; risk losing money). Van den Bos and colleagues (e.g., 2008, 2013a, 2013b) have completed several studies that validate the use of this task as a measure of socio-affectively motivated behavior. For example, adult participants have been shown to overbid significantly more when playing against human participants than against a computer, suggesting a strong social component of overbidding (van den Bos et al., 2008). In a separate study, basal levels of testosterone predicted overbidding on the social version of this task, and this effect was mediated by affective responses to social comparisons (van den Bos, Golka, et al., 2013). This suggests that overbidding against others results from an automatic valuing process that is affectively driven, in contrast to the more strategic behavior that emerges when participants play against a computer.

Self-reported pubertal development and basal hormone levels are utilized to examine the contributions of pubertal maturation to socio-affectively motivated behavior, and self-reported sensation seeking, impulsivity, and resistance to peer influence are also considered.

The specific aims of this dissertation are as follows:

Aim 1: To examine the association between pubertal maturation and sensation seeking. I hypothesize that more advanced self-reported pubertal maturation or higher levels of pubertal hormones will be associated with increased sensation seeking (but not impulsivity).

Aim 2: To examine the association between pubertal maturation and socio-affectively motivated behavior. I hypothesize that more advanced self-reported pubertal maturation or higher levels of pubertal hormones will be associated with overbidding on the Auction Task, as well as more persistent overbidding over the course of the task.

Aim 3: To examine the behavioral correlates of socio-affectively motivated behavior. I hypothesize that sensation seeking will predict overbidding on the Auction Task, and that impulsivity and resistance to peer influence will each moderate this putative association, with the positive association between sensation seeking and risk taking being strongest for those with higher impulsivity or lower resistance to peer influence. I also hypothesize that sensation seeking will predict more persistent overbidding over the course of the task.

Aim 4 (Exploratory): To examine the potential for a partially mediated pathway from pubertal maturation to increased sensation seeking to increased socio-affectively motivated behavior. Although the sample size and cross-sectional design of this initial study limit the strict testing of mediated pathways, I will perform initial tests of statistical mediation to determine the potential for increased sensation seeking to partially explain the putative pathway from pubertal maturation to overbidding on the Auction Task.

Method

Participants

Participants, specified as girls between 10-14 years of age and functioning in a developmentally normal manner, were primarily recruited via IRB-approved advertisements posted on online classified sites and in community centers, libraries, schools, and camps. Research assistants also passed out advertisements at community events. In addition, previous laboratory participants who expressed an interest in future participation were contacted. Because some of the larger study's procedures required that each participant complete some measures with peers, snowball sampling was also used (Gardner & Steinberg, 2005; Chein, Albert, O'Brien, Uckert, & Steinberg, 2011).

Participants had to meet age and gender criteria and be fluent in English; exclusion criteria included hearing/vision difficulties that would interfere ability to complete tasks, evidence of intellectual disability, and use of medication that has shown to alter concentrations of sex steroids within 24 hours of morning saliva sample collection. In addition, the Child Behavior Checklist (CBCL; Achenbach, 2001), completed by each participant's parent, was used to assess for severe attention or thought problems that appeared to influence task performance. For those participants who appeared to have attention or thought problems (three girls) on the CBCL, we investigated task performance and measure completion for signs of unpredictability or inconsistency. These participants generally showed signs of reasonable responding, so we included them in this investigation. For one participant with a quite elevated CBCL attention score (*T* = 97) and signs of inattention during the study protocol, analyses described below were conducted with and without her data. Results were virtually unchanged regardless of her inclusion, so we retained her in the sample. 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). Results were also re-run with and without one participant who may have taken her saliva samples in the evening rather than the morning; again, analyses were virtually unchanged regardless of her inclusion, so she was retained in the final sample.

Only girls with data for the Auction Task were included in the final sample for this investigation. The final sample included 63 preadolescent and adolescent girls ages 10-14 (*M* = 12.74; *SD* = 1.09). This age range was selected in order to ascertain the effects of pubertal maturation, controlling for age. 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 did include families who received public assistance as well as those at intermediate income levels.

Procedure

The procedure for this study consisted of one telephone screening to ensure a viable sample plus one laboratory visit and at-home salivary sample collection, and was fully approved by UC Berkeley's Committee for Protection of Human Subjects.

