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An investigation of risky decision-making:

The role of temperament, development, early adversity, and ADHD

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy in Psychology

by

Kathryn Leigh Humphreys

2014

ABSTRACT OF THE DISSERTATION

An investigation of risky decision-making:

The role of temperament, development, early adversity, and ADHD

by

Kathryn Leigh Humphreys

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2014

Professor Steve S. Lee, Co-Chair

Professor Nim Linnette Delafield, Co-Chair

Exploration is a process that inherently brings both risk of negative outcomes and opportunities for success. With either outcome, that exploration, or risk-taking, results in feedback and the potential for learning. Measuring risk-taking, and the ability to learn from risk-taking, has clear relevance. Previous laboratory-based assessments of risk-taking and learning have been limited. Although tasks included implicit rules that could be deduced from experience to guide subsequent decision-making, participants have had limited ability to explore the task environment. The purpose of this investigation was to examine risky decision-making on a novel task, the Balloon Emotional Learning Task (BELT), in four studies. The first provided initial validation of the BELT and examined the association of personality/temperament factors in relation to risk-taking and learning. The second study examined age-related changes in risky

decision-making in individuals ranging from 3-26 years of age. The third study examined the association of maternal deprivation, age, and sex with risk-taking and the functional outcome of risk-taking. The fourth study examined the association of childhood attention-deficit/hyperactivity disorder (ADHD) on risky decision-making and learning on the BELT measured from a two-year prospective longitudinal study. Across all samples, individual differences in learning from risk-taking were observed, and they were significantly associated with personality traits, age, early adversity, and ADHD. The results have implications for empirical investigations of risk-taking and its functional outcome, and how decision-making can be influenced by feedback. The findings also highlight the importance of considering sensitivity to negative feedback and learning from experience in the successful decision-making in the context of risk.

The dissertation of Kathryn Leigh Humphreys is approved.

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University of California, Los Angeles

2014

DEDICATION

To my parents, who always encouraged my exploration.

To my advisors, who have patiently helped me to learn.

And to Robert, for everything.

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ACKNOWLEDGEMENTS

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Only those who will risk going too far can possibly find out how far one can go.
T. S. Eliot
American-English poet, playwright, and critic

CHAPTER ONE: AN INTRODUCTION TO RISK-TAKING AND ASSOCIATED

LEARNING

Risk-taking can be considered any action that entails a chance of negative outcome. As a

result, risk-taking, and its analog exploration, may result in gains and losses. Exploratory

behavior has been studied across species and stages of human development (e.g., Montgomery &

Monkman, 1955; Welker, 1961). For example, fungi take risks when either devoting resources to

growing in its current location or using those resources to send hyphae outward (Watkinson et

al., 2005). Ants seeking a new nest must decide where to make their new home between various

potential locations (Pratt & Sumpter, 2006). In humans, exploration begins very early in

development: infants explore via passive means (e.g., looking, listening, smelling) or via active,

instrumental means (e.g., touching, tapping, moving). Although there are several potential

motives for this exploration, theorists from the functional approach to development assert that

organisms seek to "see clearly, to hear distinctly" (Woodworth, 1947; 1958). In this way,

exploring is seen as satisfying a need to know and understand the world in which we live

(Berlyne, 1966). Alternatively, transforming novelty into familiarity via exploration has been

theorized as anxiety reducing, an action performed to assuage the negative associations related to

ambiguity, or simply a necessary activity in which to achieve a goal (McReynolds, 1961).

Although risk-taking has been a focus of study in psychology and neuroscience, other

disciplines have investigated risk-taking as well. For example, educational researchers have

examined whether intellectual risk-taking (e.g., asking questions or attempting to learn new

material with a risk of making errors or facing potential embarrassment) was related to individual

differences and other salient classroom behavior (Beghetto, 2009). Individual differences in risk

preferences, as well as how one values potential gains or losses, are related to risk-taking

behavior. Accordingly, individuals who are "risk averse" are thought to sacrifice potential value gained from risk for stability, whereas "risk seekers" are thought to sacrifice stability in order to gain potential value.

One theory of individual differences, the self-regulation model (SRM; Miller & Byrnes, 1997), broadly attributes inappropriate risk-taking to dysregulation and insensitivity to outcomes. Maladaptive risk-taking has been characterized from various perspectives (e.g., externalizing behavior, drug use, sexual behavior, delinquency, gambling), and attempts to measure these tendencies have traditionally relied on self-report measures. Although self-report measures correlate with real world risk behavior (e.g., West, French, Kemp, & Elander, 1993), experimental behavioral tasks may be better able to interrogate the neurobiology of risk behavior (Jentsch, Woods, Groman, & Seu, 2010). Experimental risk-taking tasks have primarily been used to examine: (1) general factors related to risk-taking (e.g., size of reward, reinforcement schedule, inclusion of punishment conditions), and (2) individual and developmental differences in risk-taking. In the present section, I focus on this second type of differences in risk-taking.

Slovic (1966) studied risk-taking in children across the ages of 6 to 16 years using the Devil's Task. The task presents 10 switches to participants; each switch produces a prize except for one. The one switch that does not result in a prize instead incurs the loss of all prizes. Each participant may choose how many times to press a switch, with each press increasing the likelihood of loss. For example, the probability of losing on the first round is .1, and the probability of failure increases linearly across each trial. Scores from the Devil's Task (i.e., number of presses made before stopping [or losing]) differentiated objectively defined risk-takers and non-risk-takers (Slovic, 1966). More recently, five to six year-old children who pressed more switches on the Devil's Task were more likely to attempt to cross a street when it

was unsafe, compared to children who pressed fewer switches (Hoffrage, Weber, Hertwig, & Chase, 2003).

A second, similar task has been used widely to examine harmful risk-taking in individuals. The Balloon Analogue Risk Task (BART; Lejuez et al., 2002), a computerized task designed to assess risk-taking behavior, requires participants to pump up a series of simulated balloons for points by pressing a button for each pump (i.e., more pumps result in more points). In the BART, balloons explode at unknown and variable levels of pumps, requiring participants to moderate pumping behavior and save their points before the balloon explodes in order to accrue points. If the balloon explodes, no points on that trial are accrued. In addition, the choice to save points results in the end of that trial and the onset of the next trial. Importantly, this task provides the ability to examine instrumental behavior in a series, allowing for the measurement of both individual differences in risk-taking, and the relationship between risk-taking and performance on the task. Theoretically, pumping up every balloon to the point of explosion, as well as an alternative strategy of pressing very few times for each balloon, would each result in outcomes far below optimal. In prior studies, risk-taking has been operationalized as the average number of pumps made on the balloons that did not explode, which had a moderate positive association with both impulsivity and sensation seeking (Lejuez et al., 2002).

Both the BART and Devil's Task require the participant to choose to either press for a larger reward and risk failure, or stop pressing and save a potentially smaller reward than achievable. Although in both the BART and Devil's Task, any trial (from the first to the last possible switch/pump) may result in failure, the likelihood of failure increases across each successful press, and as a result the probability of each successive pump resulting in success is nonstationery. An important difference between the BART and the Devil's Task is the degree to

which participants explicitly are told the task structure. The Devil's Task presents actual switches, which can be easily observed whereas the BART provides a series up balloons, with an unknown number of potential pumps. Thus, the BART has been classified as "ill-defined" (Pleskac, 2008). Regardless of the degree to which each is "defined," both have differentiated risk-takers from non-risk-takers. The BART has the advantage of providing more data than the number of switches pressed on the single round offered by the Devil's Task. The BART provides information on presses made across all 30 balloons, the number of these balloons that exploded, and the amount of money or points earned on the task. The number of presses made on the BART may indicate an increased willingness to accept risk. In support of this, average adjusted pumps on the BART (average of all trials that did not result in a balloon explosion) correlated positively with sensation seeking and other risk behaviors (Aklin, Lejuez, Zvolensky, Kahler, & Gwadz, 2005; Bornovalova et al., 2009; Crowley et al., 2009; Hunt, Hopko, Bare, Lejuez, & Robinson, 2005; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Lejuez et al., 2002).

The validity of the BART is further supported by the development of a rodent version of the task, which has facilitated understanding of risk-taking, reward, and similar constructs in another mammalian species, and enabled the interrogation of the neurobiology of risk-taking on the task via experimental microinfusions of a gamma-Aminobutyric acid (GABA) agonist to either the medial prefrontal cortex or the ventrolateral orbitofrontal cortex (ratBART; Jentsch et al., 2010). In this task, rats pressed a lever for food pellets, and lost pellets at a variable point of failure, similar to balloon presses and explosions in the original task. Results indicated that rats were sensitive to risk, such that greater presses were made on conditions with no risk of failure, and fewer presses made in conditions with the possibility of pellet loss.

Importantly, ratBART findings suggest that both rats show similar decision-making behavior under conditions of risk compared to humans. As with findings from the BART in humans (Bornovalova et al., 2009; Humphreys & Lee, 2011; Lejuez et al., 2007; Lejuez et al., 2003; Lejuez et al., 2002), rodents demonstrated risk averse behavior, and made fewer presses than optimal (Jentsch et al., 2010). This risk averse pattern of behavior has been theorized to be due to an overestimation of risk (Bornovalova et al., 2009). Thus, although the task was designed to assess maladaptive risk-taking behavior, the majority of participants earn fewer points than optimal due to behaviors suggestive of risk aversion. In this case, some participants may make a greater number of pumps on the BART in the service of earning greater points rather than behaving in ways that are maladaptive.

Accordingly, frequent or high risk-takers may be a heterogeneous group, and as a result, it may be difficult to find individual difference traits that are highly associated with risk-taking. To minimize confounds resulting from simply comparing maladaptive risk-takers (e.g., antisocial individuals) to a healthy comparison group, Levenson (1990) examined three different groups of risk-takers using discriminant function analysis. This study found that a group of rock climbers were high on sensation seeking and moral reasoning, drug unit residents were high on antisocial function (e.g., emotionality, psychopathy), and police and firemen decorated for safety had different profiles than both other groups. These results suggest that differences in risk-taking behaviors may be, in part, related to the motivation for risk-taking behavior. Some groups of individuals who had taken great risks did so from an arguably altruistic motivation. For example, Jewish individuals who rescued others during the Holocaust were compared to bystanders and individuals who emigrated from Europe prior to World War II (Midlarsky, Fagin Jones, & Corley, 2005). The rescuers scored higher on risk-taking than both the bystander and immigrant

group. Notably, these individuals not only differed in risk-taking, but also social responsibility, empathic concern, and moral reasoning. Thus, risk-taking behavior may indeed be a positive act, and one's tendency to engage in such behavior is likely to be context dependent.

Boyer (2006) stated that "Risk-taking behaviors are not entirely foolhardy… and may be the most rational course of action given one's priorities" in his lengthy review on developmental perspectives to risk-taking. This work concludes with a call for conceptualizations of risk-taking that include the potential positive outcomes that result from risk-taking behavior, perhaps also extending to the development of methods that are more attuned to this component of risk-taking. Tasks that measure exploration of one's environment, seeking out opportunities, taking risks need not be only for those that fall on the extreme end of the spectrum given that high risk-taking may not be maladaptive. Even in infancy, exploration of the environment is considered to be essential for learning and development (Piaget, 1954). In a study of BART in children, Humphreys and Lee (2011) risk-taking increased linearly with age. Unpublished results from this study also indicated that increased risk-taking was highly correlated with increased total points earned, suggesting that older children's risk-taking may alternatively be viewed as enhanced performance, or adaptive behavior.

Risk-taking has three possible outcomes, all of which provide information: gains, losses, or no change. Frequent risk takers increase the likelihood of experiencing both successes and losses, and thus experience more opportunities to gain knowledge. Conversely, cautious individuals who take fewer risks have fewer opportunities for learning, favoring the relative safety from loss. Decisions on whether to explore or exploit known options occur in our daily lives (e.g., whether to try a different path home, whether to order our favorite meal or try a new one, whether to date several potential mates or select a monogamous relationship). Decision-

making plays an essential role in choosing among courses of action, or conversely, inaction. Decision-making is thought to consist for four discrete steps (Byrnes, 1998; Byrnes, Miller, & Reynolds, 1999): (1) goal setting, (2) compiling options, (3) rank-ordering options, and (4) selection of option. For the Devil's Task and BART, the goal is to achieve the highest payout at the end of the task; the options are to press or save points, and then to implement that choice. Participants receive immediate feedback following each press by either earning an additional prize or point, or with receiving the "Devil" or balloon explosion. This feedback is an essential for future decision-making under conditions of risk. For the BART, participants have 30 trials in all, and thus have 29 opportunities to receive feedback to guide future decisions. In this way, exploratory activity provides the opportunity to observe its consequences, thereby creating an opportunity for learning and the ability to make predictions about the world.

