Abstract

Title of thesis: DEVELOPMENTAL AND INDIVIDUAL DIFFERENCES IN REWARD PROCESSING ACROSS CHILDHOOD AND ADOLESCENCE

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Adolescence is a developmental period characterized by maturation across multiple domains. This maturation is not without difficulties, however, as adolescents also display increased negative mood, conflict with parents, and risk-taking behaviors. Increased risk-taking is thought to be the byproduct of changes in reward circuits in the brain, and while a solid foundation of research has provided evidence for changes in reward processing during adolescence compared to adulthood, little is known about the changes that occur from childhood into adolescence. The current study addresses this gap in the literature with an investigation of changes in behavioral performance on a reward-processing task using a cross-sectional sample of children and adolescents.

Three primary findings emerged from this study. First, adolescents displayed faster reaction times than 8-year-olds. Second, subjects responded faster and more accurately on trials with greater potential rewards. Finally, individual differences were related to reward sensitivity, reaction times, and response accuracies.

DEVELOPMENTAL AND INDIVIDUAL DIFFERENCES IN REWARD PROCESSING ACROSS CHILDHOOD AND ADOLESCENCE

By

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Chapter 1: General overview

Adolescence is a developmental period rife with unique challenges and changes, as adolescents mature across a variety of social, emotional, and cognitive domains (Dahl, 2000; Spear, 2000). This maturation is not without difficulties, however, as some of the best-documented changes in adolescence include increases in negative mood states, conflict with parents, and risk-taking behaviors (Arnett, 1999; Somerville, Jones, & Casey, 2010). Adolescent risk-taking has been the subject of much research because of its link to increased mortality (Dahl, 2000), and several recent theories have suggested that the increase in risk-taking behavior during adolescence is a byproduct of changes in reward processing circuits in the brain, particularly within the dopamine-rich regions of the midbrain (Casey, Jones, & Hare, 2008; Ernst, Pine, & Hardin, 2006).

Supporting these theories, increased reward responsivity in adolescents has been found with both behavioral (e.g., Figner, Mackinlay, Wilkening, & Weber, 2009a; Cauffman et al., 2010) and neuroimaging (e.g., Ernst et al., 2005; Galvan et al., 2006; van Leijenhorst et al., 2010) paradigms. These results, however, have not been unanimous. A series of recent studies using the monetary incentive delay task (MID; Knutson et al., 2000) have reported decreased neurophysiological response to reward in adolescents compared to adults (Bjork et al., 2004; 2010), which the authors attributed to the mundane nature of the task.

The current study attempts to address this critique by modifying the MID task to include colorful cartoon stimuli. Additionally, while the MID task has been used to study the transition from adolescence to adulthood, little is known about the changes in task performance that occur from childhood into adolescence. The current study addresses this gap in the literature with a systematic investigation of changes in behavioral performance on the MID task using a cross-sectional sample of children and adolescents.

Chapter 2: Literature review

"Storm and stress" in adolescence

The concept of adolescence as a period of great developmental changes filled with unique challenges has a rich history in psychological literature. Over a century ago, G. Stanley Hall (1904) described this developmental period as a time of "heightened storm and stress," while Erikson (1950) saw adolescence as a time period where individuals struggled with establishing their own identity amidst a pantheon of possible roles. In the last fifty years, a wealth of research has identified adolescence as a developmental stage that is overlapping but conceptually distinct from the well-known biological changes of puberty (Ernst, Pine, & Hardin, 2006; Spear, 2000), as adolescents display changes across a range of social, cognitive, and affective domains. Three of the best documented of these changes are variability in mood and affect, increased conflict with parents, and a rise in risk-taking behaviors (Arnett, 1999; Somerville et al., 2010).

As part of the "storm and stress" that has been documented during adolescence, adolescents experience more intense emotions in general, and especially more negative emotions (Compas, Hinden, & Gerhardt, 1995; Petersen et al., 1993). These negative emotional states have been observed as peaking in their prevalence during adolescence, with frequent negative emotionality most common during early adolescence (Larson, Moneta, Richards, & Wilson, 2002). In addition to being more intense during adolescence, emotions are also more labile during this period. Larson and colleagues (2002) conducted a longitudinal "beeper study," during which they had 220 adolescents carry beepers and self-report booklets for two one-week periods, each roughly four years apart. During those weeks, the adolescents were signaled every two hours via beeper to record their emotional state and its intensity in their booklets. Their results showed that during adolescence, especially in the earlier years, adolescents' emotions were much more susceptible to rapid changes than at other ages. This highly variable, often intense quality of affect and mood can put strain on adolescents' relationships with their parents, as patterns of increased conflict appears to parallel increases in negative affect during this period (Flannery, Montemayor, Eberly, & Torquati, 1993).

Like affective change during adolescence, adolescents' increased conflict with their parents has also been the subject of considerable research (Laursen, Coy, & Collins, 1998). Researchers who study this phenomenon have noted that these conflicts are frequent, averaging three to four conflicts per day (Laursen & Collins, 1994), and they tend to occur over everyday, mundane topics, such as chores, bedtimes, and curfews (Smetana, 1989; Yau & Smetana, 1996; Smetana & Gaines, 1999). These studies have also shown that these conflicts tend to peak in frequency during early adolescence, with a peak in intensity found in mid-adolescence (Laursen et al., 1998). Importantly, these conflicts are not unique to white, middle-class Western samples, as Smetana (Yau & Smetana, 1996; Smetana & Gaines, 1999) has extended these findings to both African-American families (Smetana & Gaines, 1999) and lower class Chinese adolescents living in Hong Kong (Yau & Smetana, 1996). The ubiquity of this finding also suggests that, despite being perceived as stressful or negative, conflict may serve an adaptive purpose in adolescents' development. Conflicts are an important form of communication, allowing individuals to express their concerns and identify topics of personal significance, and in doing so, conflict provides an opportunity for relationship transformation and growth (Sillars, Canary, & Tafoya, 2004). Supporting this view, conflict has been found to promote autonomy (e.g., Fuhrman & Holmbeck, 1995) and achievement (e.g., Adams & Laursen, 2007) during adolescence.

Like parent-child conflict, some research has also argued for an adaptive function of increased risk-taking during adolescence (Spear, 2000). The phenomenon is ubiquitous in an evolutionary sense, as it has been reported in rodents (Adriani et al., 1998; Spear et al., 1980), primates (Cambefort, 1981; Kraemer et al., 1982), and humans (Arnett, 1992; Eaton et al., 2006). However, while these risky behaviors may have originally served to encourage independence and prevent inbreeding for the developing organism, they carry a significant toll in modern society (Somerville et al., 2010; Spear, 2000). Despite sweeping maturational improvements in reasoning and resilience, adolescents face an overall morbidity and mortality rate increase of 200% compared to early school age children (Dahl, 2000). Contributing to this increase, adolescents have been observed to engage in multiple domains of risk-taking behaviors, including reckless or drunk driving, drug use and abuse, criminal activity and violence, and unsafe sexual behaviors (Arnett, 1992; Eaton et al., 2006).

Perhaps due to the potentially severe consequences of these behaviors, a great deal of research has been dedicated to understanding why adolescents take more risks, and numerous theories have been put forth from cognitive, biological, and neuroscientific researchers. Some of the first, for example, posited that increased egocentrism was the underlying cause of these behaviors (Elkind, 1967), or that adolescents failed to make sound judgments of probabilities when assessing the likelihood of negative outcomes (Arnett, 1990). More biologically based researchers have correlated risky and sensation-seeking behaviors with a number of factors, such as sex hormones (Daitzman et al., 1978;

Daitzman & Zuckerman, 1980) and monoamine oxidase levels (Murphy et al., 1977). Of late, several neuroscientists have proposed models that relate maturational changes in the developing brain to risky, incentive-driven behaviors during adolescence (e.g., Ernst, Pine, & Hardin, 2006; Casey, Jones, & Hare, 2008; Steinberg, 2008). In general, these models agree that one of the dissociable processes that is responsible for increased risk-taking behaviors is reward sensitivity; the increased salience of rewarding stimuli during adolescence, such that adolescents seek out novel and rewarding stimuli more than children and adults.