Telephone screening. Parents/guardians (hereafter referred to as "parents") who contacted the laboratory for potential participation were asked for verbal consent. If consent was given, a trained staff member administered a brief screening interview to gather information regarding basic inclusion criteria, including age, gender, and English fluency. Those parents whose children appeared eligible for the study based on this screening were informed of the full study protocol. The parent and the youth were invited to the laboratory for participation in the study. If the parent preferred not to accompany the youth to the laboratory, s/he was required to return a consent form and other questionnaires outlined below via fax or mail before the visit. Because some aspects of a larger study (not analyzed in this investigation) required peer presence, participants were scheduled with two same-age friends or unknown peers.[1]

[1] Variables were created to represent (1) whether the participant was scheduled with friends or unknown peers and (2) the order in which tasks were administered (e.g., for some girls, the Auction Task was completed after a task with a peer presence component). Analyses described below were run with each of these variables as covariates, with only minor changes in results. These changes appeared to generally be due to power, and neither of these

Laboratory visit. The full study protocol was reviewed with each participant individually, and written assent was gathered from her. The participant then completed a series of questionnaires and tasks, administered by a graduate student, postdoctoral fellow, or research assistant. Measures relevant to this study are as follows: (a) Pubertal Development Scale (PDS; Petersen et al., 1988); (b) pre-/post- Auction Task salivary sample collection and at-home salivary sample collection instructions; (c) modified Auction Task (AT; van den Bos, Golka, et al., 2013); (d) Sensation Seeking Scale for Children (SSSC; Russo et al., 1991); (e) modified Barratt Impulsiveness Scale for adolescents (BIS-M; adapted from Fossati, Barratt, Acquarini, & De Ceglie, 2002); (f) Resistance to Peer Influence Scale (RPI; Steinberg & Monahan, 2007); and (g) Wechsler Intelligence Scale for Children, 4th Edition Vocabulary subtest (WISC-IV Vocabulary; Wechsler, 2003). These measures are described in detail below. The participant's photograph was also taken for the AT, and height and weight measurements were collected.[2] Each of these tasks was administered individually to the participant by a trained research staff, with no other participants in the room.

If a parent accompanied the participant to the laboratory, s/he completed a consent form, the Child Behavior Checklist (Achenbach, 2001), the MacArthur Scale of Subjective Social Status (Adler & Stewart, 2007), and questions regarding objective socioeconomic status. If the parent/guardian did not attend the session, s/he was required to complete and return the questionnaires and consent form prior to the laboratory visit. At the end of the laboratory visit, the participant was compensated $20 for the 90-minute laboratory visit, along with a small "prize" of up to $10 based on her performance on the Auction Task (see below). Parents who did not attend the laboratory visit were asked ahead of time whether they preferred to have the compensation for participation handed to the adult accompanying the child or given directly to the child.

Salivary sample collection. After completing pre-/post- Auction Task saliva sample collection in the laboratory, each participant was given detailed at-home collection instructions and a brief diary to fill out with her parent after each at-home collection. Each participant collected and returned two salivary samples (~1 ml), collected on two separate mornings at the same time of day. Parents were asked to return the samples and diary entries in person and were compensated an additional $20 gift card payment for doing so. We encouraged parents and participants to split this payment. If requested, reminder calls or texts were made in order to increase compliance. If parents were unable to drop off the samples, project staff picked up the samples and diaries from the participants' homes.

Debriefing. 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 (see below). The parent/guardian was encouraged to contact the research team with any questions or concerns.

Measures

Pubertal Development Scale (PDS). The widely-used Pubertal Development Scale

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variables was significantly associated with outcome variables. Thus, these variables were not included in final analyses.

[2] Additional measures completed by the participant, but not utilized in this study, included (a) Single Target Implicit Attitudes Test (Karpinski & Steinman, 2006); (b) Word Association Task (Stacy, Ames, Ullman, Zogg, & Leigh, 2006); (c) Mild Non-Coital Sexual Behavior Questionnaire (Furman & Wehner, 1992); and (d) Tower of London (Berg & Byrd, 2002). Participants also viewed a short video clip of the television program Glee.

(PDS; Petersen et al., 1988) was used to determine pubertal stage. The PDS is a self-report measure consisting of five items for girls that address the development of body hair, changes in complexion, the occurrence of a growth spurt, breast development, and the onset of menarche. All questions except that concerning menarche (a dichotomy) are answered using a four-point scale. This measure can be used to assign a gonadal score (growth spurt, breast development, and menarche) and an adrenal score (pubic/body hair and complexion changes), as well as to assign pubertal stages (Shirtcliff, Dahl, & Pollak, 2009). The PDS was chosen because of its non-invasive nature, ease of completion, and good reliability and validity (Petersen et al., 1988; Shirtcliff, Dahl, & Pollak, 2009). In a large sample of girls and boys ages 9-14, the PDS was modestly correlated with physical exam stages (gonadal score: $\kappa = .36$, $\chi^2(16) = 93.0$, $p < .0001$; adrenal score: $\kappa = .36$, χ^2 $(16) = 90.6$, $p < .0001$); for girls, the PDS gonadal score captured basal hormone levels better than a physical exam (Shirtcliff, Dahl, & Pollak, 2009). In this investigation, a mean PDS score was utilized as a measure of general pubertal maturation.