Learning can occur via decision-making during this feedback period, as observations during feedback provide information on whether previous choices resulted in the desired outcome. Gibson (1988) stated that exploring the world and learning about the world are "inextricably linked." Intellectual risk-taking has been linked to academic identity development, as well as student learning (Clifford, 1991; Clifford & Chou, 1991; Donovan & Bransford, 2005; Streitmatter, 1997). Examining laboratory-based risk-taking tasks, Pleskac (2008) formally modeled how feedback informs decision-making in sequential risk-taking tasks, and asserted that most models exclude information gained via feedback, which results in learning, into decision-making theories (e.g., Busemeyer & Townsend, 1993; Gonzalez-Vallejo, 2002; Kahneman & Tversky, 1979). He cites both the BART and the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994, discussed below) as risk-taking tasks in which learning based on previous feedback plays a crucial role in guiding future behavior. The authors of the BART were

interested in assessing individual differences in risk-taking, rather than the association between risk-taking and the functional outcome of the risk-taking behavior, and thus did not examine the direct association between these measures.

Previous instrumental learning tasks (e.g., Corr, Pickering, & Gray, 1995) have been designed such that participants are asked to make a simple choice (i.e., press or no press). They typically rely on fixed pairings, such that a given behavior uniformly results in a particular outcome. As a result, the instrumental or operant piece is a single decision for each pairing. However, other computer tasks provide the ability to more closely approximate real-life decision-making, in which choices are not simply "do or do not" before a new stimulus is presented. Thus, current tasks are ill-equipped to examine adaptive aspects of risk-taking, given that the most adaptive functioning requires a balance between exploration and exploitation.

Exploration and exploitation are separable constructs, and are therefore suitable for independent examination. For example, exploration and exploitation have been experimentally dissociated via sleep deprivation manipulations (Maddox et al., 2009). Thus, it is likely that similar levels of risk-taking may result in varying levels of learning. Multiple dimensions of temperament may contribute to learning in the context of risk. Accordingly, impulsivity, sensation seeking, and anxiety, have been proposed as possible factors related to ineffective processing of probable outcomes from risk-taking (Miller & Byrnes, 1997), which are likely to directly influence accurate learning. Miller and Byrnes (1997) propose that self-regulation can be demonstrated via learning from experience. Repetition of mistakes is, therefore, a sign of dysregulation. In concert with this theory, research from an implicit learning and decision-making task indicated that the failure to learn during the Iowa Gambling Task distinguished

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healthy from atypical adult populations (Stout, Rock, Campbell, Busemeyer, & Finn, 2005;

Yechiam, Busemeyer, Stout, & Bechara, 2005).

Learning under conditions of uncertainty may differ from learning on tasks in which

tasks are well-defined. The Angling Risk Task (ART; Pleskac, 2008) was designed to assess

risk-taking under varying conditions via a computer game in which participants fished in a pond.

In sunny conditions, participants were able to see the number of fish swimming in a pond,

whereas in cloudy conditions, participants were unable to see the fish. Risk-taking on the ART

was differentially related to real world risk-taking depending on condition. Only during the

sunny condition did risk-taking positively correlate with a substance use. During ill-defined task

conditions (when the pond is cloudy and the number of fish in the pond is unable to be seen)

individuals used information based on prior trials to form estimates of probabilities of success

versus failure for each decision (to fish or save). This ill-defined condition is most like the

BART, in which participants have no knowledge to guide the number of times to pump each

balloon except from results on previous balloon trials. Pleskac's study suggests that the learning

component of the BART may inhibit its ability to clinically distinguish risk-takers from healthy

participants (Pleskac, 2008). These findings suggest that only when participants do not need to

rely on prior experience to guide behavior does risk-taking behavior on the task correlate with

real world risky behavior.

The degree in which learning occurs based on experience is an important question. It is

clear that individual differences exist in exploration. However, given the same amount of

information about one's environment, are there additional differences in how that information is

incorporated to guide later behavior? One study examined this question by measuring whether

receiving feedback about choice outcome following decisions affected later choices in both

adolescents and adults (Byrnes et al., 1999). The results suggested that adults are more likely to use outcome feedback to guide their behavior than adolescents. At present, relatively little is known about how self-driven exploration results in learning, and how individual differences may influence learning under contexts of risk. While individual difference factors related to both risk-taking and simple associative learning have received some attention, the relationship between exploration and learning, and related temperament, developmental, and psychopathological influences merits further examination.

Emotional aspects of risk-taking

Risk-taking behaviors are not exclusively cognitively mediated (Cooper, 1992; Cooper, Frone, Russell, & Mudar, 1995). The roles of emotional coping strategies, avoidance of negative affect, and desire for positive affect also underlie risk-taking. The association between the cognitive and emotional aspects of decision-making is thought to be bidirectional (Schwarz, 2000). Cognitive theorists tend to emphasize models that highly weight choices based on accurate judgments, which resulted in a relative neglect of the emotional aspects of decision-making (e.g., Bechara, 2003; Dahl, 2003; Steinberg, 2004). A large body of work on the IGT has demonstrated the role of affect in decision-making (e.g., Bechara, 2003; Bechara, Damasio, & Damasio, 2000; Bechara & Van Der Linden, 2005).

The goal of the IGT is to win as much money as possible over the course of the game by choosing cards from a series of four decks. Two decks are disadvantageous, while two decks are advantageous. Over the course of the task, the advantageous decks provide greater winnings. Probabilities of the various deck's rewards must be inferred via task experience (i.e., via learning) (Busemeyer & Townsend, 1993). Individuals with orbitofrontal cortex dysfunction

demonstrate a failure to avoid the disadvantageous decks after 40-50 trials, while typical healthy adults learn to favor the advantageous decks (Bechara et al., 1994).

Damasio (1994) proposed that somatic markers, which are emotional physical reactions, guide decision-making. Individuals who fail to learn via the IGT are thought to have difficulty using somatic markers to guide decision-making. In one study, galvanic skin response when "hovering" over disadvantageous decks was found in healthy controls after only approximately 10 trials, indicating that there is a physical bodily response to the disadvantageous decks before the participant is consciously aware of the quality of that deck (Bechara, Damasio, Tranel, & Damasio, 1997). The somatic marker hypothesis (Bechara et al., 2000; Bechara, Damasio, Damasio, & Lee, 1999; Damasio, 1994), posits that in response to positive or negative feedback, emotions guide risk-taking. This account of affective decision-making proposes that emotions play a crucial role in successful decision-making, as the positive or negative feelings experienced after choosing advantageous or disadvantageous decks lead participants to make better choices. Neuroimaging studies of participants completing the IGT resulted in claims of partial support for the somatic hypothesis (Li, Lu, D'Argembeau, Ng, & Bechara, 2010). Specifically, areas associated with working memory, emotional states, and their coupling were found to be active during decision-making. Thus, successful learning seems to be contingent on representing the associations between an affective state and a stimulus.

An additional emotional aspect in decision-making is the impact of uncertainty on behavior. The drive to explore is associated with the amount of information individuals have about the consequences of that exploration. Individuals have been found to prefer certain over uncertain alternatives, even when over the course of repeated trials the value of choosing each option is equivalent, given the underestimation of the uncertain choice (Denrell, 2005, 2007).

Two important neurotransmitters (acetylcholine and norepinephrine) have been proposed to detect sources of uncertainty (Yu & Dayan, 2005). The self-regulation model of risk-taking specifies that "a calibrated sense of certainty" is an important self-regulatory tendency associated with goal achievement under risk-taking (Byrnes, 1997). Not surprisingly, when we better understand the environment, we perform better (Yu & Dayan, 2005). Accordingly, one should undertake exploration to reduce uncertainty. J. D. Cohen, McClure, and Yu (2007) have postulated that uncertainty directly affects exploration, such that the point in which prediction errors (i.e., when an outcome deviates from what is predicted) exceed expectations one should further explore the environment. Thus, in an unknown environment, exploration is an important initial process. As information about the environment is obtained, exploitation of known options may become favored over continued exploration. However, individual and developmental differences may impact both initial exploration and decisions regarding whether the continue exploration or to exploit known options.

Knowledge behind decision-making

Bechara and colleagues developed a coding system to categorize conceptual-knowledge on the IGT in order to classify participants' explicit understanding of the underlying probabilities of the four decks (Bechara et al., 1997). This coding system was adapted for use with the IGT with children and adults (Crone & van der Molen, 2004). Their findings indicated that nearly all participants reported a representation of the task structure, such that very few individuals indicated no strategy for their choices (i.e., "I don't know"). Not surprisingly, developing a correct conceptualization of the game (i.e., having a "hunch" in regards to advantageous/disadvantageous choices or explicit understanding of these properties as they pertain to choices) was associated with task success.

Proposed Project

The Balloon Emotional Learning Task (BELT) was designed to incorporate both instrumental exploration and learning in a paradigm with fixed and variable conditions. This computerized task borrows elements from the Devil's Task and BART, as well as the IGT, to measure individual differences in risk-taking and learning. Importantly, rather than presenting three variable conditions with differing probabilities for the explosion point, as in the original BART, there is one variable condition and two stable/certain conditions (one that has a low threshold for the explosion point and the other has a high threshold for the explosion point). As in the original BART, different balloon conditions are denoted by the color of the balloon, in which the meaning is initially unknown to participants. This allows for the tracking of balloon condition differentiation and the ability to detect change in behavior from the beginning to the end of the task, which is a marker of learning. Well-structured environments can be explored systematically (M. X. Cohen & Ranganath, 2007), while unpredictable environments require reliance on cruder assumptions about options. Theoretically, one is able to identify optimal performance in the structure of the BELT given that the task is highly structured, although the variable balloon conditions may provide a challenge to fully understanding the structure given the relatively few (9) number of trials in which to explore.

An increase in points earned on the task represents learning taking place. The current tasks provides at least three notable advantages to previous tasks: (1) rather than presenting a single stimuli and participants have the option to press or not press (e.g., Corr et al., 1995), and receive immediate feedback, the BELT allows participants to determine the number of presses to make, thus allowing for the examination of the degree of risk-taking before feedback is provided, (2) the inclusion of stable stimuli conditions and a variable condition, which allows for

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examination of behavior under varying levels of certainty, and (3) the task provides separable assessments of risk-taking (pumps made) and adaptive behavior or outcome (points earned). Related to this point, learning can be assessed by the improvement in points earned with greater task experience.

Both overall risk-taking and change in behavior in response to feedback are important areas for investigation. For example, why are some individuals more risk-taking on the task versus others, and how might this difference impact later task performance? A second question is in regards to learning in response to feedback. For example, are some individuals more likely to use feedback to guide future behavior? In other words, who is using information gained via experience with the task in order to improve their performance? Previous work suggests that developmental level plays a role in the degree individuals learn from feedback, as adults and eighth graders performed similarly during initial task trials, but a gap emerged across the course of the task such that adults made greater gains in performance with greater experience (Byrnes et al., 1999).

This dissertation aims to understand risk-taking and associated outcomes in a risky decision-making task that separately measures risk-taking behavior and successful decision-making. The role of several individual difference perspectives will be examined in relation to both risk-taking and learning on the BELT. Accordingly, a four-part study is proposed to examine: (1) individual differences in selected personality traits in adults, (2) normative development from preschool-age to adulthood, (3) in children who experienced previous-institutionalization (i.e., orphanage rearing), and (4) in children with and without attention-deficit/hyperactivity disorder (ADHD).

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CHAPTER TWO: NOT ALL RISK TAKING BEHAVIOR IS BAD: ASSOCIATIVE

SENSITIVITY PREDICTS LEARNING DURING RISK TAKING AMONG HIGH

SENSATION SEEKERS[1]

Abstract

Risk taking behavior can be both adaptive and maladaptive depending on context. The

majority of studies on risk taking, however, focus on clinical populations and dangerous

or harmful risk taking. Individual differences in learning during risk taking are rarely

examined in relation to task performance. The present study examined risk taking and

associated outcomes in an exploration-based instrumental learning task (Balloon

Emotional Learning Task; BELT), which presented a series of balloons in which

participants pump up for points. Consistent with prior work, sensation seeking predicted

increased risk taking behavior. Importantly, however, a significant interaction between

sensation seeking and associative sensitivity, an attentional construct defined as the

frequency and remoteness of automatic cognitive activity, was found. Specifically, among

individuals high in sensation seeking, associative sensitivity predicted fewer balloon

explosions and an increase in points earned on the balloon condition with the most

potential for feedback driven learning. Thus, these findings suggest that sensation seekers

are a heterogeneous group, and secondary traits such as associative sensitivity moderate

risk taking and learning according to context.

