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Pubertal Development and Peer Influence on Risky Decision-Making

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Pubertal Timing and Peer Influence on Risky Decision-Making

by

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Abstract

Pubertal Timing and Peer Influence on Risky Decision-Making

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Adolescents engage in more risky behavior when they are with peers and show heightened susceptibility to peer influence relative to children and adults. Recent experimental studies suggest that peer influence on adolescent risk-taking may be mediated by activity in reward-related regions of the brain (Gardner & Steinberg, 2005; Chein et al., 2011). Because reward-related regions are modified by the hormonal changes of puberty, it is possible that the heightened influence of peers on adolescent risk-taking is more closely linked to pubertal development than chronological age. The current study examined whether the effect of peers on risk-taking was moderated by pubertal status. Participants (62 youth, ages 11-16) completed a performance-based measure of risky decision-making, once alone and once in the presence of two peers. Pubertal timing was assessed using self-report. Adolescents made riskier decisions in the presence of peers, and more advanced pubertal development predicted greater risky decision-making, controlling for chronological age. However, the relationship between pubertal timing and risk-taking was only apparent when adolescents completed the task

alone. The effect of peer presence on risky decision-making was attenuated for adolescents with more advanced pubertal development. These findings suggest that the presence of peers may override biologically-based individual differences in propensity for risk-taking.

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Chapter 1: Introduction

Adolescents show elevated involvement in an array of risk-taking behaviors, including criminal behavior, unsafe sexual practices, and initiation of alcohol use (Arnett, 1992; Jessor & Jessor, 1977; Steinberg, 2008). The consequences of adolescent risk-taking behaviors are profound: For example, mortality from unintentional injury (including motor vehicle accidents) peaks in adolescence, accounting over 40% of deaths among 10-24 years olds (Ozer & Irwin, 2009). Not surprisingly, then, researchers have paid considerable attention to the biological and social changes in adolescence that result in a developmental period of unique psychological vulnerability.

RISK-TAKING AND THE DUAL SYSTEMS MODEL

One biological explanation that has been explored in recent research is that adolescent risk-taking results from the temporal gap in the development of two distinct neurological systems. As articulated in the Dual Systems Model (Steinberg et al., 2008; Casey, Getz, & Galvan, 2008; Somerville, Jones, & Casey, 2010), the *cognitive control system*, which includes prefrontal cortical regions and their connections to subcortical areas, governs executive functioning and the processes necessary for goal-directed behavior, including impulse control and self-regulation. The cognitive control system appears to develop gradually throughout adolescence and young adulthood (Casey et al., 2008; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). In contrast, the *socioemotional system* is thought to mature relatively rapidly during early adolescence. This system comprises dopaminergic pathways in limbic and paralimbic regions of the brain, including the ventral striatum and nucleus accumbens, amygdala, and medial prefrontal cortex (Steinberg, 2008; Nelson, Leibenluft, McClure, & Pine, 2005), which underlie responses to novelty, emotion, and reward (Ikemoto, 2007; Schultz, 2006; Tobler et al., 2005). The maturation of the socioemotional system results in heightened sensitivity to the potential rewards of risky activity, such as financial gain (Zald, Boileau, El-Dearedy, Gunn, McGlone, et al., 2004), sexual pleasure (Pfaus, 2009), and social approval (Nelson et al., 2005), as well as the physical arousal induced by the act itself (Zuckerman, 1979). At the same time, adolescents may lack the cognitive control necessary to inhibit reckless or impulsive behavior, particularly in the context of emotional arousal. Thus, the gap between the arousal of the socioemotional system and the relatively slower maturation of the cognitive control system is thought to result in a period of elevated vulnerability to risk taking during middle adolescence (Steinberg, 2008; Casey & Jones, 2010; Galvan, Hare, Parra, Penn, Voss, et al., 2006; Chambers, Taylor, & Potenza, 2003; Spear, 2011).