Hormone samples. Morning saliva samples were assayed to determine levels of pubertal hormones (testosterone; estradiol; DHEA). As outlined above, participants practiced salivary sample collection in the laboratory before and after the Auction Task, and then collected two basal samples (~1 ml) on two separate mornings in 2 ml cryovials by passive drool using a household, two-inch straw. Participants were asked to collect the basal samples between seven and nine o'clock in the morning, and were instructed to rinse out their mouth with water 10 minutes before collecting each sample. In addition, participants 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.

Participants/parents 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/parents were asked to keep the samples in their home freezer until the time that they delivered them to the laboratory frozen and with provided ice packs. Saliva samples were labeled with the participant's ID number and stored in a -20° C laboratory freezer until they were analyzed. Each saliva sample was thawed and assayed within 24 hours in duplicate using well-established highly sensitive enzyme immunoassay kits (www.salimetrics.com). For each hormone, the sample was reanalyzed if the CV for the duplicate measurements was ≥ 8%. The two basal samples for each hormone were averaged to determine a mean basal estradiol, DHEA, and testosterone level for each participant.[3]

Auction Task. A version of the computerized Auction Task (van den Bos, Golka, et al., 2013), modified for adolescents, was used to assess socio-affectively motivated behavior. 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. After completing practice rounds, the participant was shown pictures of nine girls as well as brief profiles of each, and told that the girls were participating in the study at other sites. In reality, no other girls were playing the task, and the photos shown to the participant were stock photos. The participant was asked to rank order the other girls to play with in the task. The participant's 1st, 2nd, 4th, 6th and 7th choice were selected by the computer to increase the believability of mutual rankings.

[3] Saliva samples collected before and after the Auction Task (not utilized in this investigation) were similarly assayed.

During the task, the participant's photo and the stock photos of the "other players" appeared at the bottom of the screen, and the participant was assigned virtual funds of $100. Each round, the participant was shown a picture of a piece of luggage, as well as the estimated value of the item inside the luggage (e.g., $10 ± $2). The participant was asked to bid on the luggage. She was told that each player enters *one sealed bid* per round, and then the name and photo of the winner of the auction (i.e., highest bidder, actually determined by computer algorithm) would be displayed to all of the players at the end of the round. The winner of the each round won or lost money depending on the actual value of the luggage, but this monetary information was not shared with the other players. Those who did not win the auction (i.e., did not make the highest bid, actually determined by computer algorithm) did not win or lose any money. *Only the participant knew how much she bid and how much she won or lost each round.* The participant played 30 discrete rounds of this task; former rounds did not affect later rounds, but the participant's total funds increased or decreased based on her bidding each round.

For example, a participant could be shown a picture of a piece of luggage with an estimated value of $12 ± $3. If she bid $15 on the luggage, she might be informed that she won the auction, and her name and picture would be displayed on the screen for the "other players" to see. She might then be told that the actual value of the luggage was $14, and that she lost $1. Her total funds would decrease by $1; however, the "other players" would not be made aware of this information. The participant would then continue with a new round of bidding. This task assessed the participant's willingness to incur losses (overbid) 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, Golka, et al., 2013). Following participation, trained staff briefly evaluated the participant's grasp of the Auction Task and trust in the paradigm. Each participant received a small payout (up to $10) upon completion of the study, contingent on her funds at the end of the task.

Auction Task data were utilized in two ways: (a) a mean overbidding score (see van den Bos, Golka, 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.

Sensation Seeking Scale for Children (SSSC). The Sensation Seeking Scale for Children (SSSC; Russo et al., 1991) was used to evaluate sensation-seeking behaviors in each of the participants. The SSSC is a 26-item forced-choice self-report scale consisting of three factors (Thrill & Adventure Seeking; Drug & Alcohol Attitudes; Social Disinhibition) and a total sensation seeking score. Test-test reliability was found to be 0.71 ($p < .0001$) in an elementary school sample of 121 children ($\alpha = 0.49$; Russo et al., 1991). The total sensation seeking score was utilized in this investigation; it was conceptualized as a continuous variable, as it is thought to be normally distributed in the population. Total scores for each subscale were also utilized in follow-up analyses.

Barratt Impulsiveness Scale for Adolescents, Modified (BIS-M). The Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995) is a 30-item self-report measure of impulsive and non-impulsive behaviors (11 reverse-scored items) with six first-order factors (attention, cognitive instability, motor impulsiveness, perseverance, self-control, and cognitive complexity) and three second-order factors (attentional, motor, and nonplanning impulsiveness). The BIS-11-A is an Italian *a priori* adaptation of this measure for use with adolescents, which includes 11 minor modifications to items from the BIS-11, and four completely rewritten items (e.g., “I change residences” to “I change friends”; Fossati, Barratt, Acquarini, & DiCeglie, 2002). The internal consistency of this scale was found to be α = 0.78 in a sample of 563 high school students (Fossati et al., 2002). To adjust for potentially confusing idioms, this measure was very slightly adapted by Steinberg and colleagues (2008), and one item was further re-worded for the purposes of this study following pre-piloting. The resulting measure is hereafter referred to as “BIS-M” for simplicity. A mean BIS-M total score measured impulsivity in this study.