Understanding the relationship between risk, reward, and the brain

To understand the role of reward processing in the etiology of increased adolescent risk-taking, it is useful to define the concept of "risk-taking". In a broad sense, risk-taking behavior can be operationalized as approaching positive experiences without appropriate consideration of their associated potentially negative outcomes (Somerville et al., 2010). This dichotomy is an important one, as it identifies two complementary processes that may give rise to increased risk-taking: greater weighting of the positive aspects of stimuli and lesser weighting of the negative aspects of stimuli.

Studies of the brain's response to positive, rewarding stimuli have identified the striatum as an essential brain region for this function (Ikemoto & Panksepp, 1999; Schultz et al., 2000; Martin-Soelch et al., 2001). The striatum itself is located in the midbrain and can be anatomically subdivided into dorsal and ventral subregions. The dorsal striatum, also known as the basal ganglia, is composed of the caudate nucleus and the putamen, while the ventral striatum is composed primarily of the nucleus accumbens. As a whole, the striatum is rich in dopaminergic input from the ventral tegmental area, whose neurons demonstrate activity in anticipation of a rewarding stimulus (Schultz et al., 1997).

A number of human neuroimaging paradigms have implicated the striatum in the salience and perception of reward, generally demonstrating a striatal increase in dopamine release or an increase in BOLD fMRI response when a stimulus is rewarding. This effect has been demonstrated when subjects play rewarding video games (Koepp et al., 1998), guess correctly for a reward (Delgado et al., 2000), elect to take a high risk/high reward gamble (Ernst et al., 2004), or anticipate a rewarding stimulus (Ernst et al., 2004; Knutson et al., 2001a; Knutson et al., 2001b). Importantly, these results have also been related back to individuals' explicit perceptions of reward and their propensity for risk-taking. In the study by Knutson and colleagues (2001b), striatal activation in response to the most rewarding stimulus correlated with individuals' self-reported happiness in response to reward cues, such that the more responsive the striatum was, the happier the subject felt to be receiving a reward. In a more recent study by Galvan and colleagues (2007), subjects' self-report ratings of their own risky behaviors were positively associated with activation observed in their nucleus accumbens. Those individuals with a more responsive nucleus accumbens reported an increased likelihood of engaging in risky behaviors.

This relationship between striatal activation and reward sensitivity is crucial to the aforementioned theories for increased adolescent risk-taking behaviors. As the model by Casey, Jones, and Hare (2008; Figure 1) demonstrates, the brain's dopamine-rich midbrain regions like the limbic system and the striatum develop earlier than the brain's prefrontal regions. Previous research has demonstrated that the prefrontal regions are vital for regulation of behavior and the inhibition of prepotent responses (Aron et al, 2007; Dalley, Cardinal, & Robbins, 2004). Thus, this developmental gap suggests that adolescents will find stimuli more intensely rewarding than children and adults, yet they will lack the requisite cortical maturity to inhibit their responses when the negative consequences may outweigh the positive.

Behavioral studies of reward during adolescence

Supporting the idea that changes in reward sensitivity parallel the increase in risk-taking behaviors during adolescence, adolescents show significantly different behavioral responses to rewarding stimuli when compared to children or adults. In a recent study by Figner and colleagues (2009a), early adolescents (13-16), late adolescents (17-19), and adults (20+) took part in both affective and non-affective versions of the Columbia Card Task (CCT). In both versions of the task, participants were instructed to maximize the number of points they received by turning over cards that could be either rewarding or punishing. At the beginning of each trial, the values of reward and punishment cards were presented to the subject, as well as the number of punishing cards in the 32-card array. In the non-affective condition, participants only gave the number of cards that they wished to turn over in a trial, after which the computer chose the cards at random, and feedback was not given until the end of the session. In the affective condition, however, participants received feedback after every card, and were allowed to continue choosing cards in a trial until they elected to advance to the next trial with the points they had accumulated, or until they received a punishment card. Punishment cards deducted points from their total and ended the trial.

These researchers found that, compared to adults, adolescents took more risks on the affective version of the task. When they were given immediate, rewarding feedback on a trial-by-trial basis, adolescents continued to pick additional cards despite being reminded of the amount of points that they stood to lose from a punishment card. Interestingly, the sole informational factors that adolescents used in choosing to pick additional cards was the number of punishment cards left unturned. Even when the punishment consequences were astronomically high on a trial, adolescents still made their decisions based purely on the probability of being punished. Adults, on the other hand, weighed punishment probability, potential punishment value, and potential reward value when choosing to pick another card. A follow-up study also found this adult-like pattern of behavior in pre-adolescents (Figner, Mackinlay, Wilkening, & Weber, 2009b). These findings are important, as they shows that adolescents are especially responsive to immediate, rewarding feedback. So long as they continue to be rewarded for a risky decision, they will base their choices to take further risks solely on the probability of being punished, rather than considering the severity of the potential negative consequences when making a decision.

This enhanced adolescent response to rewarding stimuli has also been demonstrated in a recent study by Cauffman and colleagues (2010), who used a modified version of the Iowa Gambling Task (IGT) to dissociate reward-sensitive approach behaviors and punishment-sensitive avoidant behaviors in a sample of 10- to 30-year-old participants. The task presented participants with four decks of cards, each containing a mixture of reward cards that were worth a positive amount of pretend money and punishment cards that subtracted a certain amount of pretend money. Two of these decks provided a net gain over repeated play, while the other two provided a net loss. In each trial, participants were presented with one of the four decks in psudorandom order, and they were given the choice of whether or not to draw a card from that deck.

Their results showed that approach behavior, which was operationalized as choosing to draw from the net gain decks, displayed a curvilinear relationship with age. When presented with rewarding decks, adolescents chose to draw a card from those decks significantly more often than both children and adolescents. Avoidant behavior, on the other hand, showed a linear relationship with age. Adults drew fewer cards from the net loss decks compared to adolescents, who in turn drew fewer cards from these decks than children. This disparity between age-related trends in approach and avoidance behavior is important, as it parallels the finding by Figner and colleagues (2009a; 2009b) that adolescents are disproportionately driven by rewards and positive feedback. When paired with a lessened propensity to avoid punishment or heed negative feedback, this may lead to increased risk-taking behaviors.

Neuroimaging studies of reward during adolescence

Similar to the previously discussed behavioral differences in reward behaviors, adolescents also show markedly different neurophysiological responses to rewarding stimuli when compared to children or adults. In one of the first studies to examine these differences, Ernst and colleagues (2005) used a Wheel of Fortune task to compare reward processing between adolescents (mean age 13.3) and adults (mean age 26.7). Their findings were twofold; first, adolescents showed greater activation of the ventral striatum (specifically, the nucleus accumbens) compared to adults, while adults showed greater activation of the amygdala compared to adolescents. Amygdala activation has primarily been implicated in the anticipation of negative outcomes and response to aversive stimuli (LeDoux, 2000; 2003), and thus this result suggests that a gradual shift in activation from reward-responsive to punishment-averse brain regions may underlie the reduction in risk-taking behaviors from adolescence to adulthood. Interestingly, they also found that self-reported negative emotion during the feedback phase significantly correlated with amygdala activation in adults, while self-reported positive emotion during feedback significantly correlated with nucleus accumbens activation in adolescents. When adolescents experienced more accumbens activation in response to receiving a reward, they reported feeling much better, whereas adults' amygdala responses were linked to how much worse they felt after a reward was omitted. If the adolescent brain's response to reward has a strong relation to positive emotion, but there is little relation between punishment and negative emotion, then increased risk-taking behaviors could potentially be explained by adolescents seeking out potentially risky, highly rewarding behaviors to maximize their positive emotion.

Studies by Galvan and colleagues (2006) and van Leijenhorst and colleagues (2010a) have further demonstrated that adolescents display greater reward-related accumbens activation than children in addition to adults. Using two different tasks, their imaging results both reflected a greater increase in the overall magnitude of ventral striatal activation to reward for adolescents compared to both the adults and the children in their studies. Interestingly, Galvan and colleagues (2006) also reported greater discrimination in reward value by adolescents' accumbens responses compared to those of adults and children. Taken together, these results suggest that a similarly rewarding experience produces a more intense neurophysiological response in adolescents compared to children and adults, with differences between reward values becoming more salient during adolescence. Given the previously discussed link between accumbens response and positive emotion, this further supports the theory that adolescents seek out novel sources of stimulation because they elicit a more intense response than they previously did during childhood.