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1. Introduction

Given their clinical and public health consequences, studies of risk taking have largely focused on potentially harmful risk taking behaviors, their negative consequences, as well as identifying individuals likely to engage in these behaviors. However, as Boyer (2006) noted, "Risk-taking behaviors are not entirely foolhardy… and may be the most rational course of action given one's priorities" (p. 336). For example, while foraging behavior may increase risks of predation (Godin & Smith, 1988), hungry animals are more likely to engage in such behavior in order to reduce the risk of starvation (Van der Veen & Sivars, 2000). Thus, as a group, risk takers may be heterogeneous. Discriminant function analysis of three different groups of risk takers found that rock climbers were high on sensation seeking, residents in a long-term drug treatment facility were high on antisocial function, while police and firemen decorated for safety were lower on both sensation seeking and antisocial function, as their risk taking served a prosocial function (Levenson, 1990). These results suggest that individual differences in risk taking behaviors may be, in part, related to the functional utility of risk taking behavior, and as a result, temperament correlates may not be easily identified via a "one size fits all" approach.

1.1. Individual differences in risk taking

Although self-report measures of individual differences in risk taking, such as those that assess temperament and personality, correlate with real world risk behavior (e.g., Schwebel, Severson, Ball, & Rizzo, 2006), the use of experimental behavioral tasks may be better able to assess real-world risk taking behavior and interrogate the neurobiology of risk behavior (Jentsch, Woods, Groman, & Seu, 2010). The Balloon Analogue Risk Task (BART; Lejuez et al., 2002) has been used widely as a laboratory analogue of individual differences in risk taking. Behavior on the BART is predicted by sensation seeking (SS) (Lejuez et al., 2002), though this task has

largely been used to assess risk taking in clinical populations (e.g., Hopko et al., 2006; Lejuez et al., 2003).

Tasks that measure tendencies to explore and seek out opportunities need not be specific to clinical populations. Even in infancy, exploration of the environment is essential for learning and development (Piaget, 1954). BART-like tasks provide the opportunity to examine change across trials as a function of experience, allowing for the measurement of both individual differences in risk taking, and the relationship between risk taking and outcome on the task. For the BART, the stated goal is to achieve the highest payout at the end of the task. Learning can play a crucial role in success during this type of task. Participants receive immediate feedback (an additional point or a balloon explosion) following each press, which can guide future decision making under these conditions of risk. Gibson (1988) stated that exploring the world and learning about the world are "inextricably linked." Yet, heterogeneity in risk takers could be caused by how much they learn from their risk taking experience. The differences in the acquisition and use of relevant information may play an important role in moderating subsequent risk taking behavior. By examining how risk taking is altered in response to learning may provide a clearer picture of optimal versus suboptimal risk taking.

1.2. Learning and risk taking

Pickering and Gray (2001) stated that "the ability to detect and attend to salient stimuli may be particularly relevant in [stimulus-response] learning tasks in which the subject has to learn which stimulus features are predictive of the responses required…" (p. 115). The ability to make meaning from the associations in one's environment has clear evolutionary advantages, and like many cognitive processes, is expected to vary across the population. Associative sensitivity (AS), an attentional construct defined as "frequency and remoteness of automatic

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cognitive activity" (Evans & Rothbart, 2007), has not been examined in relation to learning. The similar Big Five construct of Openness to Experience (see Evans & Rothbart, 2007), has been described as attentiveness to inner feelings, aesthetic sensitivity, and intellectual curiosity (Costa & McCrae, 1992). In fact, AS has been theorized to be the attentional disposition that "links" Openness to actual extraction of actionable information (see Van Egeren, 2009). Implicit learning (the automatic detection of associations in the environment) has shown moderate positive associations with Openness (Kaufman et al., 2010), though we propose that AS is likely to better predict such learning. Thus, we anticipate that both individual difference traits (i.e., SS [sensitivity to rewards] and AS [sensitivity to stimulus-response associations in the environment]) would be relevant in unique ways to risk taking behavior over time.

1.3. Aims and hypotheses

The current study modified the BART to provide a tool to examine changes in risk taking behavior depending on implicit contextual information. The modified task, Balloon Emotional Learning Task (BELT), contained two stable (certain) and one variable (uncertain) balloon condition. The inclusion of balloon conditions with fixed explosion points allowed for a more direct examination of learning such parameters via task experience as the fixed information can better guide subsequent risk taking behavior, as opposed to 'ill-defined' tasks such as the BART (see Pleskac, 2008). Conditions were denoted by balloon color with initially unknown meaning to participants in order to facilitate measurement of individual differences in tracking the balloon condition and differentiation of behavior from the beginning to the end of the task. The current task is well-suited for assessing risk taking and learning for the following reasons: (1) rather than measuring a single behavioral response to a single stimulus (e.g., Corr, Pickering, & Gray, 1995), participants determine the number of presses to make (that is, to "push the limit" of each

balloon trial), thus providing a laboratory measure of risk taking, and (2) the inclusion of three

balloon conditions provides the ability to capture separable risk taking and learning outcomes.

We hypothesized that SS would predict risk taking (i.e., pumps, balloon explosions) as

found in previous research on the BART (Lejuez et al., 2002). However, we also anticipated that

sensations seekers would be a heterogeneous group. Therefore, based on Pickering and Gray's

(2001) predictions regarding individual differences in associative learning, we hypothesized that

AS would moderate the association between SS and task outcome.

2. Method

2. 1. Participants

Seventy-six (26 male, 50 female) undergraduates from a large public university in the Western

United States who received partial class requirements for participation. Participants were

required to be at least 18 years of age or older and English speaking. This sample ranged in age

from 18-26 years old (*M*= 20.15, *SD*= 1.70). One participant was excluded as an outlier due to

scores falling beyond three standard deviations from the mean.

2.2. Tasks and measures

2.2.1. Balloon Emotional Learning Task (BELT).

All participants completed a computerized associative learning task in which participants would

press a button to "pump up" balloons and earn points for each balloon (i.e., more pumps earned

more points). Too many pumps would result in balloon explosions, which occurred at an initially

unknown number of pumps, resulting in the loss of all points for that trial. Balloons appeared in

three colors with different response contingencies, counterbalanced across participants. Pink

balloons exploded at 19 pumps (certain-long), orange balloons exploded at 7 pumps (certain-

short), and blue balloons exploded variably at 7 pumps, 13 pumps, or 19 pumps distributed

equally across each third of the task (uncertain). There were 27 trials, and balloon color was distributed evenly across the task. Participants were not told that colors signified different response contingencies, but were explicitly told that not all balloons pop at the same point. Thus, the task involved associative instrumental learning because participants could make cause-effect determinations by altering their own behavior through learning how balloon color relates to task structure. In this way, the task is 'defined' given that the underlying the task structure can be determined, unlike other risk taking tasks (e.g., BART).

2.2.2. Adult Temperament Questionnaire - short form (ATQ; Rothbart, Ahadi, & Evans, 2000). This 77 item self-report measure of temperament obtains five general factors of temperament. Likert-scale ratings ranging from 1 (extremely untrue) to 7 (extremely true) were obtained on each item, and scales were composed of the mean of all items. For the present study we used the AS scale (example item: "I sometimes seem to understand things intuitively"). Previous work has found that the ATQ is correlated with individual difference traits measured using other well-validated instruments (e.g., Derryberry, Reed, & Pilkenton-Taylor, 2003), and the AS scale has been shown to have good internal consistency (.85) (Evans & Rothbart, 2007).

2.2.3. UPPS-P impulsivity scale (Lynam, Smith, Whiteside, & Cyders, 2006). This 59 item self-report measure assesses several domains of impulsivity. Likert-scale ratings ranging from 1 (agree strongly) to 4 (disagree strongly) were obtained on each item, and scales were composed as the sum of the items. In the present study, we used the SS scale, which has been shown to have excellent internal consistency (.90) and demonstrated discriminate validity from other factors of impulsivity (Whiteside & Lynam, 2003).

2.3. Data Analysis

We prioritized three outcome variables: (1) *pumps* as a measure of general risk taking, (2) *points* as a measure of outcome, and (3) *explosions* as a measure of untempered risk taking. We examined these by the type of balloon presented (certain-long, uncertain, certain-short), as well as by task third (i.e., first, second, and third) given that balloon conditions were presented equally across task third. Pairwise comparisons were conducted using Fisher's least significant difference (LSD) post hoc test to probe rule acquisition group differences, thereby providing a conservative test to protect against Type I error. For analyses using SS or AS, participant's sex was included as a covariate. Sex was uncorrelated with all BELT outcomes ($p > .05$).

3. Results

3.1. Overall task behavior and outcome

See Table 1 for descriptive statistics of study variables. We conducted three separate (balloon condition [certain-short, certain-long, and uncertain]) × 3 (task third) repeated measures ANOVAs for the dependent measures of pumps, points, and explosions. For pumps, as expected based on the task design, a main effect was found for balloon condition, $F(2,148) = 67.42$, $p < .001$, partial $\eta^2 = .48$, with the greatest number of pumps on the certain-long balloons, followed by uncertain balloons, and then certain-short balloons. While no main effect was found for task third, a significant balloon condition by task third interaction was found, $F(4,296) = 6.78$, $p < .001$, partial $\eta^2 = .08$. The interaction was driven by a strong decline in pumps made across the uncertain trials, compared to a more stable risk taking on the other balloon conditions.

For our measure of BELT outcome, points earned, a main effect was found for balloon condition, $F(2,148) = 210.63$, $p < .001$, partial $\eta^2 = .74$, such that the most points were earned in the certain-long condition, followed by the uncertain condition, and then the certain-short condition. A main effect was also found for task third, $F(2,148) = 24.53$, $p < .001$, partial $\eta^2 =$

.25, such that an points increased linearly across the task, indicating an improvement in performance with greater task experience. No balloon condition by task third interaction was found.

For our measure of untempered risk taking, explosions, there was main effect was found for balloon condition, $F(2,148) = 200.45$, $p < .001$, partial $\eta^2 = .73$, such that most explosions occurred in the certain-short balloons, followed by uncertain balloons, and then certain-long balloons. A main effect was also found for task third, $F(2,592) = 28.83$, $p < .001$, partial $\eta^2 = .28$, such that there was a linear reduction in explosions across the task. A significant balloon condition by task third interaction was also found, $F(4,296) = 4.21$, $p = .002$, partial $\eta^2 = .05$. Explosions sharply declined for the certain-short condition and uncertain condition, but not for the certain-long condition. Taken together, the pumps, points, and explosion data suggest that participants were able to learn the task parameters across the testing session.

3.2. Sensation seeking and risk taking

Previous work on individual differences in risk taking has emphasized the role of SS and risk taking behavior. We conducted separate 3 (condition) × 3 (third) repeated measures ANOVAs for pumps made with centered SS included in the model as a covariate. As predicted based on prior work (e.g., Lejuez et al., 2002), there was a between-subjects effect of SS on risk taking across the task, $F(1,71) = 5.73$, $p = .02$, partial $\eta^2 = .08$ (Figure 1). Findings were highly consistent using Average Adjusted Pumps as the outcome measure (Lejuez et al., 2002), though several participants were lost due to missing data (i.e., all balloons were exploded in a given condition in one third and no score could be calculated), $F(1,47) = 7.72$, $p = .01$, partial $\eta^2 = .14$. In both cases, participants with higher levels of SS made more pumps throughout the task. In addition, SS significantly interacted with balloon condition, $F(2,142) = 4.04$, $p = .02$, partial $\eta^2 =$

.05, such that there was an association between SS and pumps for the two stable balloon conditions (short and long) but not for the variable condition. SS did not significantly interact with task third and the three-way interaction of SS by balloon condition and task third was not significant. These findings indicate that SS did not predict a change in risk taking behavior across the task. In addition, confirming previous work, the same general pattern was found for explosions. Again, there was a between-subjects effect of SS on explosions across the task, $F(1,71) = 4.39$, $p = .04$, partial $\eta^2 = .06$, such that participants with higher levels of SS made more explosions. No two-way or three-way interactions with SS and balloon condition or task third emerged.