Resistance to Peer Influence Scale (RPI). The Resistance to Peer Influence Scale (RPI; Steinberg & Monahan, 2007) is a self-report scale that consists of 10 items (three reverse-scored). The participant is presented with a neutral peer influence situation with two “acceptable” response options (“some people….but other people….”). After the participant chooses a response option, she is asked to indicate the degree to which she belongs to the chosen group. Neutral wording is utilized to limit the influence of social desirability and increase the accuracy of self-report of peer influence. For example, one item reads “Some people think it’s more important to be an individual than to fit in with the crowd BUT other people think it is more important to fit it with the crowd than to stand out as an individual.” The internal consistency of the scale was found to be α = 0.74 in an American community sample of 11-24 year-olds (Steinberg & Monahan, 2007). A mean score for resistance to peer influence was computed for each participant.

Potential Covariates.

Socioeconomic Status (SES). Socioeconomic status (SES) was assessed with the MacArthur Scale of Subjective Social Status (Adler & Stewart, 2007) and examined as a potential covariate in all analyses. Parents were asked to indicate where they believed they fell on a 10-rung ladder compared to others in (a) their community and (b) the United States. Parents were also asked to report on objective measures of SES including education, occupation, income, and housing, but subjective measures were the primary indicator of SES, as the MacArthur Scale is both correlated with objective SES and may be a better predictor of health than are traditional objective SES measures (Adler, Epel, Castellazzo, & Ickovics, 2000).

Verbal Intelligence. The Vocabulary subtest of the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV; Wechsler, 2003) was used to approximate verbal intelligence, and scaled scores on this test were examined as a potential covariate in all analyses. The Vocabulary subtest requires participants to provide a definition for a series of vocabulary words of increasing difficulty. It is thought to measure verbal fluency, concept formation, word knowledge, and word usage. It is highly reliable (test-retest reliability = 0.92), and is the WISC-IV subscale that is most associated with Full Scale IQ (r = 0.72; Groth-Marnat, 2009).

Other Potential Covariates. Body mass index (BMI), calculated using laboratory height and weight measurements, was examined as a potential covariate, given its association with hormone levels. In addition, although no participants reported taking medications known to alter sex steroid concentrations within 24 hours of basal saliva sample collection, some participants had taken other medications (e.g., ibuprofen, allergy medication). Thus, a variable was created in which girls who had taken a medication (n = 7) were coded as 1, and those who had not were coded as 0. This medication variable was additionally examined as a potential covariate.

Results

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, medication status, 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 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 author.

Extreme values for two hormones (testosterone and estradiol; not DHEA), one SSSC subscale (Drug and Alcohol Attitudes; not total SSSC), 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 utilized because there were no values that were more than 3 SD above/below the median.

As expected, all hormones 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. BIS-M and SSSC were also moderately and significantly correlated with each other.

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, Talwar, & McClure, 2013), but their overbidding tended to decrease as the task progressed, consistent with principles of learning.

Regression Analyses

Prediction of sensation seeking and impulsivity. First, I tested the hypothesis that self-reported pubertal maturation and hormone levels would predict sensation seeking, but not impulsivity, via hierarchical regression. Covariates entered on the first step and the predictor variable of interest was entered on the second step in order to ascertain the change in R^2 associated with the predictor. The three hormones and PDS were each entered in their own regression model. Results are summarized in Table 2. PDS significantly predicted SSSC and only marginally predicted BIS-M. None of the hormones were associated with SSSC or BIS-M. Exploratory follow-up analyses were conducted to determine the subscales on the SSSC that were most strongly predicted by PDS. PDS was not a significant predictor of the Thrill and Adventure Seeking subscales ($\Delta R^2 = 0.02$, $\beta = .17$, $p = .264$), but significantly predicted Drug and Alcohol Attitudes ($\Delta R^2 = 0.07$, $\beta = .33$, $p = .029$) and especially Social Disinhibition ($\Delta R^2 = 0.15$, $\beta = .47$, $p = .001$).

Prediction of Auction Task. Next, to determine the developmental predictors of Auction Task performance, I again 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 (see Table 3). It is notable that age and vocabulary were associated with Auction Task performance in the opposite direction. This finding demonstrates that this type of socio-affectively motivated behavior that occurs at the expense strategic decision making *decreases* with age and verbal intelligence, in contrast to its association with pubertal maturation.