Still, not all imaging studies have been in agreement as to whether adolescent risk and reward behaviors are due to striatal *hyper*responsivity. One of the earliest tasks to demonstrate the role of the striatum in reward sensitivity was Knutson and colleagues' (2000) monetary incentive delay (MID) task (Figure 2). Based on a primate task devised by Schultz and colleagues (1998), a series of early studies using the MID task were some of the first to demonstrate nucleus accumbens activation during anticipation of reward (Knutson et al., 2001a), scaling levels of accumbens activation in response to different reward values, and a positive relationship between striatal response and positive emotion (Knutson et al., 2001b).

While these results were similar to those found with other reward tasks using adult samples (e.g. Ernst et al., 2004; Galvan et al., 2005), developmental studies using the MID task (Bjork et al., 2004; 2010) have shown a very different striatal response to reward in adolescents compared to the research discussed earlier (Ernst et al., 2005; Galvan et al., 2006; van Leijenhorst et al., 2010). These developmental MID studies compared adolescents (12-17) to adults (22+) and found that the ventral striatum in adolescents was *hypo*responsive during the anticipation of reward when compared to adults. These results stood contrary to previous evidence for striatal *hyper*responsivity during adolescence (Ernst et al., 2005; Galvan et al., 2006), which the authors offered several possible explanations for. Foremost among these explanatons was a critique of the “mundane” visual stimuli of the MID task compared to those used in other recent functional imaging studies of reward processing in adolescence (e.g. Galvan et al., 2006; Van Leijenhorst et al., 2010b). In contrast to the simple text and geometric shapes of the MID task, these studies employed bright images of cartoon pirates and slot machine wheels. The authors posit that when a task is highly engaging and rewarding, such as those found in other studies, the adolescent brain is more responsive than that of an adult or child. However, when a task is not engaging, the adolescent brain may be even less responsive, rather than equally responsive, when compared to other age groups. Extrapolating this to potential real world scenarios, the authors suggest that adolescents may find a risky bet as a more appealing way to earn money than by performing a mundane chore.

Individual differences and the monetary incentive delay task

In addition to developmental studies, researchers have used the monetary incentive delay task to study individual differences in striatal activation to reward. A study by Guyer and colleagues (2006) used the MID task to study behavioral inhibition, a temperamental profile characterized by increased vigilance, reactivity to novelty, and negative affect (Kagan et al., 1988), as well as distinct physiological correlates (Fox et al, 2005). Despite previous evidence for enhanced amygdalar activity in behaviorally inhibited young adults (Schwartz et al., 2003), Guyer and colleagues (2006) found greater striatal activity in behaviorally inhibited adolescents compared to their noninhibited counterparts as incentive value increased. Importantly, the enhanced striatal responses of the inhibited group were found in both the gain and loss conditions. This suggests that behaviorally inhibited adolescents are equally responsive to reward and punishment, rather than preferentially responsive to rewarding stimuli.

Unfortunately, a comparable study with bold or exuberant temperament groups has not yet been published. However, one study has used the MID task to examine a population of adolescents with attention-deficit/hyperactivity disorder (ADHD). Though this represents an imperfect comparison, some research has suggested that exuberant temperament and ADHD share certain genetic and behavioral factors (Schmidt & Fox, 2002). In a study of adolescents with ADHD, Scheres and colleages (2007) found that adolescents with ADHD showed reduced activation of the ventral striatum in anticipation of rewards compared to healthy controls. Interestingly, lower amounts of ventral striatal activation also correlated with higher levels of hyperactivity and impulsivity when controlling for inattentiveness in the patient group. Thus, lower amounts of striatal activation may indicate that the MID task was even less engaging for adolescents with ADHD than for normal adolescents (e.g., Bjork et al., 2004; 2010).

Present study

To date, no study has systematically investigated changes in behavioral performance across childhood and adolescence with the monetary incentive delay task. Though studies using the MID task have compared adolescents with adults (Bjork et al., 2004; 2010), studies involving children are noticeably absent. This study attempts to address that gap in the literature while simultaneously addressing several critiques of the original MID task presented by Bjork and colleagues (2010).

In this study, children ages 8, 10, 12, and 14 were recruited to participate in a modified version of the monetary incentive delay task known as the piñata task. The piñata task differs from the original MID task in four key aspects. First, while the original MID task involved reward, punishment, and neutral blocks, this task contains only reward blocks. Second, like the Knutson and colleagues (2001b) version of the task, the current design allows for the parametric manipulation of reward values, such that no reward, small reward, medium reward, and large reward trials are present during each block of the task. Third, to control for potentially different intrinsic values of monetary amounts between age groups, the piñata task presents stars that can be won in each trial rather than explicit monetary values. Finally, in contrast to the mundane stimuli of the original MID task, the piñata task features colorful and animated cartoon stimuli.

Hypotheses

First, as a manipulation check, reaction times are expected to decrease significantly with age, while accuracy rates are expected to remain equal between all age groups. The former prediction would agree with a previous meta-analysis showing decreasing reaction times from childhood to young adulthood (Kail, 1991). The latter prediction is based on the parameters of Knutson and colleagues' (2000) original MID task. In that study, they titrated the speed of the task so that participants all performed at close to 60% accuracy. Task speed was also matched to subject ability on this task, so response accuracy rates were expected to be equal between all subject groups.

Second, reward sensitivity is expected to increase from childhood to adolescence, as reflected by a significant age by reward value interaction for reaction time. While studies using the traditional MID task have shown a decrease in reward sensitivity during adolescence (Bjork et al., 2004; 2010), the authors of those studies have suggested that this may be due to the mundane stimuli and their failure to engage adolescent participants. Given that this study uses colorful cartoon stimuli, it is expected that adolescents will find the task more engaging. This should lead to an increase in reward sensitivity similar to what has been reported in previous behavioral studies with adolescents (Cauffman et al., 2010; Figner et al., 2009a; 2009b).

Third, rates of anticipatory responding are expected to be greater in the oldest age group compared to the younger age groups. This prediction is based on the previously discussed results showing that adolescents are preferentially sensitive to potential reward and less responsive to potential punishment (Cauffman et al., 2010). If adolescents responses are primarily driven by each trial's potential reward rather than the negative consequences of anticipatory responses, then they should display increased rates of anticipatory responding compared to the younger age groups.

Finally, questionnaire measures of individual differences are expected to show a significant relation to reward sensitivity. Previous research has shown that individual differences are associated with differential patterns in reward processing, such as increased reward sensitivity in behaviorally inhibited adolescents (Guyer et al., 2006) and reward *hypo*responsitivity in adolescents with ADHD (Scherer et al., 2007). Given these findings, variables associated with inhibited temperament and anxiety are expected to correlate significantly with increased sensitivity to reward, while variables associated with exuberant temperament and impulsivity are expected to correlate significantly with decreased sensitivity to reward.

Chapter 3: Methods

Participants

Participants consisted of 12 children age 8 years (5 female); 14 children age 10 years (8 female); 15 children age 12 years (9 female); and 12 adolescents age 14 years (3 female). Participant recruitment was conducted through Experien mailing lists and fliers handed out at University of Maryland summer camps. Interested parents completed a standard screening form that included age, birth order, gestational complications, parents' occupations, parents' education levels, and ethnicity. Only age data from the screening questionnaire was used to determine study eligibility. Participation was limited to children aged 8, 10, 12, and 14 years.

Procedures

Participant visits began with a discussion of the study procedures and the consenting process. Consent and assent forms were discussed with and signed by the parent and child, respectively. The University of Maryland Institutional Review Board approved all consent and assent forms, as well as the study procedures.

Following consent procedures, participants were instructed to select a small prize and a large prize that they could win during the ensuing piñata task. Small prizes were four age-inappropriate toys valued at under $7.00 each, with toys for children ages 5-and-under being presented to 8- and 10-year-old children, and toys for 7-year-olds being presented to 12- and 14-year-old children. Large prizes were four age-appropriate movies on DVD valued at $10.00 to $12.00 each. Participants were told that they would win a prize regardless of their performance, but the number of stars that they won would determine whether they received a small prize or a large prize.