Several lines of evidence are consistent with rapid maturational changes in the socioemotional system during early- to mid-adolescence. First, both cross-sectional and longitudinal studies have found that mean levels of sensation seeking (defined as a preference for novel or physically exciting experiences) rapidly increase from early- to mid-adolescence (Harden & Tucker-Drob, 2011; Steinberg et al., 2008), and adolescents who increase more rapidly in sensation seeking show more marked spikes in delinquent behavior (Harden, Quinn, & Tucker-Drob, 2012). Moreover, human imaging studies suggest that, relative to children and adults, adolescents show increased activation in the ventral striatum in response to reward, as well as heightened subcortical activation during risky decision-making (Ernst, Nelson, Jazbec, McClure, Monk, Leibenluft, et al., 2005; Galvan et al., 2006; Casey et al., 2008; Chein, Albert, O'Brien, Uckert, & Steinberg, 2011) Similar developmental changes are evident in non-human animals: Adolescent rodents exhibit greater novelty-seeking and impulsivity (Laviola, Macri, Morley-Fletcher,

& Adriani, 2003; Spear, 2000), and greater dopamine release in response to rewarding stimuli (Robinson, Zitzman, Smith, & Spear, 2011), relative to adults.

THE ROLE OF PUBERTAL DEVELOPMENT

Development of the socioemotional system may be more closely tied to pubertal development than to chronological age. In addition to causing extensive somatic changes, the hormonal events at puberty also precipitate a cascade of neural changes – "a second period of structural reorganization and plasticity in the brain" (Blakemore, Burnett, & Dahl, 2010). Specifically, the release of gonadal hormones and remodeling of gonadal steroid receptors in the limbic system may lead to changes in emotional responses to social stimuli (Steinberg, 2008; Nelson et al., 2005). Gonadal hormones may also exert indirect effects on the socioemotional system through their regulation of other neurotransmitter systems, including the dopamine, oxytocin, and opioid systems (Nelson et al., 2005; McEwen, 2001). Consistent with this hypothesis, pubertal status – controlling for age – is associated with sensation seeking (Martin et al., 2002; Steinberg et al., 2008; Zuckerman, Buschbaum, & Murphy, 1980). In addition, among early adolescents, more advanced pubertal development is associated with a greater postauricular reflex (a measure of appetitive motivation) in response to pleasurable visual stimuli (Quevedo, Benning, Gunnar, & Dahl, 2009), greater amygdala responding to threatening social stimuli (angry human faces; Forbes, Phillips, Ryan, & Dahl, 2011), and less activity in the striatum and greater reactivity in the medial prefrontal cortex in response to monetary rewards (Forbes & Dahl, 2010).

Given the link between pubertal development and activity in the socioemotional system, the "size" of the maturity gap between the socioemotional and cognitive control systems – and the resulting propensity for risk-taking behavior – may be determined by pubertal timing. That is, adolescents who experience the physical changes of puberty at an earlier chronological age, and who are thus at a more advanced stage in their pubertal development than their same-age peers, are predicted to be *more* sensitive to the rewarding aspects of risk-taking behavior, without any corresponding increase in their capacities for impulse control. More generally, a large body of observational research has found that earlier pubertal timing is associated with increased involvement in delinquency and substance use (reviewed in Mendle, Turkheimer, & Emery, 2007; Mendle & Ferrero, 2012). Most of the research on pubertal timing has focused on girls' menarcheal age and has emphasized the unique environmental challenges faced by early maturing girls. However, recent genetically-informed research has suggested that, for girls, the association between earlier pubertal timing and delinquent behavior, specifically, can be attributed to biological rather than environmental mechanisms (Harden & Mendle, 2011). Moreover, associations between earlier pubertal timing and risk-taking behaviors are also evident in boys (Duncan, Ritter, Dornbusch, Gross, & Carlsmith, 1985; Tschann, Adler, Irwin, Millstein, Turner, et al., 1994; Bratberg, Nilsen, Holmen, & Vatten, 2007), although male pubertal development has been the focus of considerably less research.

In summary, previous empirical and theoretical work suggests that (a) adolescents' propensity to engage in risk-taking behavior is the result of a temporal imbalance between the maturity of the socioemotional and the cognitive control systems results; (b) changes in brain activity in regions comprising the socioemotional system are tied to the process of pubertal development; (c) individuals who experience puberty earlier show increased involvement in a wide variety of risk-taking behaviors.