I also expected that sensation seeking would predict Auction Task overbidding. In addition, as a means of comparison, I inspected the association between BIS-M and Auction Task overbidding. I entered SSSC and BIS-M in separate models (see Table 3 for results). Sensation seeking predicted overbidding on the Auction Task after adjusting for age, verbal intelligence, and socioeconomic status, and BIS-M did so marginally. Exploratory follow-up analyses were conducted to determine the subscales of the SSSC that most strongly predicted Auction Task overbidding. Overbidding was significantly predicted by SSSC Thrill and Adventure Seeking ($\Delta R^2 = .07$, $\beta = .28$, $p = .020$) and Social Disinhibition ($\Delta R^2 = 0.07$, $\beta = .29$, $p = .023$), but not Drug and Alcohol Attitudes ($\Delta R^2 = 0.00$, $\beta = .04$, $p = .757$).

Moderation analyses. Next, I hypothesized that (a) impulsivity and (b) resistance to peer influence would moderate the association between sensation seeking and overbidding on the Auction Task. That is, I expected that those participants with high sensation seeking *and* high impulsivity or low resistance to peer influence would be most likely to overbid. These hypotheses were tested via hierarchical multiple regression analyses utilizing freely available software developed by Hayes and Matthes (2009; MODPROBE). For each regression, all covariates, the focal predictor, and the putative moderator were entered simultaneously on the first step. The interaction term was entered on the second step, and the change in R^2 was examined for statistical significance. Although impulsivity did not moderate the association between sensation seeking and Auction Task overbidding ($\Delta R^2 = 0.00$, $b = 0.00$, $p = .895$), resistance to peer influence did moderate this association ($\Delta R^2 = 0.10$, $b = 0.03$, $p = .004$). In particular, and in contrast to expectations, the association between sensation seeking and overbidding was strongest at high self-reported levels of resistance to peer influence (see Figure 1). At low levels of resistance to peer influence, sensation seeking did not reliably predict overbidding on the Auction Task, suggesting that other influences were at play in this case. Of note, there was no main effect for resistance to peer influence ($b = 0.06$, $p = .320$), but the simple effect of SSSC remained significant ($b = 0.02$, $p = .005$).

Multilevel Modeling

Hierarchical Linear Modeling (HLM v6.05; Raudenbush, Bry, Cheong, & Congdon, 2004) was used examine the persistence of overbidding over the course of the Auction Task. Thus, overbidding was the outcome of interest. A level-1 dummy coded variable represented the Auction Task bin (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 best-fitting base model that captured overbidding included this dummy variable ($\beta = -.07$; $p < .001$) and the intercept ($\beta = .91$; $p < .001$). 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 impact level-1 associations, specifically changes in overbidding across the task.[4]

Age, race/ethnicity, vocabulary, BMI, medication status, and multiple measures of sociometric status were examined first to assess their impact on overbidding over the course of the task. Vocabulary was significant predictor ($\beta = -.01$; $p = .003$), and age was a marginal

[4] 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.

predictor (β = -.01; *p* = .100), so they were included in the final model. Two measures of SES were significant predictors; for consistency with previous analyses, the Community Ladder (β = -.02; p < .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, predictors of interest were examined, adjusting for covariates. Hormones, PDS, SSSC, and BIS-M were each examined in separate models. As expected, PDS significantly predicted the slope of overbidding over the course of the Auction Task (β = .03; *p* = .032), in that more pubertal maturation predicted more persistent overbidding. A similar effect emerged for testosterone (β = .001; *p* = .005), as well as for SSSC (β = .004; *p* = .007) and BIS-M (β = .06; *p* = .002). Neither estradiol nor DHEA significantly predicted the persistence of overbidding over the course of the task.

Mediation Analyses

Finally, because PDS predicted SSSC as well as Auction Task overbidding in regression analyses, and SSSC predicted Auction Task overbidding, I sought to determine whether SSSC could partially explain the pathway from increased pubertal development to overbidding on the Auction Task. That is, could the higher levels of overbidding on the Auction Task observed with more pubertal development be explained by sensation seeking?

I tested mediation via bootstrap procedures (Shrout & Bolger, 2002) utilizing freely available software developed by Preacher and Hayes (2008; INDIRECT), with 10,000 bootstrap samples and 95% bias-corrected confidence intervals (CI). Mediated effects were considered significant if the CI did not contain zero (Shrout & Bolger, 2002). After adjusting for covariates (age, vocabulary, and SES), I found a direct effect of PDS on Auction Task overbidding (*b* = 0.12, p = .047), but no direct effect of SSSC on the Auction Task (*b* = 0.01, p =.130). Assessment of the indirect effects based on bootstrap procedures revealed that the 95% confidence interval contained zero, indicating no significant mediation (*b* = 0.03, CI = -.003, .091). I also tested the Social Disinhibition subscale of the SSSC as a potential mediator of the association between PDS and overbidding, given its prediction from PDS and to overbidding, with a similar pattern of results (*b* = 0.03, CI = -.012, .101).

Discussion

In this investigation, I sought to examine the developmental underpinnings of risk-taking tendencies in adolescence by examining pubertal contributions to socio-affectively motivated behavior at the expense of strategic decision making. I also aimed to clarify the role of sensation seeking and measures of cognitive control at this important inflection point. 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.