After both a small prize and a large prize were selected, children were given the instructions to the piñata task. Next, they engaged in a single block of practice trials on the second fastest possible difficulty setting. Accuracy from the practice block was then used to determine the difficulty setting for the six experimental blocks of the task. Once the practice block was completed, the instructions of the task were re-explained to the participant, after which the participant began the six experimental blocks. The participant was allowed breaks between each block to minimize fatigue. Following the last block of the piñata task, participants were told that they won enough stars for the large prize that they had selected earlier (see Appendix for a full piñata task instruction script).

While participants were completing the piñata task, parents completed three questionnaires about their children: the Screen for Child Anxiety Related Emotional Disorders (SCARED) questionnaire (Birmaher et al., 2007), the Child Behavior Questionnaire (CBQ; Rothbart et al., 2001; Putnam & Rothbart, 2006), and the Behavior Inhibition System/Behavioral Activation System (BIS/BAS) scales (Carver & White, 1994). Following the completion of the piñata task and all parent questionnaires, the participant received $20.00.

Measures

Piñata Task. The piñata task was designed to assess reward-related behaviors in age groups ranging from early childhood to young adulthood. The piñata task was modified from the original monetary incentive delay task (Knutson et al., 2000; Figure 2) in four distinct ways. First, while the original MID task involved reward, punishment, and neutral blocks, this task contains only reward blocks. Second, like the Knutson and colleagues (2001b) version of the task, the current design allows for the parametric manipulation of reward values, such that no reward, small reward, medium reward, and large reward trials are present during each block of the task. Third, to control for potentially different intrinsic values of monetary amounts between age groups, the piñata task presents stars that can be won in each trial rather than explicit monetary values. Finally, in contrast to the mundane stimuli of the original MID task, the piñata task features colorful and animated cartoon stimuli.

Task trials (Figure 3) were comprised of four phases: (1) the *cue* phase informed the participant of how many stars they stood to win on the trial; (2) the *delay* phase allowed participants to prepare a response for the trial; (3) the *response* phase signaled the participant to press a button when the target appeared; and (4) the *feedback* phase notified the participant as to whether their response was fast enough to earn the available stars on that trial. The feedback phase was followed by a variable inter-trial interval (ITI).

Each task trial began with the presentation of one of four possible incentive cues. The cue was located at the top of a computer screen, displaying half of that trial's piñata (target) image with the number of stars at stake visible inside of it. The cue duration was jittered between 990 and 1990 ms.

Following the cue presentation, the piñata was replaced by a blank screen, after which the piñata (target) reappeared in the center of the screen. The target stimulus remained on the screen for a variable interval that was determined by subjects' performance during the practice round. After the subject's response, the target shape changed to provide feedback for the trial. When the subject responded quickly enough, the piñata was shown breaking open with its stars falling into a basket below. On trials when the participant was too slow in their responding, the intact piñata was shown swinging to the left side of the screen with no stars falling out of it. Trials where the participant responded during the delay period prior to the target's appearance (anticipatory responses) were not rewarded, and the feedback for these responses also displayed the piñata as intact with no stars falling out of it. After the feedback phase, a background screen with no piñatas reappeared for the duration of the inter-trial interval (ITI). ITIs were of random duration between 990 and 1990 ms.

The piñata task included 132 trials total and was presented in six blocks of 22 trials. These trials comprised 33 trials each of zero-star, one-star, two-star, and four-star trials. Though total task duration depended on the length of the breaks taken by the participant, the average duration was roughly 15 minutes. At the end of each block, participants were shown the total amount of stars that they had won during that block. Subjects were told that they needed to win as many stars as possible to receive the large prize, though no specific number was given to prevent participants from counting the total stars in their head or changing their performance once a certain number of stars had been won.

Screen for Child Anxiety Related Emotional Disorders (SCARED). The Screen for Child Anxiety Related Emotional Disorders (SCARED; Birmaher et al., 1997) is 38-item self-report questionnaire with both parent and child forms designed to screen children with anxiety disorders. The questionnaire items load onto five unique factors representative of somatic anxiety/panic (e.g., "when frightened, it is hard to breathe"), general anxiety (e.g., "I am nervous"), separation anxiety (e.g., "I worry about sleeping alone"), social phobia (e.g., "I'm shy with people I don't know well"), and school phobia (e.g., "I worry about going to school"). Subjects rate items on a 3-point Likert-type scale from 0 ("Not true or hardly ever true") to 2 ("Very true or often true").

Children's Behavior Questionnaire (CBQ). The Short Version of the Children's Behavior Questionnaire (CBQ; Putnam & Rothbart, 2006) is a 94-item temperament questionnaire divided into 15 scales: Activity Level (e.g., "Seems always in a big hurry to get from one place to another"), Anger/Frustration (e.g., "Gets angry when told s/he has to go to bed"), Approach/Positive Anticipation (e.g., "Gets so worked up before an exciting event that s/he has trouble sitting still"), Attentional Focusing (e.g., "When practicing an activity, has a hard time keeping her/his mind on it"), Discomfort (e.g., "Is quite upset by a little cut or bruise"), Soothability (e.g., "Has a hard time settling down after an exciting activity"), Fear (e.g., "Is afraid of loud noises"), High Intensity Pleasure (e.g., "Likes going down high slides or other adventurous activities"), Impulsivity (e.g., "Usually rushes into an activity without thinking about it"), Inhibitory Control (e.g., "Has trouble sitting still when s/he is told to [at movies, church, etc.]"), Low Intensity Pleasure (e.g., "Enjoys just being talked to"), Perceptual Sensitivity (e.g., "Notices the smoothness or roughness of objects s/he touches"), Sadness (e.g., "Tends to become sad if the family's plans don't work out"), Shyness (e.g., "Is sometimes shy even around people s/he has known a long time"), and Smiling and Laughter (e.g., "Smiles a lot at people s/he likes"). Additionally, these 15 scales load on to three overarching factors: Surgency, Negative Affect, and Effortful Control. Subjects rate items on a 7-point Likert-type scale from 1 ("extremely untrue") to 7 ("extremely true").

Behavioral Inhibition System/Behavioral Activation System (BIS/BAS). The Behavioral Inhibition System/Behavioral Activation System scales (BIS/BAS; Carver & White, 1994) were originally created to assess two opposing motivational systems. Broadly, the behavioral inhibition system (BIS) is sensitive to punishment and non-reward, while the behavioral activation system (BAS) is sensitive to reward and avoidance of punishment. A parent-report version of the questionnaire (Blair, Peters & Granger, 2004) was later developed for use in samples of children and adolescents. The parent-report BIS/BAS consists of 20 items, each scored on a 4-point scale ranging from "Strongly Agree" to "Strongly Disagree". These items load onto four unique factors: the BIS factor measures reactions to the anticipation of punishment (e.g., "If my child thinks something unpleasant is going to happen he usually gets pretty 'worked up'."); the BAS Drive (BASd) factor measures the persistent pursuit of desired goals (e.g., "My child goes out of his way to get things he wants."); the BAS Fun Seeking (BASfs) factor measures the desire for new rewards and spur-of-the-moment behaviors in novel reward seeking (e.g., "My child is always willing to try something new if he thinks it will be fun."); and the BAS Reward Responsiveness (BASrr) factor measures positive responses to the occurrence or anticipation of reward (e.g., "When my child gets something he wants, he feels excited and energized.").

Analysis

Behavior analysis. Raw behavioral data were obtained using EPrime software (Psychology Software Tools, Inc.) that was exported to Microsoft Excel (Microsoft Corporation) and PASW 18.0 software (SPSS, Inc.) for post-processing. *Reaction time* was the elapsed time between target appearance and participant response. *Response* *accuracy* was the percent of trials when the participant responded quickly enough to break the piñata and win the stars inside of it. *Anticipatory responding* was operationalized as the percentage of trials when subjects responded during the delay period before the onset of the target stimulus. A *magnitude of reward sensitivity* variable (RS) was also created by subtracting the mean of all positive reward value trials from the mean of all no-reward (zero-star) trials:

$$RS = M_{no-star} - \frac{(M_{one-star} + M_{two-star} + M_{four-star})}{3}$$

Analyses of reaction time, accuracy, and anticipatory responding employed 4 × 4 × 2 (Reward Value × Age × Gender) repeated-measure ANOVAs. Analyses of reward sensitivity magnitude utilized 4 × 2 (Age × Gender) univariate ANOVAs. In all cases, significant main effects and interactions were followed by Bonferroni corrected *post hoc* analyses.