PUBERTAL DEVELOPMENT AND PEER INFLUENCE

In addition to these biological effects, advanced pubertal timing may moderate social influences on risk-taking. Along with increases in sensation-seeking and reward-motivated behavior, adolescence is also characterized by a dramatic social re-orientation towards valuing peer, romantic, and sexual relationships (Blakemore, 2008; Forbes & Dahl, 2010; Spear, 2009; Larson & Richards, 1991). This social reorientation serves to reinforce predispositions toward risk-taking behavior: Adolescents report engaging in more substance use (Chassin, Hussong, & Beltran, 2009), criminal activity (Zimring, 1998), and risky driving (Ouimet et al., 2010) when they are with their peers. While it is likely that selection accounts for some part of the "peer effect" evident in observational studies (adolescents with higher propensity for risk-taking may gravitate toward similarly risk-inclined peers), there is also evidence of a causal relationship between peers and adolescent risk-taking from studies using longitudinal (Curran, Stice, & Chassin, 1997), genetically informative (Harden et al., 2008), and instrumental variable approaches (Christakis & Fowler, 2007; Norton, Lindrooth, & Ennett, 1998).

Using an experimental approach that assessed risk-taking with a behavioral task, Gardner & Steinberg (2005) found that adolescents (but not adults) who were randomly assigned to complete the experiment with two same-sex peers observing made riskier decisions than those who completed the study alone. In a follow-up study using fMRI, Chein et al. (2011) found that adolescents showed increased activity in reward-related brain regions (ventral striatum and orbitofrontal cortex) when making behavioral decisions in the presence of peers, compared to when they were alone. Moreover, individual differences in the "neural peer effect" (i.e., the difference in striatal activity in the peer versus the alone conditions) were significantly associated with self-reports of resistance to peer influence. These results were interpreted to mean that peers “sensitize” the socioemotional system, resulting in increases in reward-motivated behavior.

How these peer effects intersect with individual differences in pubertal development, however, is unclear. On the one hand, puberty may sensitize adolescents to the effects of peers. Forbes and Dahl (2010) suggested that the social re-orientation of adolescence was driven, at least in part, by the hormonal events of puberty, mediated in part by gonadal hormones influence on oxytocin. Tangential evidence for this hypothesis comes from Gardner and Steinberg (2005) who found the effect of peer presence on risk-taking was greater among non-White adolescents – who have, on average, earlier pubertal timing than White adolescents. In addition, Harden and Mendle (2012) found that non-shared environmental influences on delinquency (which included non-familial influences such as peers) were more pronounced for earlier maturing girls than later maturing girls. On the other hand, the effect of peers on risk-taking may be attenuated among more pubertally-advanced adolescents, whose socioemotional systems are already comparatively sensitized. Exposure to peers may also *suppress* biologically-influenced individual differences in risk-taking, including those that are related to pubertal timing. For example, an early-maturing adolescent who is high in sensation-seeking and generally inclined to take risks may take fewer risks in the presence of peers in response to overt or implicit peer pressure. The "social push" hypothesis posits that biological influences on delinquent behavior are less apparent in contexts with strong social pressure (Raine, 2002). This hypothesis may also apply to risky decision-making in general, such that individual differences in propensity for risk-taking due to pubertal development may not be expressed in the presence of peers. This question has not yet been examined empirically.

Goals of the Current Study

The current study examined the associations between pubertal development, peer presence, and risky decision-making on an experimental task. In particular, this study tested three main hypotheses. First, after controlling for chronological age, more pubertally advanced adolescents were expected to show more risky decision-making than pre- or early pubertal adolescents. This prediction follows from the Dual Systems Model and the association between puberty and activity in the socioemotional system. Second, in accordance with previous experimental findings (Chein et al., 2011; Gardner & Steinberg, 2005), adolescents were expected to show more risk-taking behavior when in the presence of same-age peers than when alone. Third, given evidence of hormonally-driven changes in social behavior during adolescence, the effect of peers on risk-taking behavior was expected to be magnified among more pubertally-advanced adolescents.