3.3. Associative sensitivity and learning

Taken together, these findings replicate previous work on the BART, such that SS predicted increased risk taking (i.e., number of pumps made and balloon explosions). However, because the BELT allowed for an assessment of learning (particularly in the certain-short condition, as feedback [i.e., explosions] was most likely to be encountered, see Table 1), we chose the certain-short balloon condition to examine the potential moderating effect of AS on the functional outcome of risk taking behavior (i.e., balloon explosions and points earned). Following the approach of previous studies (e.g., Palmgreen, Donohew, Lorch, Hoyle, & Stephenson, 2001; Rosenbloom, 2003), we dichotomized our sample into a low and high sensation seekers based on their mean score. AS was also dichotomized into high and low groups and both SS and AS were entered into a repeated-measures ANOVA (first third vs. last third) as between-group variables. A significant SS × AS interaction predicted explosions in the certain-short condition, $F(1,68) = 4.40$, $p = .04$, partial $\eta^2 = .06$. Specifically, the high SS/high AS group made fewer explosions on the last third of the task compared to both the high SS/low AS and low

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SS/high AS groups (Figure 2A). We repeated this analysis using points earned across the task, and again found a significant SS by AS interaction, $F(1,68) = 4.29$, $p = .042$, partial $\eta^2 = .06$ (Figure 2B). Posthoc probing revealed that among individuals high in SS, those who also were also high on AS had greater gains in points earned than those with low AS. Analyses were conducted using continuous variables with results in the same direction. As such, it was postulated that among a group expected to be high risk takers, the outcome of the risk taking behavior (i.e., points earned) may vary based on this secondary trait.

We next examined whether the avoidance of the explosions was responsible for the increase in points (subtracting first third from last third) during the short balloon condition. Accordingly, we tested whether the association between AS and the increase in points was mediated by a change in explosions (subtracting first third from last third) separately for the low SS and high SS groups. As can be seen in Figure 3A, in the low SS group, AS was unrelated to outcome. In contrast, for the high SS group, AS scores predicted the outcome. As shown in Figure 3B, we conducted a mediation analysis using a nonparametric resampling method to derive the 95%CI for the indirect effect of the AS through a change in explosions on the change in points earned, using the SPSS Macro provided by Preacher and Hayes (2008). For AS predicting the change in points, the true indirect effect was estimated to lie between 0.38 and 7.41 (95%CI). Because zero is not within the 95%CI, the indirect effect is significantly different from zero at p < .05. These analyses suggest that AS moderates the association of high risk taking and points through the avoidance of poor risk taking (i.e., pressing balloons to the explosion point), thus resulting in an increase in points.

4. Discussion

Consistent with previous work, SS predicted increased risk taking on a computerized risk

taking laboratory task (Lejuez et al., 2002). While there was a main effect of SS on risk taking during the task, the combination of SS plus AS was associated with better performance, as AS predicted more avoidance of balloon explosions (while maintaining sufficient pumps to obtain increased points) for those individuals with high SS on the certain-short condition. Accordingly, AS emerged as useful for detecting patterns in the environment. Thus, whereas SS predicted general risk taking during the task, individuals high in SS and AS obtained the greatest number of points by the end of the task, but those high SS individuals with low AS obtained the fewest. A mediation analysis showed that for those individuals scoring high on SS, the AS trait was associated with increased points earned by the end of the task because of decreased explosions with greater task experience. This mediation suggests that higher levels of AS increased the high SS individual's learning to avoid explosions. These findings support the notion that sensation seekers are a heterogeneous group, and that heightened risk taking is not uniform among those high in SS. In particular, AS helped to guide appropriate behavior via forming associations provided by the environment in those high in SS.

The temperament trait of AS emerged as an important individual difference trait related to adaptive behavior on the task. AS moderated the association between SS and functional risk taking behavior, given that individuals high on both traits reduced risk taking when it was not adaptive (i.e., on the certain-short balloon condition). These findings are consistent with the adaptive function of some risk taking, and may provide insight into temperament differences in the ability to behave flexibly in response to a changing and variable environment. To date, this trait has been relatively neglected, as few studies have included AS in relation to risk taking. In a review of sensory processing sensitivity (Aron, Aron, & Jagiellowicz, 2012), it was stated that constructs such as AS motivate learning because heightened sensitivity "serve[s] the general

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evolutionary purpose of noticing more aspects of Situation A to make better choices in later

Situation B" (pp. 276). The results from the current study support this hypothesis and underscore

the importance of considering AS in studies of learning and risk taking. Without examining a

subject's sensitivity to associations, one may incorrectly predict that increased risk taking is

associated with poor outcome. However, in a study of the BART in children, Humphreys and

Lee (2011) found that risk taking increased with age, as older children pumped more on the task.

Unpublished results from this study also indicated that increased risk taking was highly

correlated with increased total points earned, suggesting that the increased risk taking observed

may alternatively (or additionally) be viewed as adaptive behavior. Similarly, a recent study

found that number of alcohol use disorder symptoms negatively correlated with adjusted mean

pumps on the BART (Ashenhurst, Jentsch, & Ray, 2011). The majority of participants made a

suboptimal number of pumps (i.e., participants generally fell on the left side of the U-shaped

function between pumps and money earned), indicating that conservative BART behavior in

those with greater symptoms also resulted in less money awarded at the end of the task.

Although SS may provide the drive to seek out new experiences and explore one's

environment and opportunities, it does not guarantee success in those ventures. The positive

association between SS and financial matters has been well documented (e.g., Grinblatt &

Keloharju, 2009; Wong & Carducci, 1991). Yet, while there is a moderate effect size for traits

such as SS or risk propensity in the prediction of entrepreneurship, recent reviews clarify that

there is likely to be other personality traits that predict *successful* entrepreneurship (Rauch &

Frese, 2007). Indeed, among entrepreneurs, social adaptability was found to significantly predict

financial success (Baron & Markman, 2003). In a study of risk taking behaviors in college

students, Fischer and Smith (2004) found that SS predicted both negative and non-negative risk

taking behaviors, but that the separate construct of (lack of) deliberation predicted only the likelihood of engaging in maladaptive risk behaviors. Taken together, it appears that SS provides greater opportunities for potential successful (and failure) opportunities, but that it is important to consider secondary traits, including AS, in the role for tempering maladaptive risk taking through learning mechanisms. We encourage researchers to examine personality traits beyond SS as they pertain to risk taking and related performance.

The findings from the present study should be considered in light of important limitations. First, it is likely that, given a greater number of trials, learning might have eventually been observed among participants who did not show evidence of learning during the task. Another important limitation is that the present task includes both rewards (points) and punishment (removal of points) simultaneously, which precludes the ability to examine the potential differences motivated by these two factors. Future research should consider including approach related instrumental learning tasks that vary reward and punishment to allow for the independent examination of these motivating factors.

5. Conclusions

The present study supports the finding that temperament influences risk taking on a novel task. Importantly, we measured the heterogeneity in risk taking as it relates to specific contexts. In the current study, under conditions that allow for learning (i.e., the stable conditions), individuals learned and subsequently gained more points on trials across the task. We found evidence for individual differences in temperament that were associated with learning. SS was associated with increased risk taking on the task, but it was the combination of high SS and high AS that resulted in optimal performance (i.e., decreasing explosions and increasing points). Disentangling SS

from learning may be useful in understanding the predictors of successful versus unsuccessful

risk taking behavior.

Table 1

Mean (SD) for Pumps, Points, and Explosions by Task Third and Balloon Condition

	First Third	Second Third	Last Third
Pumps			
Certain-Short	18.53 (1.98)	18.48 (1.69)	18.20 (1.85)
Uncertain	25.13 (7.74)	22.44 (5.46)	21.93 (5.22)
Certain-Long	29.41 (12.12)	29.28 (11.63)	30.91 (13.10)
Points			
Certain-Short	6.49 (4.43)	8.03 (5.21)	10.64 (5.08)
Uncertain	14.15 (5.38)	15.39 (4.01)	16.23 (4.17)
Certain-Long	24.85 (9.08)	27.00 (8.94)	28.37 (10.28)
Explosions			
Certain-Short	1.72 (0.85)	1.49 (0.92)	1.08 (0.93)
Uncertain	1.15 (0.78)	0.89 (0.58)	0.75 (0.59)
Certain-Long	0.24 (0.54)	0.12 (0.33)	0.13 (0.34)

Figure 1. Sensation seeking predicted increased risk taking across the task for certain-long, uncertain, and certain-short balloon conditions.
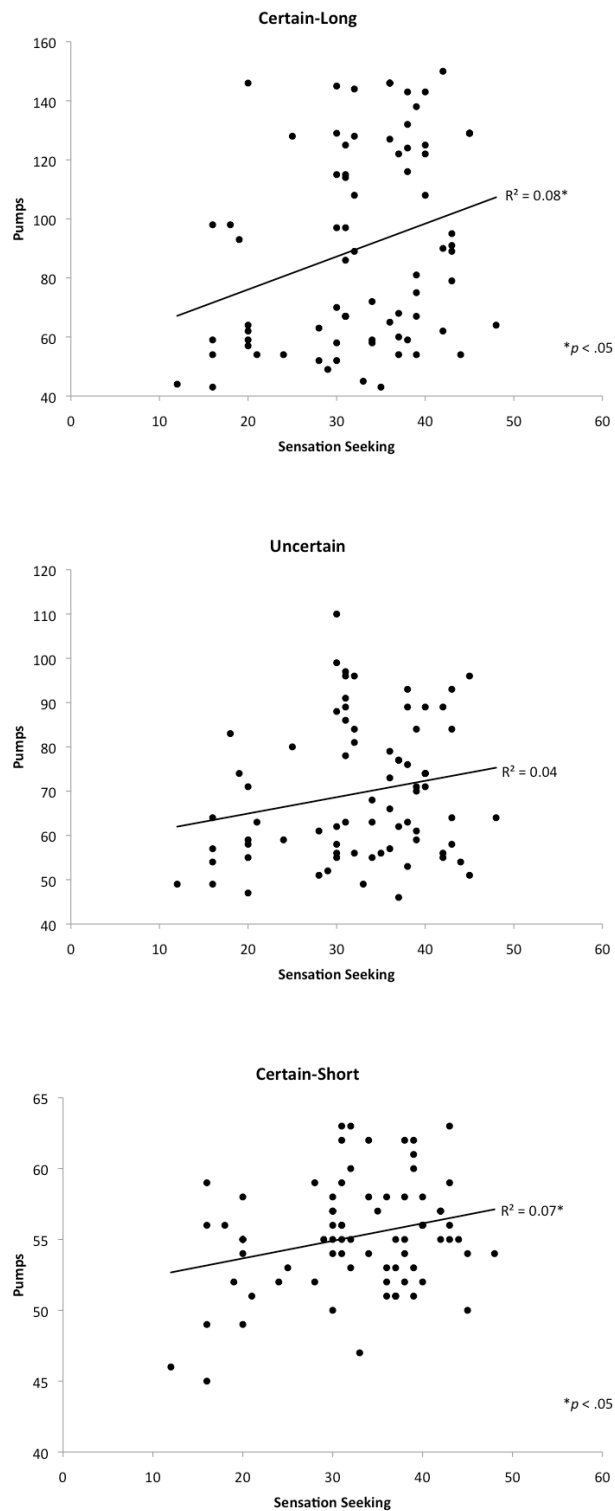
Figure 2. A significant sensation seeking (SS) by associative sensitivity (AS) interaction was found for (A) number of explosions and (B) points on the last third of the task in the certain-short condition. Individuals high on both traits made fewer explosions than those high in SS but low in AS.