Individual differences questionnaire analysis. Individual differences questionnaires were entered into PASW 18.0 (SPSS, Inc.) using the coding schemes associated with their respective coding manuals. The *BIS* subscale from the BIS/BAS and the five subscales of the SCARED (*somatic anxiety/panic*, *generalized anxiety*, *separation anxiety*, *social phobia*, and *school phobia*) were used to assess anxious, inhibited, and punishment-sensitive traits, while the three BAS subscales of the BIS/BAS (*BASd*, *BASfs*, and *BASrr*), the *Surgency* super-factor of the CBQ, and its composite factors (*Activity Level*, *High-Intensity Pleasure*, *Impulsivity*, and *Shyness* [reverse coded]) were used to assess exuberant, impulsive, and reward-sensitive traits. Bivariate tests of the Pearson correlation were used to determine the relationship between these temperament variables and the behavioral variables (*reaction time*, *response accuracy*, *anticipatory responding*, and *magnitude of reward sensitivity*) described above.

Chapter 4: Results

Group composition

Three subjects' data were excluded prior to the behavioral analyses. Two of these subjects failed to complete the full number of trials for each condition in the task, while the reaction times of the third were greater than two standard deviations outside the mean of their respective age group. The remaining sample consisted of 50 participants (24 female). A Pearson Chi-square test for gender and age found no significant differences of gender within any of the age bins ($\chi^2(3, N = 50) = 4.45$, $p = ns$).

Behavioral results

Reaction Time. The effects of reward value on reaction time were analyzed with a 4 × 4 × 2 (Reward Value × Age × Gender) repeated-measures ANOVA, in which the first factor was within-subjects and the last two factors were between-subjects. Significant main effects of Reward Value ($F(3,42) = 5.75$, $p < 0.01$, $\eta^2 = 0.120$, Figure 3) and Age ($F(3,42) = 3.195$, $p < 0.05$, $\eta^2 = 0.186$, Figure 4) indicated that reaction times differed as a function of the trials' values and subjects' ages, respectively. No other main effects or interactions reached statistical significance.

With respect to Reward Value, post hoc tests using the Bonferroni correction revealed that subjects responded significantly faster on four-star trials ($M = 258.79$, $SE = 6.38$) than no-star trials ($M = 270.19$, $SE = 7.68$, $p < 0.01$). No other comparisons reached significance.

With respect to Age, post hoc tests using the Bonferroni correction revealed that 8-year-olds ($M = 296.46$, $SE = 13.44$) responded significantly slower to targets than 14-

year-olds (*M* = 236.15, *SE* = 14.52, $p < 0.05$). No other comparisons reached significance.

Accuracy. The effects of reward value on response accuracy were analyzed with a 4 × 4 × 2 (Reward Value × Age × Gender) repeated-measures ANOVA, in which the first factor was within-subjects and the last two factors were between-subjects. A significant main effect of Reward Value ($F(3,42) = 5.28$, $p < 0.01$, $\eta^2 = 0.112$, Figure 5) indicated that response accuracy differed as a function of the trials' values. No other main effects or interactions reached statistical significance.

Post hoc tests using the Bonferroni correction revealed that subjects' accuracies were significantly lower on no-star trials (*M* = 0.73, *SE* = 0.03) than four-star trials (*M* = 0.80, *SE* = 0.02, $p < 0.05$). No other comparisons reached significance.

Anticipatory responding. The effects of reward value on accuracy were analyzed with a 4 × 4 × 2 (Reward Value × Age × Gender) repeated-measures ANOVA, in which the first factor was within-subjects and the last two factors were between-subjects. This test revealed no significant main effects or interactions.

Reward sensitivity. As an alternative method for testing the magnitude of sensitivity to reward, a difference score was computed by subtracting the average of all positive reward value trials (1-, 2-, and 4-star) from the average of all no reward (zero-star) trials. Group differences in this outcome variable were analyzed with a 4 × 2 (Age × Gender) univariate ANOVA, in which both factors were between-subjects. This test revealed no significant main effects or interactions.

Individual differences questionnaire results

BIS/BAS. Tests of the Pearson correlation were used to explore the relationships between the five BIS/BAS variables (BIS, BASrr, BASd, BASfs, and BAS) and the four behavioral variables (reaction time, accuracy, anticipatory responding, and reward sensitivity). These tests revealed two sets of statistically significant correlations. First, the BIS/BAS Drive subscale (BASd) was significantly and positively related to overall reaction time ($r = 0.37$, $p < 0.05$ (two tailed)), as well as the average reaction times for zero-star trials ($r = 0.35$, $p < 0.05$ (two tailed)), one-star trials ($r = 0.38$, $p < 0.05$ (two tailed)), two-star trials ($r = 0.35$, $p < 0.05$ (two tailed)), and four-star trials ($r = 0.37$, $p < 0.05$ (two tailed)).

A second set of significant correlations were found between BIS/BAS Reward Responsiveness subscale (BASrr) and a subset of the of the accuracy variables. These tests revealed a significant and positive correlation between Reward Responsiveness and overall accuracy ($r = 0.41$, $p < 0.01$ (two tailed)), as well as accuracy on all positive reward value trials: one-star trials ($r = 0.40$, $p < 0.01$ (two tailed)), two-star trials ($r = 0.39$, $p < 0.05$ (two tailed)), and four-star trials ($r = 0.36$, $p < 0.05$ (two tailed)). No other correlations reached statistical significance.

CBQ. Tests of the Pearson correlation were also used to probe the relationships between CBQ Surgency and the four behavioral variables, as well as the relationships between Surgency's composite factors (Activity Level, High-Intensity Pleasure, Impulsivity, and Shyness [reverse coded]) and the four behavioral variables. These tests revealed no significant correlations.

SCARED. A final set of Pearson correlation tests were used to explore the relationships between the six parent-report SCARED variables (Somatic Anxiety/Panic, Generalized Anxiety, Separation Anxiety, Social Phobia, School Phobia, and Total Anxiety) and the four behavioral variables. These tests revealed a significant and positive correlation between the Generalized Anxiety subscale and the reward sensitivity variable ($r = 0.35$, $p < 0.05$ (two tailed)). No other correlations reached statistical significance.

Chapter 5: Discussion

With regard to the study's first hypothesis, both of the study's manipulation checks were validated. First, the significant main effect of age on reaction time suggests that the subject population used was developmentally similar to those found in studies with larger samples (e.g., Kail, 1991). Second, response accuracy levels were equivalent across all age groups. Although the mean accuracy level (78.14%) was higher than that found in Knutson and colleagues' (2000) original monetary incentive delay task (60%), the equivalent accuracy levels at least suggest that the task was equally difficult for all age groups. Thus, the results of the other behavioral variables (reaction time, anticipatory responding, and magnitude of reward sensitivity) cannot be explained by differences in task difficulty alone.

The study's second hypothesis was that adolescents would show increased sensitivity to reward amounts as evidenced by a significant age by reward value interaction for reaction times. This finding would indicate that the colorful cartoon stimuli were adequately engaging for adolescents, and that the task had successfully addressed the critiques presented by Bjork and colleagues (2004; 2010). This hypothesis, however, was not confirmed, as the interaction failed to reach statistical significance. Additionally, an exploratory within-group ANOVA suggested the results were opposite of the predicted direction. This ANOVA found that the 8-year-old group displayed faster reaction times with increasing reward values ($F(3, 27) = 3.188$, $p < 0.05$), and while the lack of significance of the original all-ages ANOVA limits the interpretability of this finding, it nonetheless suggests that the task may have been most engaging to the youngest age group.

The failure of this hypothesis to reach significance has several potential explanations. First, the task's stimuli and prizes may not have been equally salient to all age groups. Anecdotally, younger participants seemed much more excited by the prospect of winning a DVD prize than did older participants. If the potential prize was not equally rewarding to each group, then that could explain the absence of a significant interaction. Similarly, the deception used in the study may not have been equally successful with each age group. Participants were told that they needed to earn enough stars to receive the large prize, but a lack of debriefing questions assessing subjects' level of deception makes it possible that older subjects were not successfully deceived. If they believed that they would receive the large prize regardless of their performance, they would not be incentivized to try harder on high-reward trials compared to low-reward trials. Finally, the sample sizes may not have been large enough to probe this interaction successfully, as the standard errors for the 8-, 10-, and 12-year-old age groups suggested a substantial within-group variability with respect to reaction time.