Several interesting findings emerged. Adjusting for covariates, self-reported pubertal maturation significantly predicted sensation seeking but not impulsivity, consistent with existing literature on the development of reward-related processes versus cognitive control systems (e.g., Steinberg et al., 2008). In particular, pubertal development predicted drug and alcohol attitudes and social disinhibition. In contrast to self-reported pubertal development, pubertal hormones did not predict sensation seeking. There are several possible explanations for this null finding. For example, the development of sensation seeking may be tied to aspects of pubertal maturation other than hormonal changes, and/or the PDS may be a more sensitive measure of processes tied to the development of sensation seeking. Of note, and in contrast to a significant body of literature, our self-reported impulsivity measure was not associated with age either in bivariate associations or in hierarchical regression analyses. It is possible that our narrow age range, though advantageous in examining the pubertal maturation while controlling for age, interfered with our ability to see age-related changes in impulsivity. In addition, our behavioral measures may have in some ways conflated impulsivity with sensation seeking and inattention.

After adjusting for covariates, self-reported pubertal development predicted mean overbidding on the Auction Task, as did testosterone. 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 highlights the importance of the bold, socio-affectively motivated behavior that emerges with pubertal maturation in contrast to the more strategic 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, Tong, Chen, Bassett, Stein, & Meyer-Lindenberg, 2008), and provides additional evidence of the importance of social status as particularly rewarding with increased pubertal maturation (e.g., Crone & Dahl, 2012). Furthermore, the association between testosterone and Auction Task performance is in line with research by van den Bos and colleagues (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, Newman, Brown, & Beer 2003).

Sensation seeking also predicted overbidding on the Auction Task, and impulsivity did so marginally. The specific aspects of sensation seeking that were most related to overbidding were thrill and adventure seeking and social disinhibition, consistent with our conceptualization of gaining social status on the task as a somewhat thrilling social experience. Although self-reported sensation seeking and impulsivity did not interact to predict overbidding on the Auction Task, sensation seeking did interact with resistance to peer influence. In contrast to our expectations, at high and mean levels of resistance to peer influence, a girl’s level of sensation seeking was significantly associated with overbidding. At low levels of resistance to peer influence, there was virtually no association between sensation seeking and Auction Task performance. Although there was no simple effect of resistance to peer influence, it is clear that this is an important variable to consider. For a girl who is easily influenced by peers, it appears that factors other than sensation seeking, perhaps characteristics of the environment or context (e.g., peer composition) play a more important role in determining her behavior than her own level of sensation seeking. This interpretation parallels findings by Kretsch and Harden (2013) in which pubertal status predicted risky decision making when adolescent boys and girls were alone, but this individual-level effect became less important with the presence of peers.

In multilevel modeling, PDS and testosterone predicted the *slope* of overbidding over the course of the Auction Task. This 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). Sensation seeking and impulsivity also predicted persistence of nonstrategic bidding behavior, suggesting these characteristics may have also interfered with learning to bid more strategically.

Finally, in mediation analyses, I examined a possible pathway from pubertal development to sensation seeking to Auction Task performance. Despite associations amongst these variables, sensation seeking did not appear to even partially mediate the direct pathway from pubertal development to overbidding on the Auction Task. This null finding suggests that, although sensation seeking and socially motivated behavior may interact to predict real-world risk behavior and may both increase with pubertal maturation, they may be largely separate processes. For example, as discussed above, we found that socio-affectively motivated behavior was predicted by testosterone, as has been consistently described in the literature in human and non-human primates, especially when status is not yet established or stable (e.g., Josephs, Sellers, Newman, & Mehta, 2006; Morgan et al., 2000). In contrast, sensation seeking was predicted by pubertal maturation but not testosterone and may emerge via a related but separate process such as dopaminergic reorganization (e.g., Andersen, Rutstein, Benzo, Hostetter, & Teicher, 1997).

The current findings invite further investigation of the development of risk taking. As a next step, I plan to examine the ways in which a putative pathway from pubertal development to sensation seeking and socio-affectively motivated behavior may ultimately lead to real-world risk behavior such as substance abuse, sexual risk taking, or risky driving. Given the young age of the girls on which this research is based, it will be important to oversample at-risk youth, capture the earliest stages of risk behavior, and/or complete longitudinal investigations that predict later behavior from laboratory measures. It will also 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.

Although pubertal maturation, sensation seeking, and socio-affectively motivated behavior all 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 sensation seeking and 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 & Dahl, 2012).