(A)
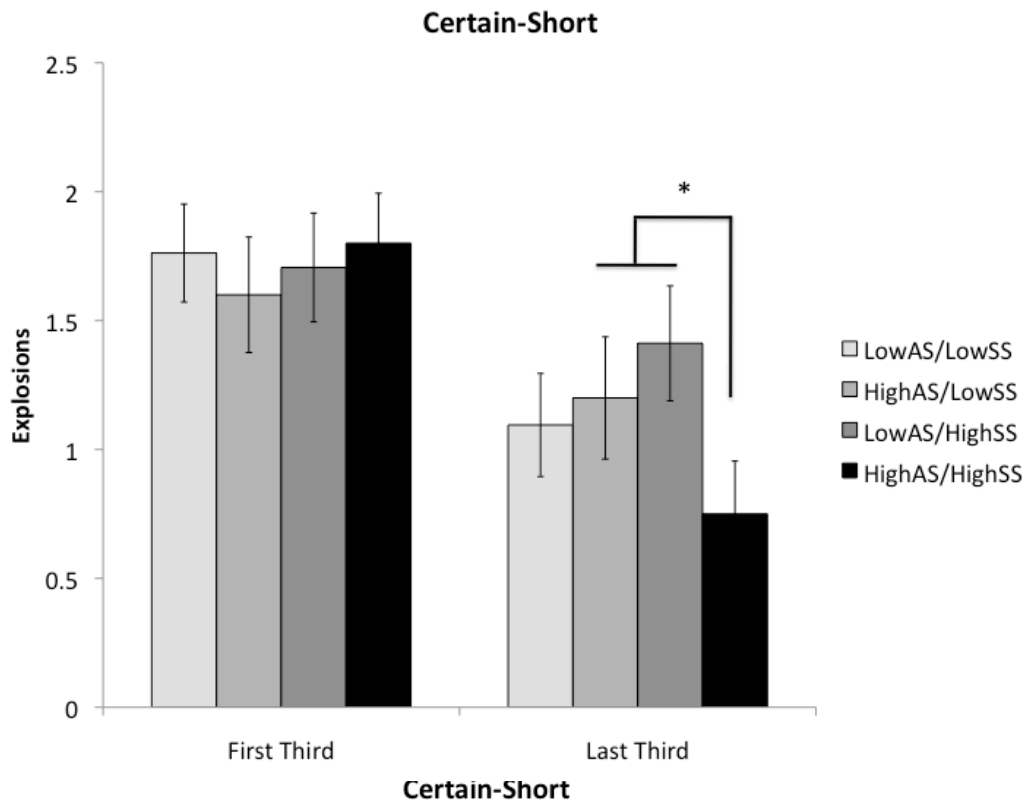
(B)
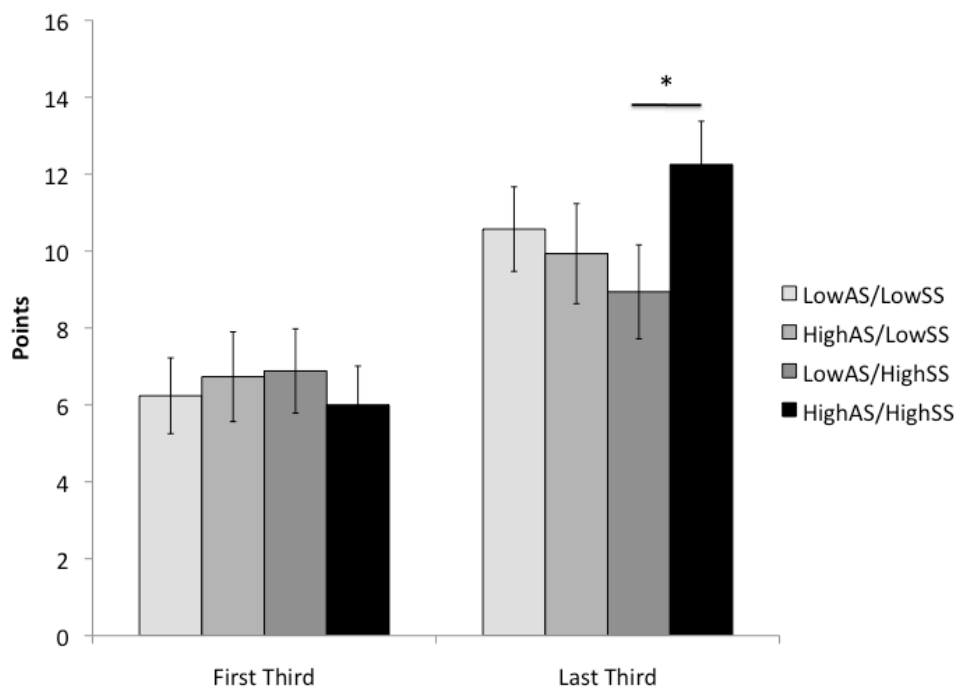
Figure 3. (A) Among low sensation seekers (SS) associative sensitivity predicted no change in points earned for the certain-short condition. (B) Mediation Model: Among high sensation seekers the association between associative sensitivity and an increase in points is mediated via a reduction in balloon explosions on the certain-short condition. $*p \leq .05$, $***p < .001$.

(A) Among Low SS
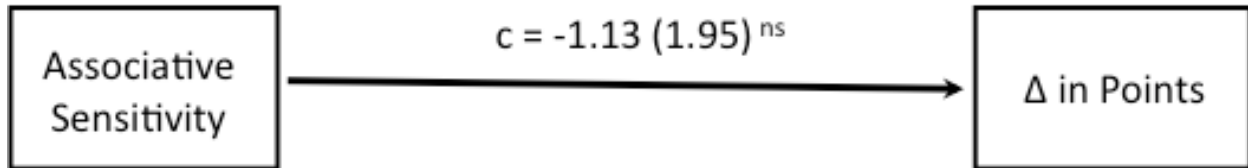
(B) Among High SS
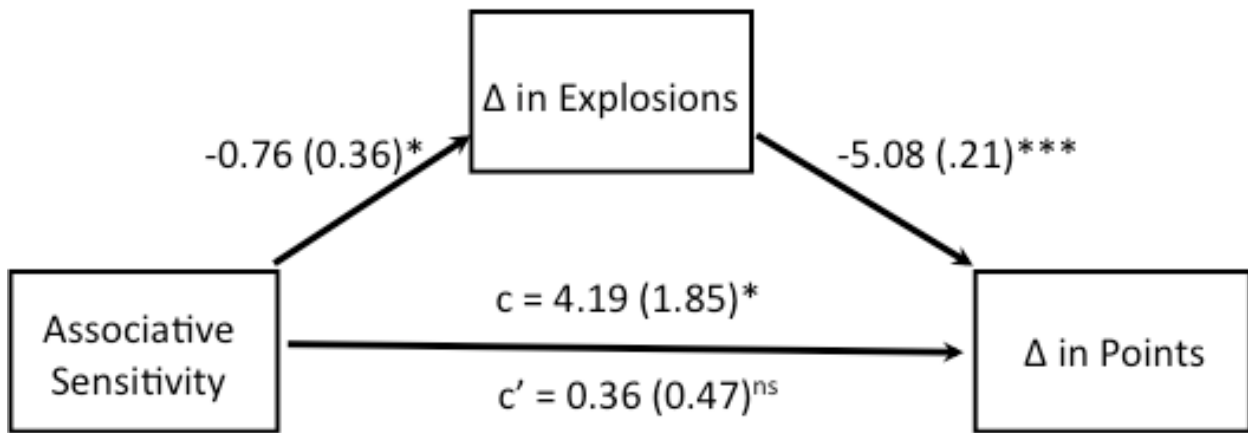
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CHAPTER THREE: RISKY DECISION-MAKING FROM CHILDHOOD THROUGH

ADULTHOOD: CONTRIBUTIONS OF LEARNING AND SENSITIVITY TO PUNISHMENT

Abstract

Decision-making under risk is a complex and dynamic behavior that changes across development. It is influenced by the ability to learn from previous trials as well as potential sensitivity to negative feedback, both of which can show unique developmental trajectories. The present developmental study examined risky decision-making in 216 individuals, ranging in age from 3-26 years old, using the Balloon Emotional Learning Task (BELT), a computerized task in which participants pump a series of balloons with three distinct, but initially unknown, limits. There were linear age-related increases in the number of pumps made (and points earned) for two conditions. The third condition, which had the lowest threshold for negative feedback, resulted in a non-linear adolescent-unique pattern of decision-making success. Follow-up analyses indicated that adolescent-specific success on this condition was associated with age-related changes in learning (which increased linearly with age) and sensitivity to negative feedback (which decreased linearly with age). Taken together, these findings suggest that two components of decision-making under risk change across the development, as young adults were better able to learn from experience and children were more reactive to negative feedback. Adolescence was marked by intermediate values on both these measures, resulting in adolescent-specific risky decision-making. These findings suggest that increased tolerance to risky decision-making in adolescence, relative to childhood, predicts learning from experience and successful outcomes.

Introduction

Decision-making is a complex behavior (Rangel, Camerer, & Montague, 2008), and perhaps not surprisingly, adaptive decision-making under conditions of risk is slow to develop, exhibiting non-linear paths (Boyer, 2006). Adaptive risk-taking appears to reach maturity in adulthood (Byrnes, 2002). Decision-making is comprised of multiple psychological processes, including learning from experience, which increases with development, and sensitivity to negative feedback, which declines over development. These processes may undergo unique developmental trajectories and therefore contribute to the patterns of decision-making observed across development (e.g., nonlinear paths towards mature performance). Characterizing the confluence of these two processes may provide some insight into developmental patterns of decision-making. The current study examined the roles of sensitivity to negative feedback and learning in the development of risky decision-making in a cross-sectional sample of children, adolescents, and young adults.

Developmental Changes in Sensitivity to Negative Feedback

The impact of negative feedback (e.g., loss or punishment) differs across development. Numerous cross-sectional studies have shown that negative feedback is more salient at younger ages (Levin, Hart, Weller, & Harshman, 2007; Slovic, 1966), where children are particularly sensitive to potential punishment (Crone, Bunge, Latenstein, & van der Molen, 2005; van Leijenhorst, Crone, & Bunge, 2006; Van Leijenhorst, Westenberg, & Crone, 2008). In addition, children are more likely to learn from negative feedback, an effect that diminishes with increasing age (van den Bos, Cohen, Kahnt, & Crone, 2012), as learning from positive feedback begins to dominate. These findings run parallel to findings that early life is normatively characterized by excessive fears (Gullone, 2000; Marks, 1987) and a negativity bias (Tottenham,

Phuong, Flannery, Gabard-Durnam, & Goff, 2013) that attenuate with age. Based on these findings, it may be anticipated that decision-making is heavily influenced by sensitivity to negative information for children, resulting in more conservative decision-making, and the effect of sensitivity to negative feedback on decision-making should attenuate with increasing age.

Development of Learning

While sensitivity to negative information declines with across development, learning from feedback increases with age. Learning of stimulus-response associations often requires repetition and trial-and-error processes. Basic associations can be learned as early as the preschool years (Guo, North, Gorden-larsen, Bulik, & Choi, 2007; Herbert, Eckerman, & Stanton, 2003), though associative learning undergoes significant maturation across from childhood into adulthood (Dumas, 2005). Successfully learning stimulus—outcome associations is essential for making correct predictions to guide future decision-making (Pleskac, 2008). Learning from feedback has been found to improve across development (Byrnes, Miller, & Reynolds, 1999). Given that successful decision-making is dependent on learning from experience, decision-making under risk should also improve across development.

Current Study

In the current study, we used an adaptation of the Balloon Analogue of Risk Task (BART) (Lejuez et al., 2002) to examine age-related changes (from a 3-26 year old cross-sectional sample), in sensitivity to negative feedback and learning as they relate to decision-making under risk. Both the BART and our adaptation, the Balloon Emotional Learning Task (BELT) (Humphreys, Lee, & Tottenham, 2013), involve a series of risky decisions because the stated goal of the task is to earn as many points as possible by deciding whether to continue pumping up a balloon while knowing that it could explode at an initially unknown point. In the

BELT, participants can learn through experience the color of the balloon is associated with a specified explosion point schedule. This task provides the ability to obtain measures of (a) decision to pump (pumps), (b) successful decision-making (points), (c) sensitivity to negative feedback (post-explosion pump reduction), and (d) learning (change in points earned). Our goal was to examine linear and non-linear effects of age on each of these domains, and to explicitly assess how sensitivity to negative feedback and learning during the task impacted the decision to pump and successful decision-making. Based on previous work (e.g., Peper, Koolschijn, & Crone, 2013), we anticipated that average pumps and points would increase with age. We anticipated that learning would linearly improve with increasing age, given age-related improvements in learning from feedback, such that young adults would appropriately inhibit pumping for the low punishment threshold condition (early-to-explode balloons). We anticipated that sensitivity to negative information would be high in younger children and linearly decrease with increasing age, such that younger age would be associated with the most dramatic post-explosion pump reduction. Given that we expect sensitivity to negative information to decrease with age *and* associative learning increase with age, we plan to examine whether these age-related changes mediate the association between age and successful decision-making under risk.