The study's third hypothesis, that adolescents would show increased rates of anticipatory responding, also failed to reach significance. This was not entirely unexpected, as the piñata task is not designed to directly assess inhibitory control. Still, the failure of this hypothesis to reach significance may have been due to the overall low rates of anticipatory responding (2.88%) and the relatively high overall accuracy rate of the sample (78.14%). In other words, the task may not have been difficult enough to require subjects to risk an anticipatory response in exchange for a potential reward.

Finally, both of the study's individual differences hypotheses were partially confirmed. With respect to inhibited temperament, the BIS subscale of the BIS/BAS failed to achieve a significant correlation with any of the task's behavioral measures. However, the Generalized Anxiety subscale of the SCARED questionnaire did show a significant correlation with the magnitude of reward sensitivity variable. Although anxiety and inhibited temperament are not directly related, inhibited temperament during childhood has been researched as a potential precursor to anxiety disorders later in life (Perez-Edgar & Fox, 2005; Degnan & Fox, 2007). That said, the finding of increased behavioral sensitivity to reward in more anxious individuals does agree with the neuroimaging findings by Guyer and colleagues (2006), who found increased sensitivity to both reward and punishment in adolescents characterized as behaviorally inhibited compared to noninhibited adolescents.

With respect to exuberant temperament, there failed to be any significant correlations between CBQ Surgency or its composite factors and any of the task's behavioral measures. However, the BAS Drive subscale of the BIS/BAS, which is related to the persistent pursuit of desired goals, displayed a significant correlation with reaction time. Higher BAS Drive scores were related to faster reaction times, suggesting that more approach-oriented individuals responded faster to targets in anticipation of potential rewards. The BAS Reward Responsiveness subscale of the BIS/BAS also correlated significantly with accuracy rates, such that more Reward Responsive individuals had lower accuracy percentages. This finding is opposite of its expected direction and is somewhat difficult to explain, though one potential explanation could be a lower salience of the task stimuli and prizes to high Reward Responsive individuals. If the stimuli and prizes were not intrinsically interesting to these individuals, then they would not be as motivated to respond correctly on the task.

As a whole, these findings suggest that the piñata task is a behavioral paradigm that is sensitive to gross developmental changes such as decreasing reaction time from childhood to adolescence, but it lacks the acuity to detect fine-grained differences in reward sensitivity. Given that monetary incentive delay task studies typically do not report behavioral differences between groups (e.g., Guyer et al., 2006; Scherer et al., 2007; Bjork et al., 2004; 2010), eschewing these in favor of neuroimaging differences, the task may be better suited to examine developmental differences in brain activation with complementary fMRI.

It should be noted that this study possessed several limitations that are worthy of discussion. First, as was discussed previously, the size of the age groups may not have been adequately large to detect significant differences in reward processing. This limitation is evident in the high degree of within-group variability, reflected by the relatively large standard errors of the younger age groups compared to the oldest age group. Second, the study may have lacked a wide enough range of ages to capture the developmental trends of interest. Given that previous neuroimaging research (e.g. Galvan et al., 2006) has shown adolescents as differing from both children and adolescents with respect to reward processing, the inclusion of older comparison groups could have elucidated whether the patterns of reaction time and response accuracy observed during ages 10, 12, and 14 continue to change through later adolescence and early adulthood. Third, as previously discussed, the study lacked complementary neuroimaging data. Given that all the previously cited studies using the MID task have paired it with functional imaging, conducting this study without that data removes an entire dimension with which to observe differences between subject groups. Fourth, some of the questionnaire measures may not have been age-appropriate for the entirety of the sample. While using a uniform measure across groups allows direct comparisons to be made, it is also challenging to find measures that are developmentally appropriate for both children and adolescents. The CBQ in particular seemed developmentally inappropriate for the older age groups, and could have been replaced with an equivalent measure for older ages such as the Early Adolescent Temperament Questionnaire (EATQ; Capaldi & Rothbart, 1992). Finally, as discussed earlier, stars and DVDs may not have been an equally salient prize for all age groups. The use of explicit monetary rewards carries its own challenges (see discussion in Bjork et al., 2010), but the previously cited studies using the MID task have all employed explicit monetary amounts as its rewarding stimuli.

Without complementary neuroimaging data, it is impossible to claim that the piñata task cannot measure reward sensitivity. Future research with these methods is needed to validate or invalidate the piñata task as a useful tool for studying reward-related differences in developmental samples. While the colorful cartoon stimuli are notably different from the stark geometric stimuli of the original MID task (Knutson et al., 2000), the results of future studies would be more reconcilable with previous MID studies if actual monetary incentives were used. Finally, given the hypothesized link between reward sensitivity and risk-taking behaviors during adolescence (Casey, Jones, & Hare, 2008; Ernst, Pine, & Hardin, 2006; Steinberg, 2008), future studies should relate behavioral or imaging data using the piñata task to a developmentally-appropriate measure of risk taking like the Behavioral Analogue Risk Task (BART; Lejuez et al., 2002) or the Behavioral Analogue Risk Task for Youth (BART-Y; Lejuez et al., 2007).

Figures

Figure 1. Casey, Jones, and Hare (2008) model for developmental trajectories of prefrontal and limbic brain regions. Reward-responsive limbic regions develop earlier than the prefrontal regions involved in inhibitory control. During adolescence, this gap in relative maturity may prevent adolescents from inhibiting their own reward-seeking behaviors.

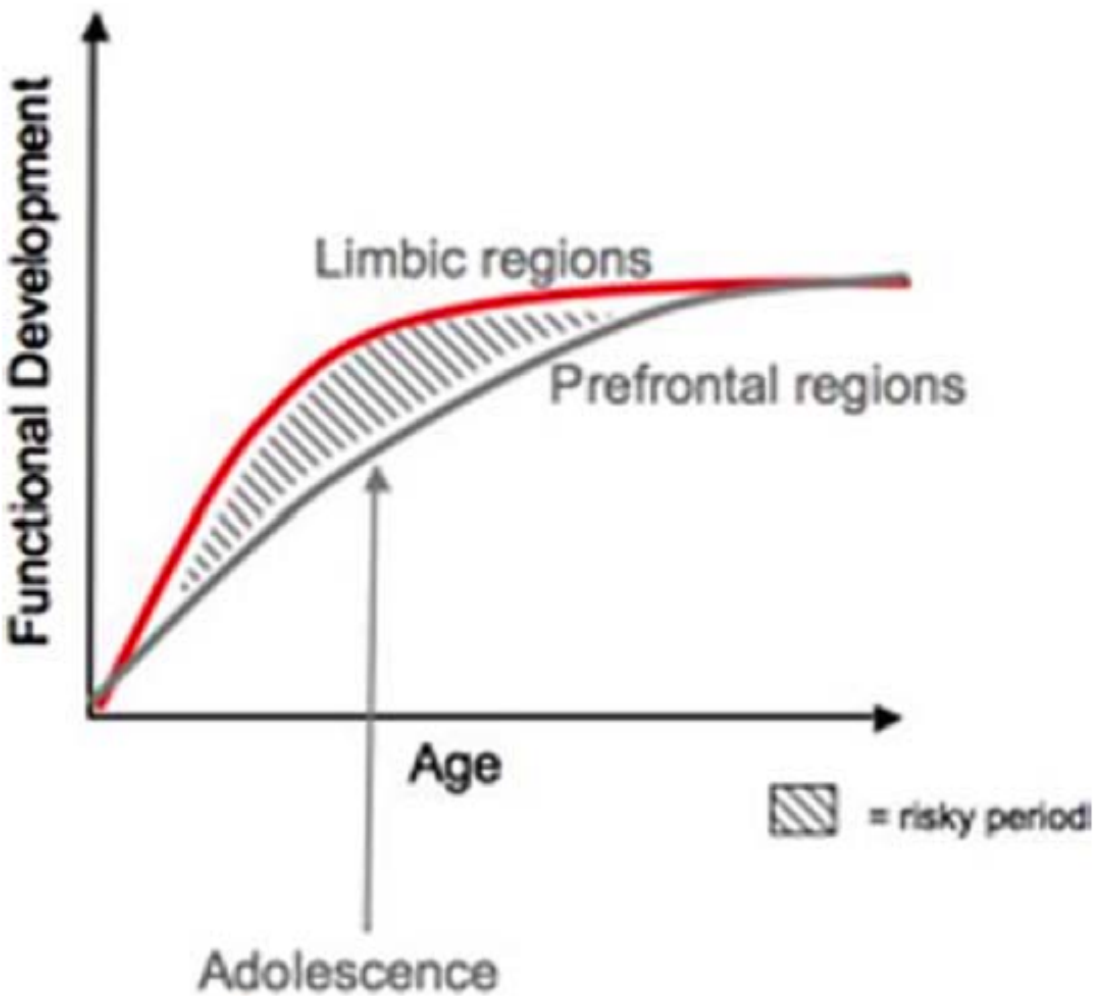


Figure 2. Timeline of the original Knutson and colleagues (2000) monetary incentive delay (MID) task. Note the three trial types. Subjects are rewarded during incentive trials on the reward block, punished on incentive trials during the punishment block, and given neither reward nor punishment on the control block.