Several limitations are noteworthy. First, in addition to measurement of hormones and a behavioral task, I utilized several self-report measures. It is possible that some of the associations I found, such as that between sensation seeking and impulsivity, are due to shared method variance. Still, many key analyses included both self-report and other measures. In addition, there is some evidence that self-reported pubertal development on the PDS is reliable and valid, on top of its ease of completion and non-invasiveness (Petersen et al., 1988; Shirtcliff, Dahl, &

Pollak, 2009). Despite this, future work should strive to incorporate behavioral measures whenever possible. A related issue concerns our measure of pubertal hormones. Without a longitudinal design, it is difficult to 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 noise in our hormonal measures, including circadian rhythm and menstrual cycle timing. These complications could explain the lack of association between hormones and SSSC described above.

Also, the version of the Auction Task utilized in this study is a new adaptation of previous versions. I took several steps to ensure the appropriateness of this task for youth and its believability to them as a social task. First, instructions were carefully adapted for youth in our pre-piloting phase. Second, staff took a picture of the participant and allowed her to choose preferable opponents, but did not pair this participant with all of her top-choice peers to simulate mutual nominations. In addition, staff gave the girls quiz questions with corrective feedback as well as practice trials, and girls had an opportunity to ask questions about the task. Fourth, following completion of the task, we asked girls about their understanding of the task and any remaining questions. Through the implementation of these steps, I am confident that the task was both well understood by our participants and believable. As expected, I did find that with increased verbal abilities as measured by WISC-IV Vocabulary, girls' performance was increasingly strategic (i.e., less overbidding). In some ways, the highly verbally skilled nature of the sample (see Method) is an advantage in that it gives confidence in participants' comprehension of the task. Still, further adjustments may need to be made to ensure the appropriateness of this task for a more generalizable sample. In addition, it will be important to continue to investigate the nuances of Auction Task behavior. Although we have highlighted the importance of socio-affective motivation, it is possible that for some participants a more explicitly cognitive valuing process was at play. In order to validate the use of this task as a measure of socio-affectively motivated behavior, future research should investigate predictors of Auction Task behavior and more closely examine participants' motivation (both explicit and implicit) for this behavior.

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., Rothspan & Read, 1996; Wills, Sandy, & Yaeger, 2001), 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., Fuchs, 1982; Lamm, Schmidt, & Trommsdorff, 1976; Guthrie, Butler, & Ward, 2009).

In sum, these findings provide additional evidence for the association between pubertal development and sensation seeking, and highlight pubertal girls' drive for the affective experience of social status. 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. Next steps will include the mapping of these processes onto real-world risk behavior as well as the investigation of sex/gender differences.

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Table 1.

Study Variable Descriptives and Correlations.

	1	2	3	4	5	6	7	8	9	10	N	M	SD
1. Age											63	12.74	1.09
2. Vocab	-.11										63	13.87	2.61
3. SES	.06	.05									63	6.83	1.47
4. PDS	.56***	-.08	.13								62	2.68	0.65
5. Testo.	.13	-.08	-.05	.29*							60	54.01	21.43
6. Est.	.31*	-.22†	-.14	.45***	.58***						60	1.24	0.54
7. DHEA	.35**	-.14	-.04	.39**	.66***	.43***					60	173.14	110.68
8. SSSC	.24†	.06	-.04	.41**	.22†	.10	.11				63	11.97	5.13
9. BIS-M	.17	-.13	.13	.28*	.07	.05	-.04	.52***			63	2.05	0.41
10. RPI	-.10	.18	-.02	-.11	-.09	-.01	-.10	-.14	-.12		63	2.90	0.45
11. AT	-.26*	-.24†		.09	.28*	.05	.11	.19	.18	.07	63	0.72	0.26

Note. Vocab = WISC-IV Vocabulary, SES = Socioeconomic Status (Community Ladder), PDS = Pubertal Development Scale, Testo = testosterone, Est. = estradiol, SSSC = Sensation Seeking Scale for Children, BIS-M = Barratt Impulsiveness Scale 11 for Adolescents (Modified), RPI = Resistance to Peer Influence, AT = Auction Task. Valid *N* listwise = 59. † = $p < .10$, * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 2.

Prediction of Sensation Seeking and Impulsivity from Self-Reported Pubertal Development and Pubertal Hormones.

Predictor	SSSC			BIS-M		
Variable	β	R	ΔR^2	β	R	ΔR^2
Step 1		.25	.06		.24	.06
Age	.25†			.15		
Vocab	.09			-.12		
SES	-.05			.13		
Step 2		.43	.12**		.32	.05†
PDS	.42**			.26†		
Step 1		.29	.09		.20	.04
Age	.25†			.13		
Vocab	.18			-.07		
SES	-.05			.12		
Step 2A		.35	.04		.20	.00
Testo.	.20			.05		
Step 2B		.30	.00		.20	.00
Est.	.06			.02		
Step 2C		.30	.00		.22	.01
DHEA	.05			-.10		

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, SSSC = Sensation Seeking Scale for Children, BIS-M = Barratt Impulsiveness Scale 11 for Adolescents (modified). † = $p < .10$, * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 3.