Chapter 2: Method

PARTICIPANTS AND PROCEDURES

Participants were 62 youth (50% male), ages 11 to 16 (M age=13.6, SD=1.67) enrolled in after-school programs for socioeconomically disadvantaged children and adolescents in a metropolitan area in the southwest United States. The sample was predominantly African American (63.9%) and Hispanic (19.7%). Seventy-six percent of participants reported receiving free or reduced-price lunch at their school, for which children are eligible if their family income is at or below 185% of the federal poverty line.

Participants were recruited from two after-school programs in the Austin area, and all recruitment and data collection occurred on-site. Investigators distributed parental consent forms to all youth ages 11-16. Adolescents who brought back signed parental consent forms were assigned to a group with two peers of the same age (within one year) and gender. Although the participants in each group were not always close friends (they were not self selected), all participants knew one another. This method of group assignment was consistent with the procedure used by previous studies (Gardner & Steinberg, 2005), and has the advantage of simulating the context in which adolescent risk-taking often occurs -- adolescents are often with same gender peers who are not necessarily close friends. Moreover, given evidence that adolescents are more influenced by close friends than by acquaintances (McPhee, 1996), this method provides a more conservative test of the hypothesis that peers influence adolescent behavior (Gardner & Steinberg, 2005).

Each participant completed a simulated driving task designed to measure risky decision making twice--once individually (Alone condition) and once while being observed by his/her two peers (Peer condition). In the Peer condition, the peer observers were instructed that they could talk to the player and to each other during the task and that they could give the player advice on how to proceed. The player was instructed that he/she could choose whether or not to follow the advice of the observing peers. Groups were counterbalanced for the order in which the behavioral tasks were completed, with half the groups completing the task in the Alone condition first and half completing it in the Peer condition first. Within the Peer condition, the order in which the participants completed the task was also recorded. In addition to the risky driving task, a working memory test was administered by trained research assistants. All participants were compensated $25 for their time. This procedure was approved by the Institutional Review Board of the University of Texas.

MEASURES

Pubertal Status

Pubertal status was assessed with the Pubertal Development Scale (PDS; Petersen, Crockett, Richards, & Boxer, 1988), a widely used self-report measure of perceived pubertal changes. The PDS includes five items asking about skin, height, underarm and pubic hair, breast development (for females), menarche (for females) and voice changes (for males). Participants rated each measure with the following scale: 1="Has Not Yet Begun to Change," 2="Has Barely Started," 3=Is Definitely Underway," 4="I Don't Know."

Pubertal development is triggered by two distinct hormonal release signals--the early release of adrenal hormones and the later release of gonadal hormones (testosterone and estradiol). Using an algorithm developed by Shirtcliff & colleagues (E. Shirtcliff, personal communication), PDS scores were translated into four-point scales, to parallel Tanner stages, for each of these systems. For both sexes, the Adrenal Scale (PDSA) was computed based on skin changes and pubic hair development. The Gonadal Score (PDSG) was computed based on growth spurt, breast development, and menarche for girls and on growth spurt, voice changes, and facial hair for boys. Because males and females were aggregated in a single group, we used the Adrenal stage as the primary measure of pubertal development for these analyses. The PDS has been shown to have high reliability (α=.77 for boys, α=.81 for girls; Shirtcliff, Dahl, & Pollak, 2009). PDS scores have been shown to predict basal hormone levels (estradiol, testosterone, and DHEA) as well as physical examinations (Shirtcliff, Dahl, & Pollak, 2009). The median stage for both adrenal and gonadal scales was 3.