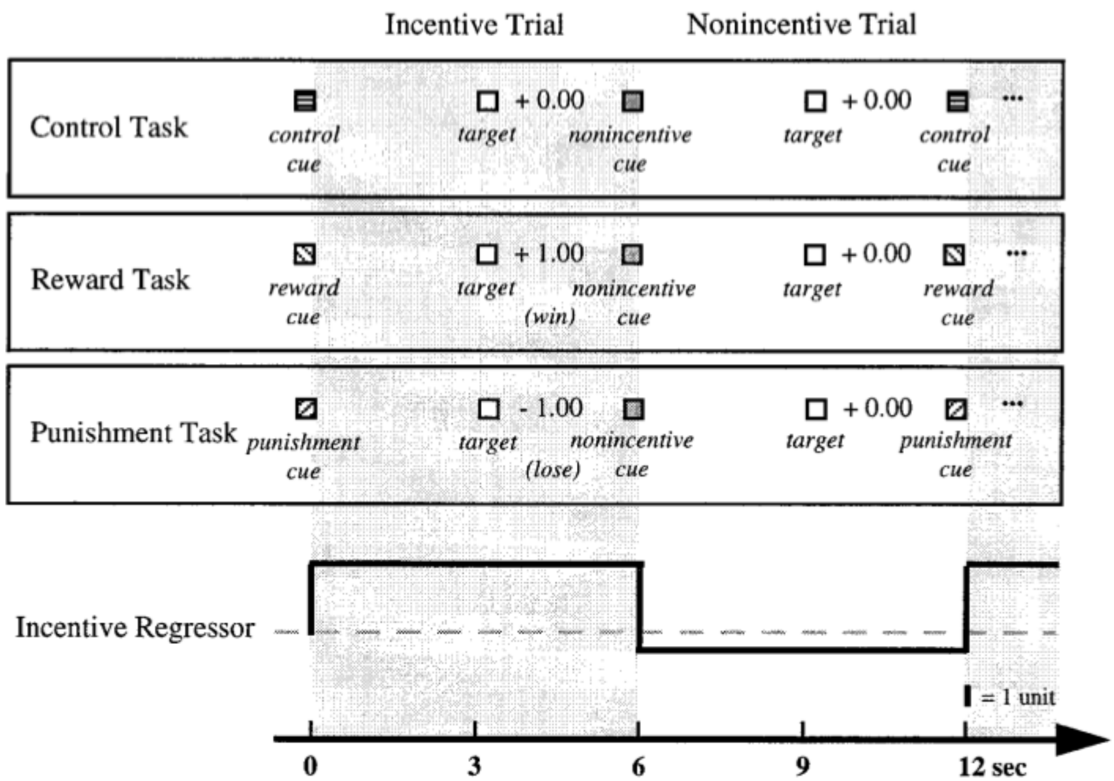


Figure 3. Timeline of the piñata task. This diagram displays a successful trial, where the subject has responded quickly enough to the target to break the piñata and win the stars inside. Responses that are too early (anticipatory) or too late result in the piñata swinging away to the left side of the screen with that trial's stars being lost. Trials can be worth zero, one, two, or four stars.

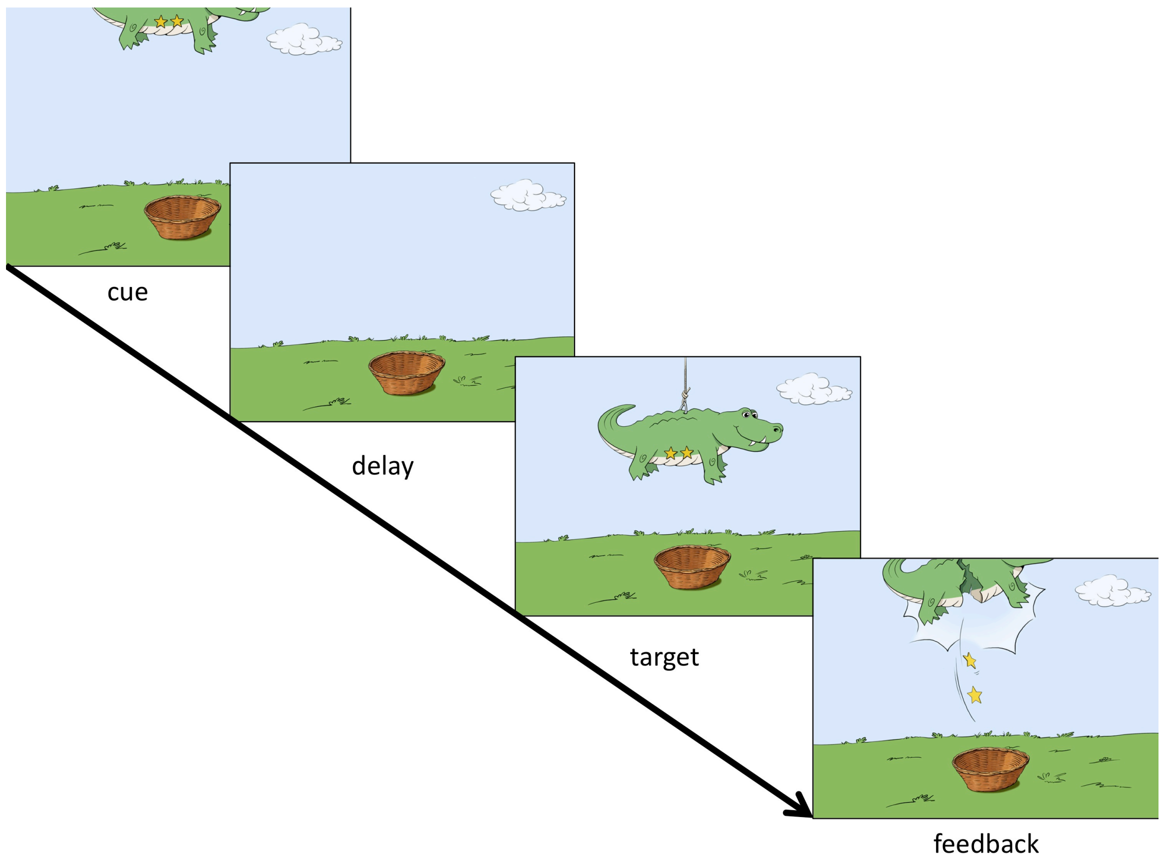


Figure 4. Mean reaction times for no-star, one-star, two-star, and four-star trials. Four-star trials were responded to significantly faster than no-star trials. ** = $p < 0.01$, * = $p < 0.05$.