Prediction of Auction Task Overbidding from Self-Reported Pubertal Development, Pubertal Hormones, Sensation Seeking, and Impulsivity.

Predictor Variable	β	R	ΔR^2
Step 1		.42	.18*
Age	-.28*		
Vocab	-.24*		
SES	-.20†		
Step 2		.50	.09*
PDS	.37**		
Step 1		.41	.17*
Age	-.28*		
Vocab	-.24†		
SES	-.21†		
Step 2A		.50	.08*
Testo	.29*		
Step 2B		.41	.00
Est.	.07		
Step 2C		.45	.03
DHEA	.19		
Step 1		.42	.18**
Age	-.28*		
Vocab	-.26*		
SES	-.20†		
Step 2A		.50	.07*
SSSC	.28*		
Step 2B		.48	.05†
BIS-M	.24†		

Note. Target predictors (PDS; Testo.; Est., DHEA; SSSC; BIS-M) 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, SSSC = Sensation Seeking Scale for Children, BIS-M = Barratt Impulsiveness Scale 11 for Adolescents (modified). † = $p < .10$, * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

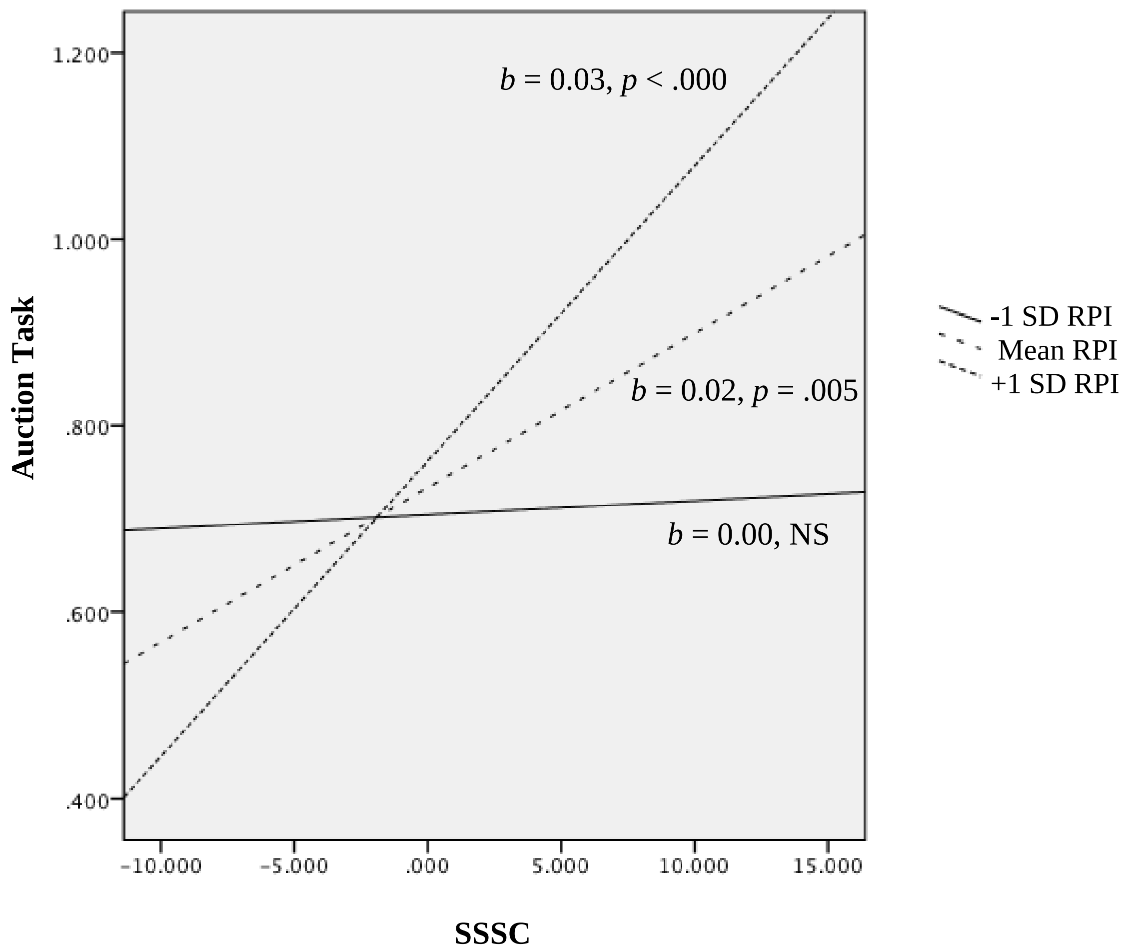

Figure 1. Interaction between sensation seeking and resistance to peer influence in predicting Auction Task overbidding. Graphed values are mean centered. RPI = Resistance to Peer Influence, SSSC = Sensation Seeking Scale for Children.