Risky decision-making

Risky decision-making was assessed using *The Stoplight Game* (Chein et al., 2011; Steinberg et al, 2008; Gardner & Steinberg, 2005), a simulated driving task in which the player "drives" a car along a straight track to a specified location. The game was played on a laptop computer and was set up from the driver's point of view. The game required players to choose between a low-risk, low-benefit option and a high-risk, high-benefit option under conditions of uncertainty. Performance on the task has been shown to correlate with self-reported measures of risk-taking behavior and sensation seeking and to discriminate between sensation seeking and impulsivity (Gardner & Steinberg, 2005; Steinberg et al., 2008). The objective of the game was to “drive” the car to a specified location in the shortest amount of time (under 5 minutes) for a hypothetical monetary reward. The car passed through 20 intersections, each of which had a stoplight that cycled from green to yellow to red as the vehicle approached it. When the light turned yellow, the player decided whether to stop, which resulted in a short delay, or to go through the intersection and risk a “crash” with another vehicle, which resulted in a longer delay. The timing of the traffic signals and the probability of a crash were varied--at some intersections, not braking in time inevitably resulted in a crash, while at others, it was possible to drive through safely. Each intersection had three possible outcomes: 1) the player applied the brakes and safely stopped, 2) the player went through the intersection successfully, or 3) the player crashed into another car, which could result from either failure to brake at all or failure to brake in time to avoid the crash. The computer recorded the total time to complete the task, the outcome at each intersection, and the latency between the appearance of the yellow light and the application of the brakes. The current study used two primary outcome variables--Percentage of Risky Decisions, which was percentage of intersections at which the player did not stop, and Latency to Brake, which was the average time between the appearance of the yellow light and the application of the brakes. If the participant did not apply the brakes on a round, a maximum value was imputed for Latency to Brake to reflect the time that the player had the opportunity to brake, but did not. In the case of a crash, this was the time between the yellow light and the crash. Otherwise, this was the time between the yellow light and the beginning of the next round. The mean Percentage of Risky Decisions was 30% (SD=.18); the mean Latency to Brake was 1676.75 ms (SD=465.92).

Working memory

Working memory was assessed using a digit span memory test similar to the Wechsler digit span subtest. Participants were asked to recall digit sequences of increasing length. The total number of sequences that were accurately recalled was used as an index of working memory (maximum possible score 26). The mean number of correctly recalled sequences was 13.11 (*SD*=2.84).

ANALYTIC PLAN

The current study aimed to assess three main hypotheses: 1) Adolescents would engage in more risky decision-making when they were with peers (main effect of peer condition); 2) Late-pubertal adolescents would engage in more risky behavior than early-pubertal adolescents (main effect of pubertal status); and 3) Late-pubertal adolescents would be more susceptible to peer influence on risk-taking than early-pubertal adolescents (condition x status interaction).

Analyses were performed using R version 2.11.1. The Linear Mixed Model (LMM) procedure was used to account for multiple observations for individuals and for individuals clustered within groups. Separate analyses were conducted for each outcome variable (Risky Driving Index and Latency to Brake) and for each measure of pubertal development (adrenal and gonadal). In addition, for each analysis, age and working memory were entered as continuous predictor variables, and gender, race, and condition order were entered as fixed factors.

Chapter 3: Results

Results from the LMM analyses, using adrenal score as the measure of pubertal development, are shown in Table 1. For the percentage of risky decisions, we found no significant main effect for condition ($t(52) = 1.76$, $p = .09$). A main effect for pubertal status was found, with more advanced development predicting riskier decision-making, $t(29) = 2.17$, $p<.05$. A status x condition interaction was found. Contrary to predictions, we found that adolescents with more advanced pubertal status were less risky in the Peer Condition, $t(52) = -2.11$, $p < .05$. As shown in Figure 1, risk-taking appeared to increase with pubertal status, but only in the Alone condition. There was also a positive effect of working memory on percentage of risky decisions. Higher scores on the digit span task, which reflected greater working memory skills, were associated with more risky decision-making, $t(29) = 2.07$, $p < .05$.

For latency to brake, a main effect of condition was found, $t(52) = 2.05$, $p < .05$; adolescents in the Peer condition had greater latency to brake, indicating greater risk-taking among peers, as predicted. A main effect for adrenal pubertal status was also found. More pubertal development predicted greater risk-taking, $t(29) = 3.13$, $p < .01$. Again, there was a status x condition interaction in the opposite direction than predicted, $t(52) = -2.39$, $p < .05$. The association between pubertal development and risk-taking was only apparent in the Alone Condition, as shown in Figure 2.