<center>Methods</center>

Participants

The youth (children and adolescents) included were part of a larger, ongoing study of children with and without a history of early-life stress via institutional rearing, from a large metropolitan area in the western United States. However, none of the children in the present study had any history of institutional care. Portions of the data on relatively healthy children without institutional care were part of a comparison group in previous research (Humphreys et

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al., 2014). We included a total of 158 healthy youths (46% male), though 18 were excluded due to invalid responses (e.g., pressing each balloon to the explosion point), resulting in a total of 140 valid participants. This sample ranged in age from 3.21-17.56 years old (M= 9.11, SD= 4.05). The adult sample and procedures have been described previously (Humphreys et al., 2013). This sample ranged in age from 18-36 years old (M= 20.36, SD= 2.48). A total of 216 participants were included in the analyses.

Procedures

Recruitment methods for the youth sample included California birth records, IRB approved local newspaper ads, and online classifieds. To be eligible for the study, all participants were required to be free of psychiatric/neurological illness and major life trauma as determined via phone screening. Exclusionary criteria included an estimated IQ of less than 80 or severe physical handicap (e.g., quadriplegic, blind, or deaf), and due to the imagining portion of the larger study, history of surgery involving metal implants, possible metal fragments in the eyes, or pacemaker, or subjects with a history of claustrophobia, braces or weighing over 250 lbs.

Families were then invited to our laboratory for in-person assessments. Following parent consent and child assent, children completed standardized test of cognitive ability, self-report measures, and computerized games of memory, emotion, and risk-taking, and response inhibition. Parents completed rating scales based on the child's behavior and parenting practices. The Institutional Review Board approved all study procedures.

Measures

Demographic information

Child age and sex were collected via parent report during the phone screen. Date of birth was confirmed at the in-person assessment. The adult sample completed this information via self-report at the time of the assessment.

Balloon Emotional Learning Task (BELT; Humphreys et al., 2013).

All participants completed a computerized risky decision-making task, in which participants pump up 27 balloons and earn points based on the number of pumps for each balloon (i.e., more pumps earned more points). Too many pumps would result in balloon explosions, which occurred at an initially unknown number of pumps, resulting in the loss of all points for that trial. Balloons appeared in three colors with different response contingencies, counterbalanced across participants. See Figure 1 for a visual display of the task. Pink balloons always exploded at 19 pumps (certain-long), orange balloons exploded variably at 7 pumps, 13 pumps, or 19 pumps distributed equally across each third of the task (variable), and blue balloons always exploded at 7 pumps (certain-short). For each third of the task, there was an equal number of each balloon color. Participants were not told that colors signified different response contingencies, but were explicitly told that not all balloons pop at the same point. Color-condition pairings were counterbalanced across participants.

Data Analysis Plan

The BELT produces several potential outcome measures of interest: (1) pumps made out of possible pumps, as a measure of the decision to pump, (2) points earned out of possible points as a measure of successful decision-making, (3) post-explosion pump reduction as a measure of sensitivity to negative feedback, and (4) change in points earned (from the first third to the second third) as a measure of learning. Linear mixed models with maximum likelihood estimation were used to accommodate the nested structure of the data (i.e., trials within

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individuals). Age was examined as both a linear and quadratic predictor (following winsorizing of one adult participant's age from 36 to 26 because it fell three standard deviations above the mean). Participant age (centered), age-squared, balloon condition (certain-long, certain-short, and variable), and trial number were examined as fixed effects predictors of outcomes. Random slope and intercept within individuals was specified. Balloon condition by age and age-squared interactions were tested. Sex was included as a covariate for all analyses, though was not a significantly predictor for any outcome.

Results

Table 1 provides a correlation matrix and descriptive statistics for age, sex, and the risk-taking outcomes by condition produced by the BELT. Age was positively correlated with pumps on all three balloon conditions, and points on the certain-long and variable condition. There was no association between age proportion points earned on the certain-short condition. There was a positive correlation between proportion pumps and proportion points for the certain-long and variable conditions, and a negative correlation between these metrics in the certain-short condition, indicating that these metrics represent separable constructs.

Proportion Pumps

Proportion pumps provided a behavior measure of risky decision-making. The mixed effects analysis for proportion pumps on the task indicated significant effects of balloon condition ($F(1,5661.71) = 889.53$, $p < .001$), trial ($F(1,348.46) = 6.02$, $p = .015$), and age ($F(1,222.07) = 42.13$, $p < .001$). On average, proportion pumps was greatest on the certain-short condition, followed by the variable condition, which both significantly differed from the certain-long condition. Pumps *decreased* over the course of the task. Age was associated with less conservative decision-making (higher proportion pumps) where sex and age-squared were

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unrelated to overall proportion pumps. However, a significant balloon condition by age-squared interaction was found ($F(1,5661.71) = 38.50$, $p < .001$). Analyses were then conducted within each balloon condition to determine the shape of age-related change within each type, controlling for balloon trial (see Figure 2). For the certain-long condition, there was a linear effect of age ($F(1,219.01) = 11.21$, $p < .001$), as well as a quadratic effect ($F(1,219.01) = 4.22$, $p = .04$). For the variable condition, there was a linear effect of age ($F(1,222.76) = 31.46$, $p < .001$), but the quadratic effect was not significant ($F(1,222.76) = 2.73$, $p = .10$). For the certain-short condition, there was both a significant linear ($F(1,217.65) = 42.35$, $p < .001$) and quadratic effect of age ($F(1,217.65) = 12.38$, $p < .001$). As can be seen in Figure 2, proportion pumps on the certain-long and variable conditions was relatively flat until adolescence, and demonstrated a steep incline from adolescence into adulthood. However, proportion pumps on the certain-short condition increased in early childhood and peaked in late adolescence. In summary, the overall number of pumps made increased with age, and for the certain-short condition, pumps peaked during adolescence.

Proportion Points

Proportion points provided an index of successful decision-making. The mixed effects analysis for proportion points on the task indicated significant effects of balloon condition ($F(1,5804.07) = 194.37$, $p < .001$), trial ($F(1,678.86) = 30.99$, $p < .001$), and age ($F(1,222.54) = 58.32$, $p < .001$). On average, successful decision-making was greatest on the certain-short condition, while the variable and certain-long condition did not significantly differ from one another. Successful decision-making *increased* over the course of the task and increased with age. There were no main effects of sex and age-squared. However, significant balloon condition by age and balloon condition by age-squared interactions were found ($F(1,5804.07) = 5.27$, $p =$

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.005 and $F(1,5804.07) = 26.24$, $p < .001$, respectively). Analyses were conducted within each balloon condition to determine the shape of age-related change within each type. For the certain-long condition, there was a linear ($F(1,224.30) = 20.97$, $p < .001$) and quadratic effect of age ($F(1,224.30) = 4.13$, $p = .04$). For the variable condition, a linear effect of age was found ($F(1,223.53) = 22.88$, $p < .001$), but the quadratic effect was not significant ($F(1,223.53) = 2.70$, $p = .10$). For the certain-short condition, there was both a significant linear ($F(1,224.93) = 7.63$, $p = .006$) and quadratic effect of age ($F(1,224.93) = 14.26$, $p < .001$). As can be seen in Figure 3, proportion points earned on the certain-long and variable conditions were relatively flat until adolescence and steeply inclined from adolescence into adulthood. Proportion points earned on the certain-short condition, however, demonstrated a clear peak in mid-adolescence. Though young adults were most successful (i.e., proportion points earned) in the certain-long and variable conditions, adolescents exhibited the most success for the certain-short condition, which had the lowest explosion point and therefore provided feedback regarding its explosion point at the earliest point. We next sought to examine the potential differences in task response that resulted in adolescents and young adults differing success based on balloon condition.

Learning

In order to assess the extent to which participants learned during the task, we examined the change points earned from the first third to the second third of the task within each balloon condition. Ordinary least squares linear regression was used to examine the impact of age and age-squared on learning, covarying points earned on the first third in that condition and sex. As shown in Figure 4, for plotting purposes and posthoc testing, age group was divided into three groups [children (age 3-11; n = 103), adolescents (12-17, n = 37), and young adults (18+, n = 76)], there was a significant effect of linear age on the certain-long condition ($\Delta R^2 = .05$, $\beta =$

.23, $p < .001$). The quadratic effect was not significant ($\Delta R^2 = .01$, $\beta = .08$, $p = .19$). Posthoc pairwise comparisons using the Least Significant Difference test for the age groups described above revealed that young adults demonstrated significantly more learning than both adolescents and children ($ps < .002$), who did not significantly differ from each other ($p = .86$). For the variable condition, there was a significant effect of linear age ($\Delta R^2 = .02$, $\beta = .16$, $p < .001$). The quadratic effect was not significant ($\Delta R^2 = .001$, $\beta = -.03$, $p = .48$). Posthoc comparisons found that young adults and adolescents did not significantly differ from each other ($p = .86$), and both groups demonstrated significantly more learning than children ($ps < .04$). For the certain-short condition, linear age was not a significant predictor of learning ($\Delta R^2 = .001$, $\beta = .04$, $p = .54$). The quadratic effect was a significant predictor of learning ($\Delta R^2 = .04$, $\beta = -.19$, $p < .001$). Pairwise comparisons using the groups demonstrated that adolescents showed significantly more learning than both young adults and children ($ps < .02$), and those groups did not significantly differ from each other ($p = .90$).

Learning as a Mediator of the Association between Age and Points

In order to explore whether age-related increases in learning explained age-related improvements in decision-making success, we conducted a mediation analysis to examine whether learning mediated the association between age and total points earned, covarying for points earned on the first third of the task and sex. Per expert recommendations (Preacher & Hayes, 2008) a bootstrap approach was used with 5000 estimates of the indirect effect. This derives a point estimate of the indirect effect with 95% confidence intervals (CI). If the confidence interval does not include zero, the indirect effect is considered statistically significant. The total effect indicated a significant association between age and total points (Coeff. = 1.35 [0.20], $t = 6.83$, $p < .001$). The individual indirect effect (mediation effect of associative

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learning) was significant, and the 95% CI did not include zero (95% CI 0.51, 1.21). The direct

effect was reduced but remained significant (Coeff. = 0.50 [0.11], $t = 4.56$. $p < .001$), indicating

that learning did not fully mediate the association between age and total points.

Post-explosion Behavior

Because decision-making is influenced by feedback (i.e., explosions) from previous trials

(Humphreys & Lee, 2011; Humphreys et al., 2014), we examined age-related change in

sensitivity to negative feedback using post-explosion pump reduction on the certain-short

condition. This balloon condition had the lowest threshold for explosions and accordingly

provided the most opportunity to examine post-explosion reactivity. Post-explosion pump

reduction was calculated for each exploded certain-short balloon by taking the difference in

proportion pumps from that trial and the trial immediately following from the same balloon

condition. The mean of this metric was used to measure sensitivity to negative feedback, where

positive values indicate fewer pumps on the subsequent balloon whereas a value of zero indicates

there was no change in pumps following the balloon explosion. Thirteen individuals did not

explode this balloon, and were therefore not included in this analysis. The mean for post-

explosion pump reduction was 0.21 ($SD = 0.14$), and a one-sample t-test demonstrated that this

significantly differed from zero ($t(202) = 21.55$, $p < .001$), such that, on average, individuals

pumped less following an exploded balloon. There was a linear effect of age on post-explosion

pump reduction ($t(200) = -4.32$, $p < .001$), but no quadratic effect ($t(199) = -0.32$, $p = .75$). For

graphing purposes, we plotted standardized (Z-score) reactivity after creating three age groups

(children, adolescents, and young adults) against standardized learning (see above; points on

second third minus points on first third) (see Figure 5). This figure indicates that while learning

increases across developmental periods, sensitivity to negative feedback decreases. Whereas

children and young adults were high on at least one of these scores, adolescents were intermediate on both.

Sensitivity to Negative Feedback as a Mediator of the association between Age and Points

Given that sensitivity to negative feedback may also play a role in explaining age-related increases in decision-making success, we conducted another mediation analysis to examine whether post-explosion pump reduction mediated the association between age and total points earned, with sex as a covariate. The total effect indicated a significant association between age and the total points (Coeff. = 2.13 [0.26], $t = 8.27$, $p < .001$). The indirect effect (mediation effect of post-explosion pump reduction) was significant, and the 95% CIs did not include zero (95% CI 0.02, 0.36). The direct effect was reduced, but remained significant (Coeff. = 1.97 [0.27], $t = 7.36$, $p < .001$), indicating that our metric of sensitivity to negative feedback partially mediated the association between age and total points.