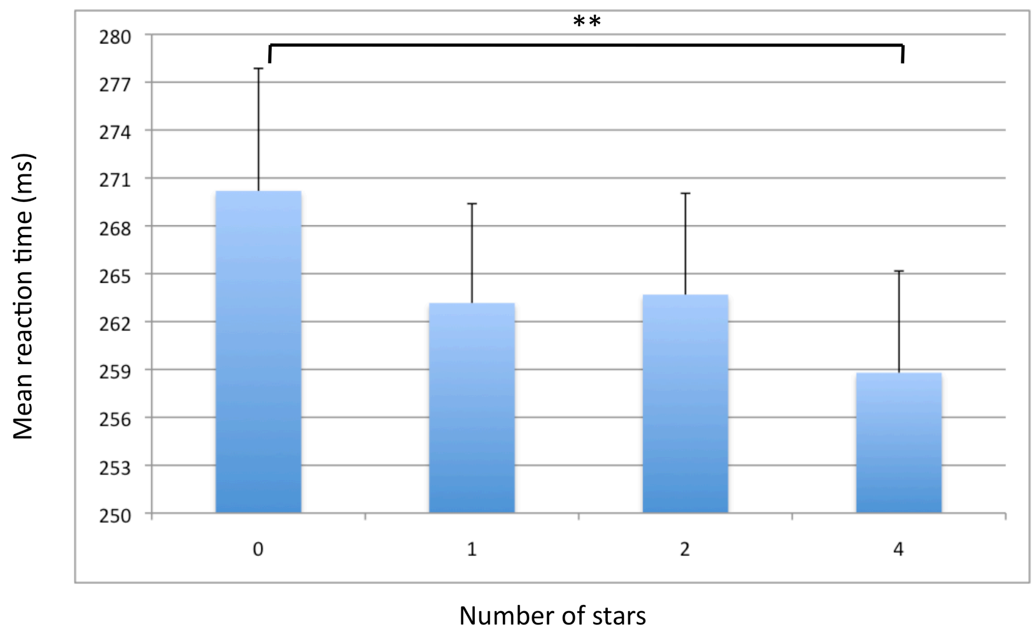


Figure 5. Mean reaction times for 8-, 10-, 12-, and 14-year-old age groups. Fourteen-year-old subjects responded significantly faster than 8-year-old subjects. ** = $p < 0.01$, * = $p < 0.05$.

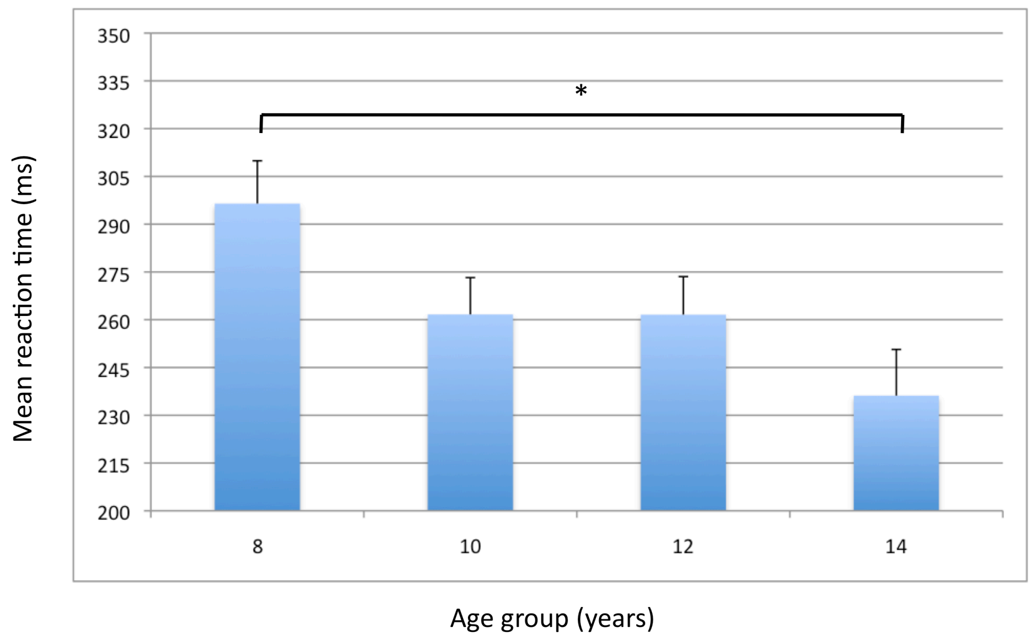
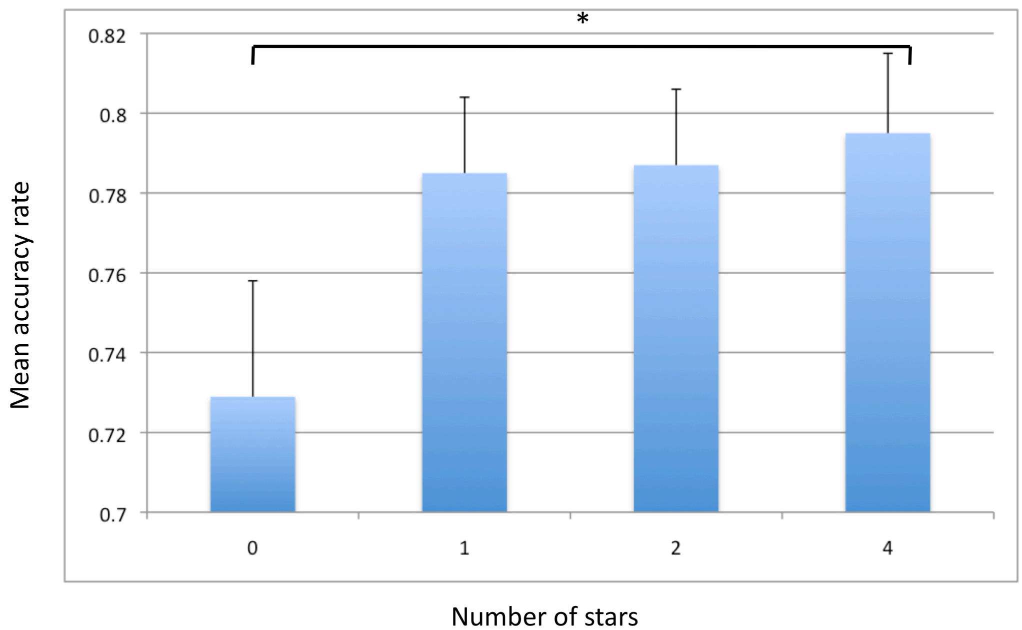


Figure 6. Mean response accuracies for no-star, one-star, two-star, and four-star trials. Subjects were significantly less accurate at responding to zero-star trials compared to four-star trials. ** = $p < 0.01$, * = $p < 0.05$.



APPENDIX

Piñata Experiment Script

PRIZE SELECTION

1) Tell the child that in the piñata game they will have a chance to win a prize. No matter what, they'll get a prize just for playing, but if they do really well at the game, then they'll get a really big prize.
2) Explain that the toys in the basket (the small prizes) are the prizes they can win just for participating, and that the prizes on the table (DVDs) are the ones they can win if they do really well.
3) Ask them to select a prize from the basket, and ask them to select a prize from the table that they would like to try and win instead of the little prize.
4) Once they've selected their prizes, leave the two chosen prizes on the table, and move the rest of the toys to the ground, out of their line of sight.

Practice

1) Seat the child in front of the laptop.
2) Say "This game is called the piñata game. Do you know what a piñata is? [Yes.] So tell me how you play with a piñata. [Child explains.] That's right. You hit it with a stick and candy comes out. So that's what you'll be doing in this game, except instead of having candy inside of them, our piñatas have stars. And those stars are what you need to get to win the big prize. So in the game, you're going to see a piñata way up at the top of the screen, with stars inside its belly. Then the piñata will drop down to the middle of the screen. As soon as it comes down, hit the spacebar as fast as you can to whack it. If you hit it fast enough, it'll crack

open and you'll win all the stars that are inside of it. But if you don't hit it fast enough, the piñata will swing off to the side of the screen and you won't get to win those stars. Does that make sense? Do you have any questions?"

3) Once the child has asked any questions s/he has, say, "OK, we're going to start by playing a practice round so you can see what the game is like. The piñatas go really fast in the practice, so don't worry how many you get right or get wrong, just hit them as fast as you can. Are you ready to start playing?"
4) Complete practice round.

Task

1) Remind the child of the rules of the game. If the child had anticipatory errors during the practice block, explain that they have to wait until the piñata has dropped down to whack at it. If they whack before it appears in the middle of the screen, they will miss the chance to win the stars inside.
2) Explain that there are six rounds of the game, with each round as long as the practice round they just played. Tell them that they can take breaks between rounds. Ask them if they're ready to begin.
3) Play the game!
4) At the end of each run, ask the child if they would like to continue or take a break. When they are ready to continue, press the space bar to advance to the next run.
5) When six runs have completed, the game will shut off. Tell the child congratulations, s/he won enough stars to get the big prize!

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