Secondary analyses were conducted using the gonadal measure of pubertal development, yielding different results, as shown in Table 2. For the percentage of risky decisions, there were no main effects of condition ($t(52) = .29$, $p = .77$), or gonadal pubertal status ($t(29) = .71$, $p = .48$) and no status x condition interaction ($t(52) = -.50$, $p = .62$) As in previous models, there was a significant positive association between digit span score and percentage of risky decisions, $t(29) = 2.25$, $p < .05$. Likewise, for latency to brake, there were no main effects of condition ($t(52) = .54$, $p = .59$) or status ($t(29) = .50$, $p = .62$) and no status x condition interaction ($t(52) = -.73$, $p = .47$). The association between digit span score and latency to brake was again significant, indicating riskier decision-making among adolescents with better working memory, $t(29) = 2.10$, $p < .05$.

Chapter 4: Discussion

The current study examined the influence of pubertal development and peer presence on risky decision-making in adolescents using an experimental paradigm. As predicted, results showed that after controlling for chronological age, self-reported adrenal pubertal development predicted risky decision-making on a risk analogue task. Adolescents showed more risk-taking behavior when they completed the task in the presence of peers than when completing the task alone. However, the effect of adrenal pubertal development on risk-taking was only apparent when adolescents completed the task alone.

The main effect of pubertal development on risky decision-making is consistent with the large body of evidence showing higher rates of risk-taking in adolescents with more advanced pubertal development (Tschann, et al., 1994; Graber, Lewinsohn, Seeley, & Brooks-Gunn, 1997; Dick, Rose, Pulkkinen, & Kaprio, 2001). Adolescents—particularly girls—with early pubertal timing show higher rates of delinquency, substance use, and risky sexual activity (Mendle, Turkheimer, & Emery, 2007). Recent research suggests that this may be due to the temporal gap between the development of the socioemotional system, which is linked to pubertal maturation, and the cognitive control system (Casey & Jones, 2010; Spear, 2011; Nelson et al., 2005; Steinberg et al., 2008; Forbes & Dahl, 2010). The neurological mechanisms of the behavioral outcomes in this study are unknown; however, the finding that risk-taking was associated with pubertal status controlling for chronological age is consistent with this biological model. This study is one of the first to examine the relationship between puberty and risky behavior using a lab-based task. There is a growing interest in using behavioral measures to measure developmental differences in risky decision-making (Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Smith, Xiao, & Bechara, 2011; Cauffman, Shulman, Steinberg, Claus, Banich, et al., 2010). Yet despite the robust association between pubertal timing and risky behavior that has been found in correlational research, few experimental studies have considered pubertal timing as a predictor. These findings highlight the importance of considering pubertal development in experimental studies of risky behavior.

This study also provides support for a causal relationship between peer context and risky decision-making, which is consistent with previous experimental, observational, and epidemiological research on peer influence (see Brechwald & Prinstein, 2011, for a review). Peer influence has been investigated using a wide range of methodological approaches, including direct self-report (Steinberg & Monahan, 2007), social network approaches (Haynie, 2003), performance-based measures (Allen, Porter, & McFarland, 2006), observed peer interactions (Dishion, Spracklen, Andrews, & Patterson, 1996) and genetically informative studies (Harden et al., 2008), all of which have unique strengths and drawbacks. Experimental designs offer an opportunity to randomly assign participants to different social contexts and use direct behavioral measures of risky decision-making, allowing researchers to empirically test causal relationships between context and behavior. These methods allow researchers to control for selection effects and self-report biases while also approximating the real-world environment in which risk-taking occurs.

This study examined whether the effect of peers on risky decision-making was moderated by pubertal status. It was hypothesized that because the social reorientation of adolescence may be driven by hormonal changes at puberty, the effect of peers would be enhanced for adolescents with more advanced pubertal development. Contrary to predictions, we found that the effect of peers on risky decision-making was attenuated for more developed adolescents, and that the effect of pubertal development on risk-taking was only apparent when adolescents were alone. There are several possible explanations for these results. First, individual differences in propensity for risk-taking, which, in this study, were associated with pubertal development, were only expressed when adolescents were alone. The presence of peers may have suppressed these differences, as adolescents may have been more influenced by the social context. This explanation is consistent with the "social push hypothesis" (Raine, 2002), which suggests that biological influences on risky behavior may be strongest in contexts without strong social pressure. The social push hypothesis was developed to explain interactions between socioeconomic status and biological influences on more serious forms of antisocial behavior (Gao, Baker, Raine, Wu, & Bezdjian, 2009). However, this theory may apply to more proximal social influences (such as peer presence) on risky decision-making in general.