Discussion

We examined developmental change in risky decision-making and its behavioral components in a cross-sectional sample of individuals from preschool age to early adulthood. Results indicated that age-related changes in risky decision-making (i.e., pumps) and successful decision-making (i.e., points) varied by task condition, such that conditions with higher thresholds for negative feedback (certain-long, variable) exhibited positive age-related increases in these outcomes. However, on the condition with the lowest threshold for negative feedback (certain-short), an adolescent-emergent pattern was found in pumps, where both adolescents and young adults made significantly more pumps on this condition than children. Taken together, we observed differential age-specific outcomes as a function of feedback availability, such that linear age increases were found in points earned on the certain-long and variable conditions, but

an adolescent-specific peak was found in successful decision-making on the certain-short condition.

Overall, young adults demonstrated greater learning on the task, supporting considerable research demonstrating age-related increases in effective decision-making under risk. However, adolescents demonstrated better learning than both young adults and children on the certain-short condition. Examination of the behavioral components of risky decision-making showed that this adolescent phenotype was mediated by changes in both age-related changes in associative learning and sensitivity to negative feedback. The behavior of the youngest participants was characterized by a high sensitivity to negative feedback and decreased pumps. The behavior of the oldest participants was characterized by a high degree of learning, as demonstrated by an increase in points on the task. Adult participants were able to distinguish between balloon conditions (Humphreys et al., 2013), and determining via experience that the certain-long balloons would explode later and the certain-short balloons would explode earlier. However, this group's relative insensitivity to balloon explosions appeared to result in a slower learning regarding the limits of the certain-short balloon compared to adolescents. Adolescents were intermediate in both sensitivity to negative feedback and associative learning, resulting in their high pumps and points earned in this condition.

Research on the development of risky decision-making has largely focused on age-related changes in the interactions between reward-related processing and cognitive control (Casey, Getz, & Galvan, 2008; Cohen et al., 2010; Galvan et al., 2006; Luna, Paulsen, Padmanabhan, & Geier, 2013; Somerville, Jones, & Casey, 2010; Steinberg, 2007). Casey (2013) pointed out that poor decision-making that can occur during adolescence is not "defective," but rather a consequence of biological and experiential changes specific to this developmental period. The

current study adds to this body of work by providing evidence that risky decision-making is also influenced by age-related changes in learning and sensitivity to negative feedback.

The Role of Learning during Risky Decision-Making.

Learning from experience is of clear importance to successful decision-making, and sequential tasks provide the ability to show that learning can affect subsequent behavior (Pleskac, 2008). Reinforcement learning holds that learning is dependent on prediction errors - the difference between the expected outcome and the actual outcome (Rescorla & Wagner, 1972; Sutton & Barto, 1998). Age has been found to be positively associated with the ability to use this feedback to guide behavior (Byrnes & Beilin, 1991; Byrnes & Overton, 1986). Consistent with the learning findings from the present study, Byrnes and colleagues found adults not only made better choices at the beginning of a decision-making task compared to adolescents, but also learned more via task experience (Byrnes et al., 1999). The mediation analyses in the current study supported the role of learning as a mediator of the association between age and successful decision-making. Findings within each balloon condition revealed different patterns of age-related learning. While young adults learned the most on the certain-long balloon, both young adults and adolescents demonstrated learning on the variable condition. Though all ages evidenced some learning on the certain-short balloon, adolescents clearly showed the most learning on this condition.

The Role of Sensitivity to Negative Feedback during Risky Decision-Making.

Consistent with recent work indicating a negativity bias in childhood (Tottenham et al., 2013) and developmental declines in amygdala reactivity (Gee et al., 2013), the present study found increased sensitivity to negative feedback in children, which decreased across development. An intermediate level of sensitivity to negative feedback, coupled with

intermediate learning abilities, appeared to result in greater decision-making success for adolescents compared to young adults on the certain-short condition, which has a low threshold for negative feedback. Thus, increased sensitivity to negative feedback may be advantageous only under certain conditions. Several converging studies have provided evidence that children and adolescents' sensitivity to negative feedback affects risky decision-making (Aïte et al., 2012; Cassotti, Houdé, & Moutier, 2011; Huizenga, Crone, & Jansen, 2007). Taken together, the relatively decreased sensitivity to negative feedback found in young adults, in combination with prediction-error learning, leads to the most successful decision-making under risk. While detecting errors facilitates learning, so does the ability to tolerate negative feedback.

There are several limitations to this study that should be noted. Firstly, although we treated age as a continuous variable in initial analyses, we defined adolescence broadly, and therefore may not be directly comparable to studies using alternative cut points. Secondly, though our wide age-range allows us to consider changes across development, the cross-sectional nature of the sample precludes us from studying intraindividual change. Thirdly, the participants were obtained from two sample sources, which differed not only in age but also the broader goals of the study in which data was collected. Related to this, testing procedures necessarily varied based on participant age, with younger children generally requiring greater assistance to complete the task. Though assessors were trained to minimize assessor influence on child behavior on the task (e.g., not provide emotional feedback to the children regarding their behavior), the role in which task motivation differed based on assessor help and main study goals are unclear. Lastly, although the BELT provides some distinct advantages over more simplistic tasks, complex tasks tend to have better naturalistic risk-taking correlation (Schonberg, Fox, & Poldrack, 2011), recommendations from a neuroeconomic approach has separated the study of

risky choice and sensitivity to gains and losses (van Duijvenvoorde & Crone, 2013), which are combined in the present task. As with Cohen et al. (2010), our task allows for the decomposition of stimulus, choice, and feedback, but also differs from other risk-taking/decision-making tasks in that the parameters are fixed but unknown to participants, who may or may not determine the explosion points during the 27 trials. Future research will need to address these methodological issues with longer tasks and more varied rewards and punishments.

In conclusion, we found overall age-related increases in learning on a risky decision-making task, as well as overall age-related decreases in sensitivity to negative feedback. Both factors predicted changes in successful risky decision-making. Examining developmental changes in risk-taking and the result of this behavior should take into account these two changing systems. The use of instrumental learning tasks in which participants chose the degree to which to explore the environment, provides a useful addition to traditional implicit learning and decision-making tasks.

Table 1. Correlation matrix and descriptive statistics for study variables.

	1.	2.	3.	4.	5.	6.	7.	8.
1. Age	1							
2. Sex (Male= 1)	-.12†	1						
3. Certain-Long Proportion Pumps	.30***	.04	1					
4. Variable Proportion Pumps	.39***	.02	.79***	1				
5. Certain-Short Proportion Pumps	.41***	-.02	.55***	.72***	1			
6. Certain-Long Proportion Points	.46***	.01	.89***	.76***	.50***	1		
7. Variable Proportion Points	.32***	-.11†	.38***	.52***	.62***	.50***	1	
8. Certain-Short Proportion Points	.10	-.10	-.39***	-.41***	-.27***	-.31***	-.02	1
Mean (SD) or %	13.02 (6.32)	42%	.41 (.19)	.51 (.16)	.81 (.14)	.39 (.15)	.40 (.09)	.46 (.19)

Note. †$p < .10$. ***$p < .001$.