Alternatively, the influence of peers may not have necessarily resulted in increased risk-taking, but rather as a homogenizing effect. The design of the current study differed from previous studies in an important aspect: two out of the three adolescents in each triad observed the game being played by their peers before playing it themselves. Our results may reflect social learning; that is, participants observed their peers playing the game and may have adjusted their own behavior based on these observations, in an effort to maximize chances for winning and/or to conform to the behavior of their peers. The role of observational learning in adolescent behavior is of considerable interest given that adolescents frequently observe their peers engage in risky activity and model their own behavior based both on the consequences they observe and their desire to conform regardless of the consequences. Future experimental designs provide an optimal strategy for disentangling these processes, as one can assess both within-person differences in risky decision-making across conditions and associations between an individual's task performance and the performance of his/her peers. This association between peer and individual risk-taking is how peer influence is commonly assessed in epidemiological and longitudinal studies (e.g. Harden et al., 2008; Haynie, 2003). Further research on susceptibility to peer influence would benefit from utilizing multiple measures of this construct, particularly when examining peer influence on other behaviors in adolescence.

Findings from this study must be interpreted in light of several limitations. First, as with any laboratory-based, behavior analogue measure of risky decision-making, the ecological validity of the task used is unclear. Performance on the Stoplight Game was previously found to be correlated with self-reported sensation-seeking and risky decision-making (Steinberg et al., 2008; Gardner & Steinberg, 2005), as well as self-reported resistance to peer influence, which provides some evidence for convergent validity. However, whether either self-report measures or behavioral analogue measures reflect real-world behavior remains an important question for further inquiry. Second, while the PDS is a well-validated self-report measure of pubertal development, self-report is not the ideal way to assess physical development. More accurate measures include results from physical examinations and hormone samples, neither of which were feasible in the current study. The composition of the sample also presents limitations. In particular, the homogenous racial composition of the sample—namely, lack of Caucasian participants—did not allow us to fully examine racial and ethnic differences. It remains uncertain whether these findings would be replicated in a predominantly Caucasian sample. The effects of race and ethnicity are of particular interest given racial and ethnic differences in pubertal timing (Sun et al., 2002).

Despite these limitations, this study offers a novel contribution to the rapidly advancing research on adolescent risk-taking. Scientific investigation of peer influence has moved well beyond determining whether peers play a role in risk-taking and into understanding how, why, and when this socialization process occurs (Brechwald & Prinstein, 2011). These findings suggest that the social context plays an important role in the expression of biologically-based individual differences in propensity for risk-taking and underscore the importance of including biological factors—specifically, measures of pubertal development—in experimental studies of adolescent risky decision-making.

Predictor	Outcome	
	Percent Risky Decisions	Latency to Brake (ms)
Intercept	-22.46 (23.75)	-150.03 (618.76)
Condition (0=Alone/ 1=Peer)	12.95 (7.37)	365.32* (178.06)
Age	.75 (1.32)	23.52 (34.66)
Gender (0=Female/ 1=Male)	-2.05 (4.56)	-8.83 (120.27)
African American (0=no/ 1=yes)	9.22 (5.68)	198.78 (144.92)
Hispanic (0=no/1=yes)	-9.47 (5.48)	-207.80 (140.48)
Working Memory (Digit span score)	1.60* (.77)	35.06 (19.83)
Order (0= First condition/ 1=Second condition)	4.04 (4.52)	100.75 (119.16)
Adrenal Pubertal Status	5.56* (2.56)	201.79** (64.56)
Condition*Adrenal Pubertal Status	-5.42* (2.56)	-148.28** (61.94)

Table 1: Linear Mixed Models Predicting Risky Decision-Making: Adrenal Pubertal Status.

Note: Values are parameter estimates (standard error). * $p < .05$ ** $p < .01$.

Predictor	Outcome	
	Percent Risky Decisions	Latency to Brake (ms)
Intercept	-19.02 (23.79)	171.06 (627.04)
Condition (0=Alone/ 1=Peer)	2.72 (9.32)	123.60 (226.85)
Age	.95 (1.33)	42.66 (35.26)
Gender (0=Female/ 1=Male)	-.24 (4.53)	-45.33 (119.38)
African American (0=no/ 1=yes)	10.31 (5.81)	272.52 (154.27)
Hispanic (0=no/1=yes)	-8.23 (5.55)	-161.23 (147.10)
Working Memory (Digit span score)	1.74 (.77)*	42.79 (20.37)*
Order (0= First condition/ 1=Second condition)	3.61 (4.46)	94.15 (117.73)
Gonadal Pubertal Status	1.89 (2.67)	34.42 (69.38)
Condition*Gonadal Pubertal Status	-1.30 (2.59)	-46.18 (63.18)

Table 2: Linear Mixed Models Predicting Risky Decision-Making: Gonadal Pubertal Status.

Note: Values are parameter estimates (standard error). * $p < .05$ ** $p < .01$.

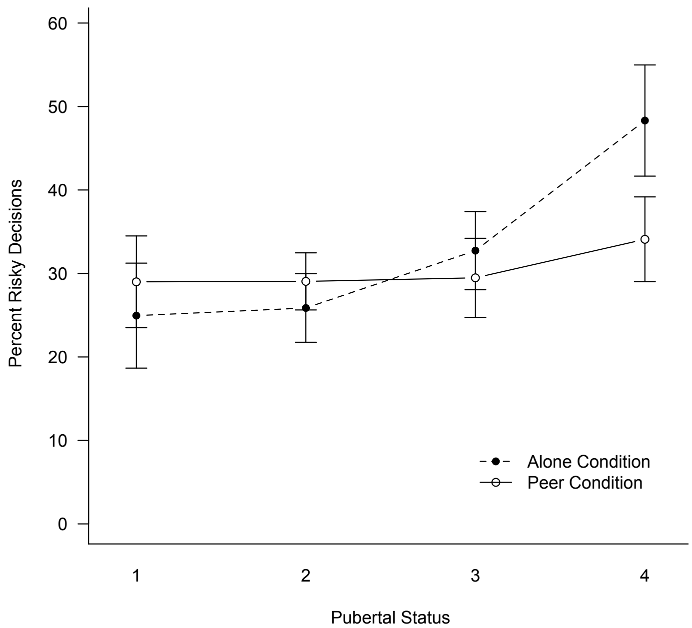

Figure 1: Percentage of risky decisions on the Stoplight Game, by adrenal pubertal status and experimental condition.

Note: Error bars represent 95% Confidence Intervals.

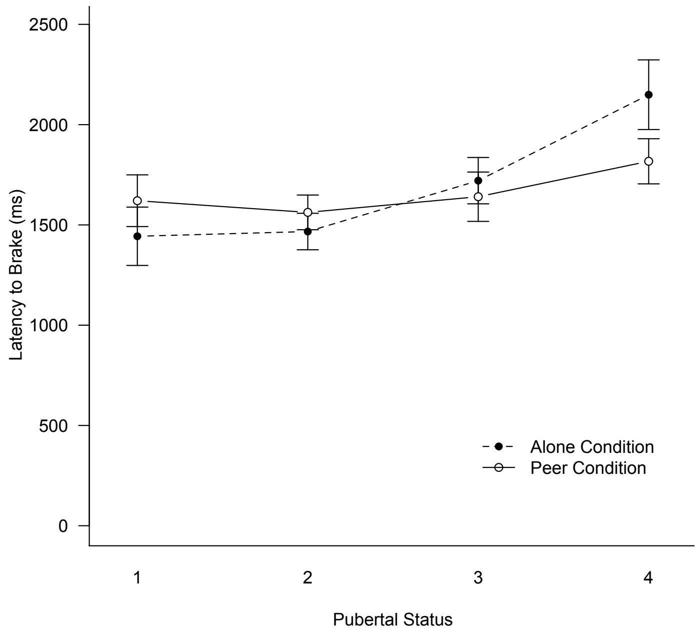

Figure 2: Latency to brake on the Stoplight Game, by adrenal pubertal status and experimental condition.

Note: Error bars represent 95% Confidence Intervals.

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