Figure 1. Visual display of the Balloon Emotional Learning Task by Balloon Condition: (A) Certain-Long, (B) Variable, and (C) Certain-Short.
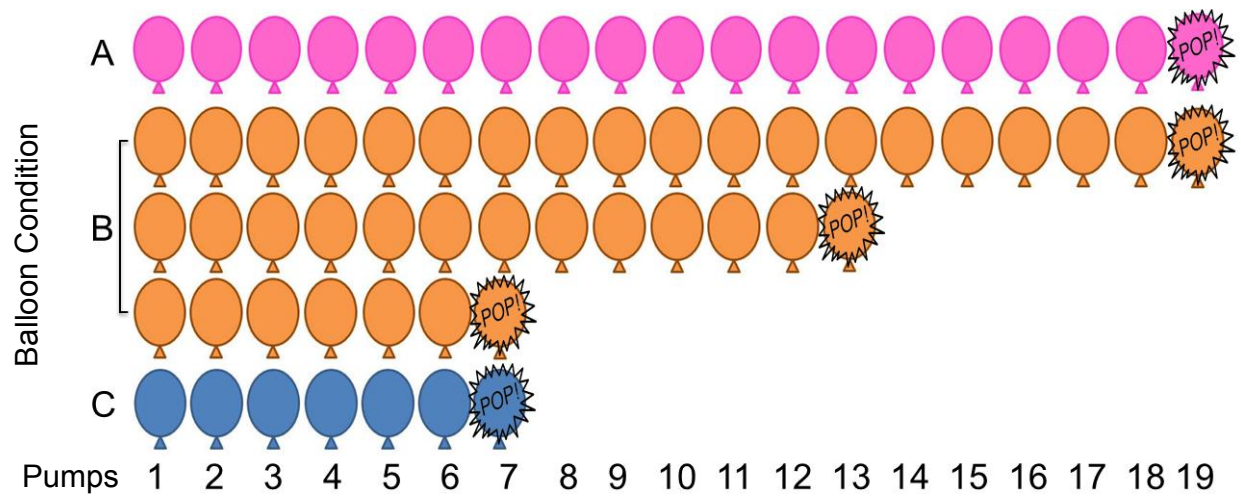
Figure 2. Proportion pumps across development age by task condition.
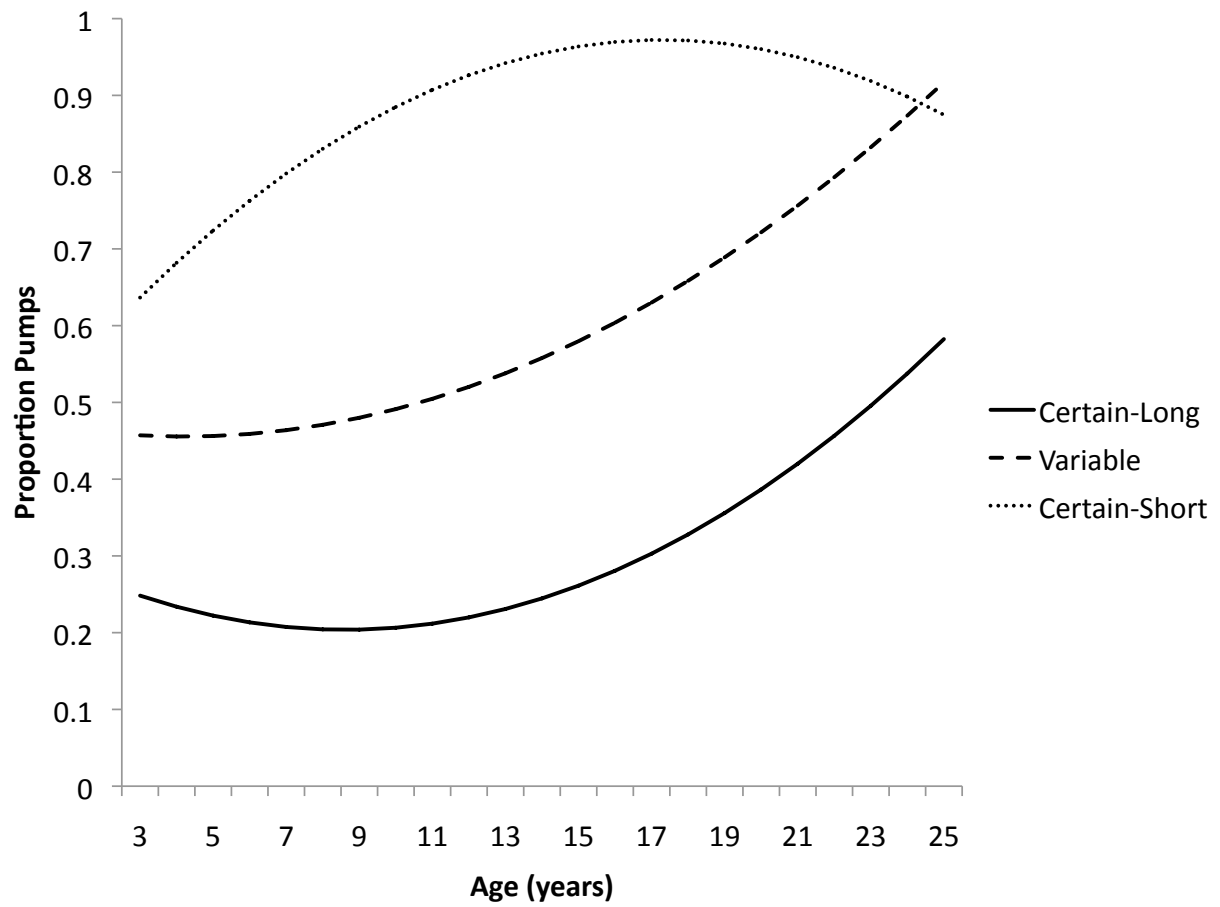
Figure 3. Proportion points across development age by task condition.
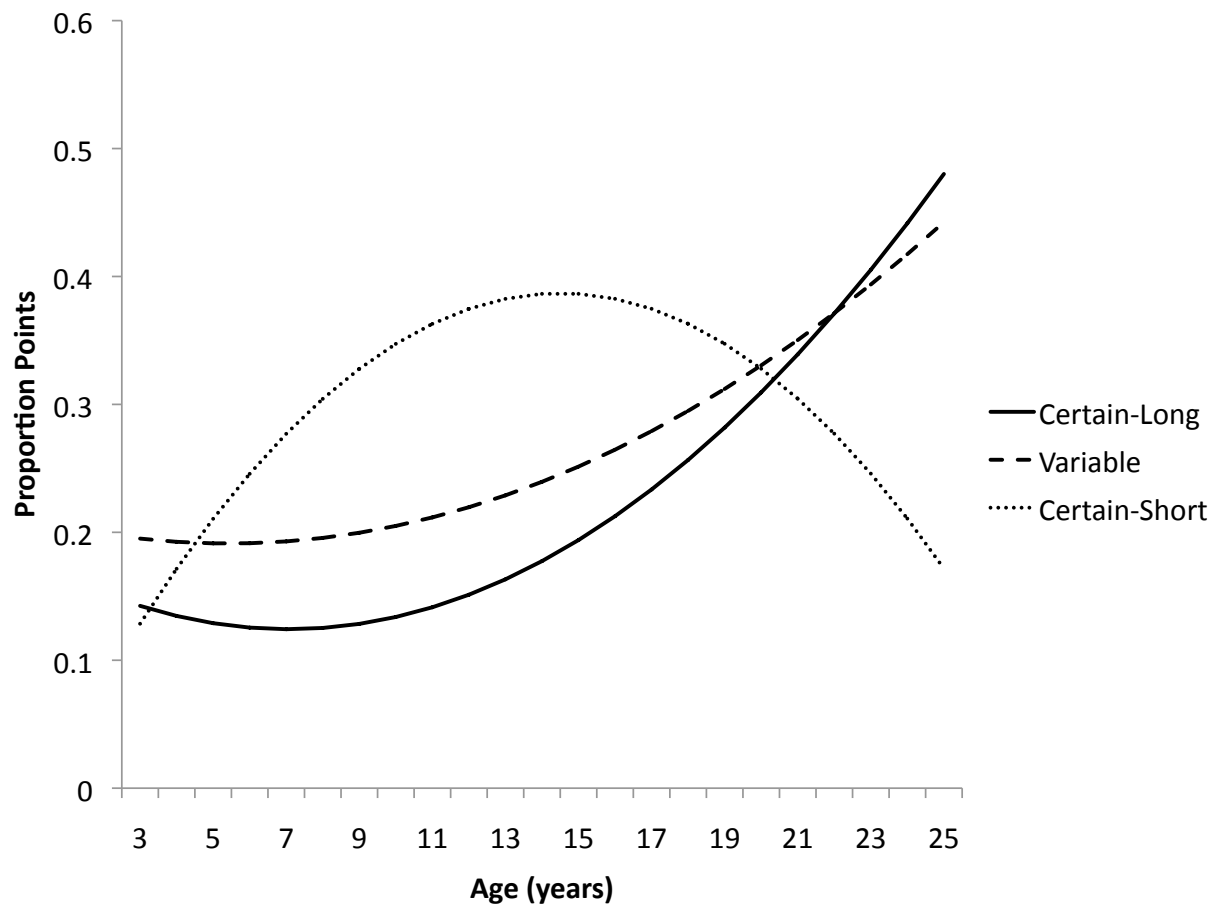
Figure 4. Learning by age group and condition.
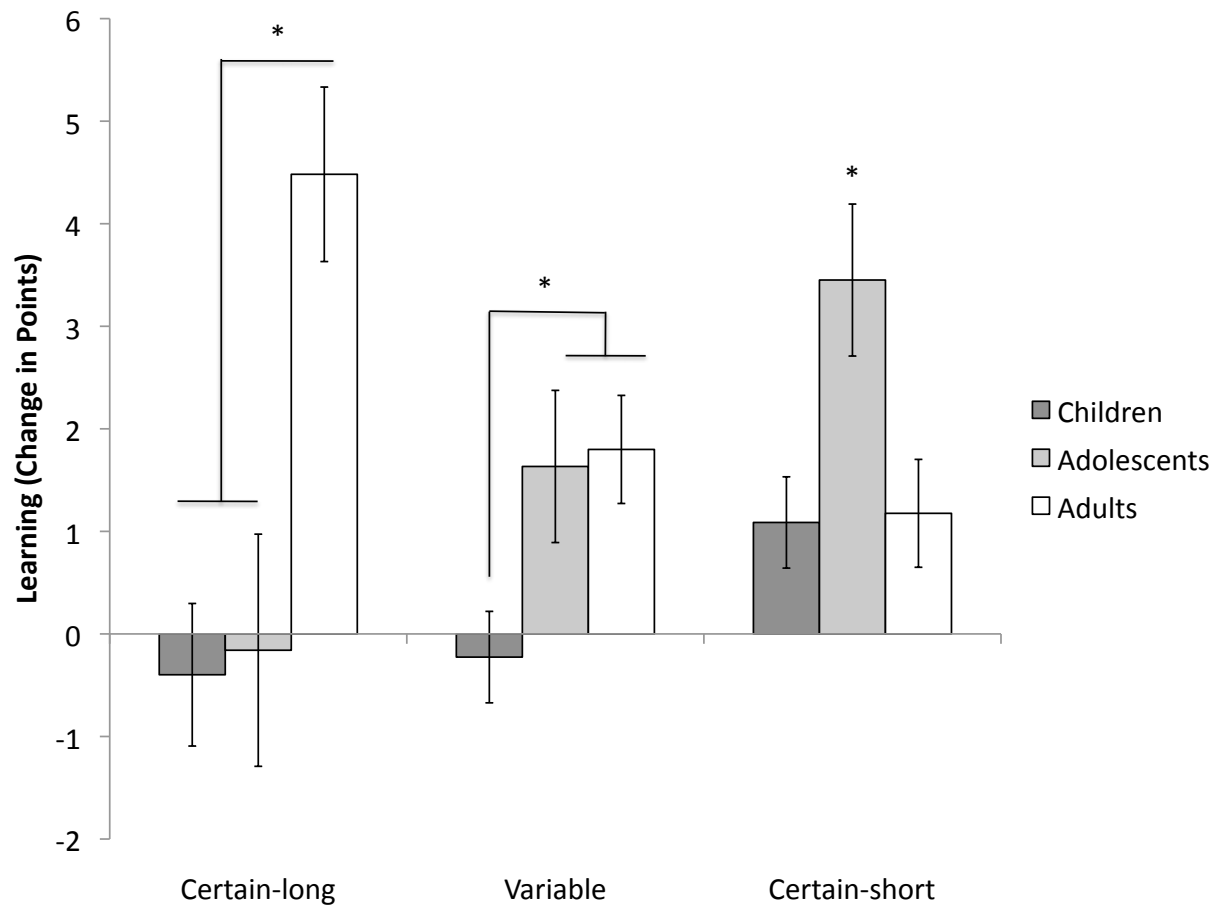
Figure 5. Post-explosion pump reduction on the certain-short balloon condition and learning by age group.
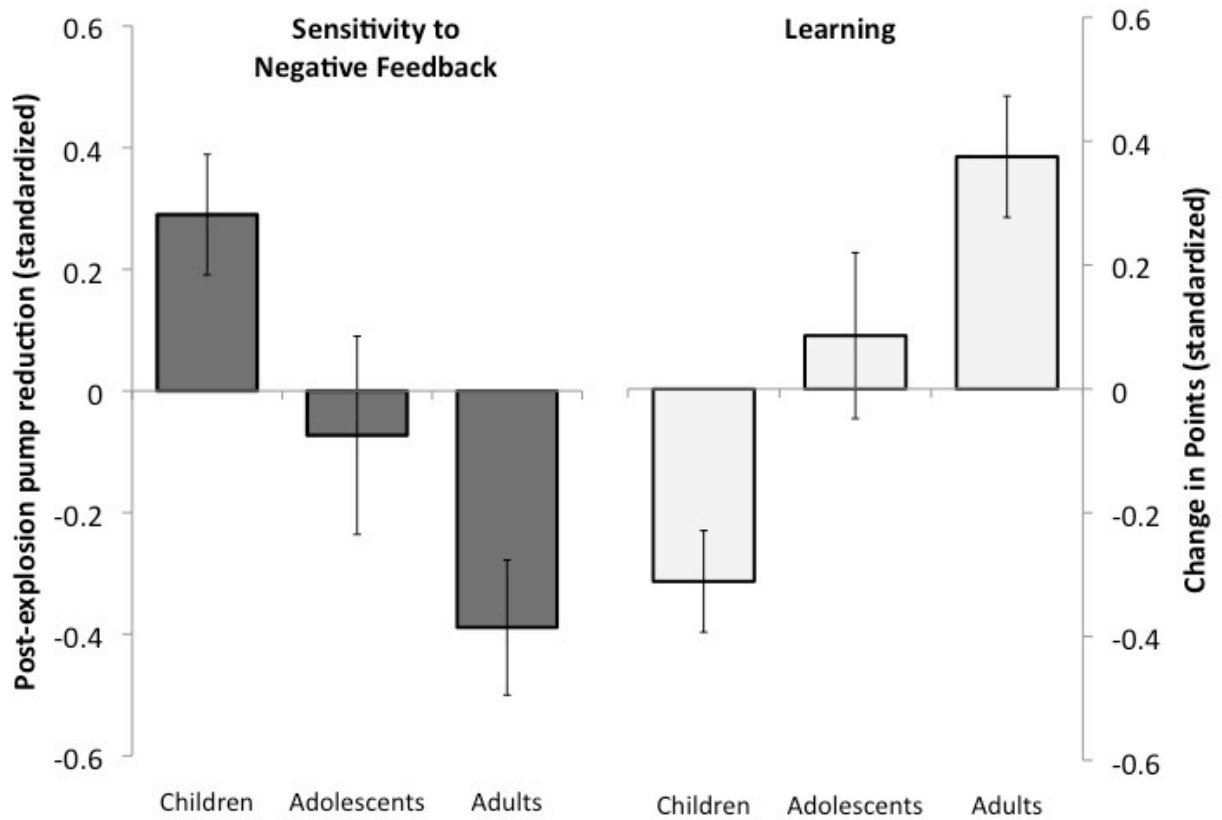
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CHAPTER FOUR: RISKY DECISION-MAKING IN CHILDREN AND ADOLESCENTS FOLLOWING MATERNAL DEPRIVATION

Abstract

Background: This study investigated the association between laboratory-based risky decision-making following maternal deprivation across age and sex in youths with and without a history of orphanage rearing (post-institutionalized; PI). Methods: One-hundred thirty-eight (PI [N= 47] and comparison [N= 91]) male and female youths ages 6-15 (M age= 10.11 years [SD= 2.76]) completed the Balloon Emotional Learning Task, to provide metrics of risky decision-making, outcomes from these decisions, task learning, and sensitivity to negative feedback. Early-care group × sex × age interactions were examined utilizing mixed modeling. Results: Overall, PI youth exhibited more conservative decisions under risk (i.e., made fewer balloon pumps), which resulted in lower levels of task success (i.e., earned fewer points). A group × sex × age interaction showed that unlike other PI youth, adolescents PI males made the riskiest decisions (more pumps), which resulted in more risk-taking failures (i.e., more explosions). These sex differences were associated with the male PI youth exhibiting a lack of learning across trials. In contrast, female PI youth exhibited heightened sensitivity to negative feedback, which mediated more conservative risk-taking. Conclusions: Maternal deprivation predicted conservative decision-making under risk overall, but the effect was moderated by both age and sex. PI youth were either too conservative or too risky depending on sex and age. Adolescent males from this group were significantly more risk-taking than all other groups, suggesting that this group may constitute a high-risk group for harmful risk-taking behavior.

Introduction

Decision-making is a complex behavior (Rangel, Camerer, & Montague, 2008), and involves

selecting potentially risky options based on accumulated experience from previous trials. Early

experiences during development can shape the emergence of these behaviors later in life

(Stoltenberg et al., 2011). Decision-making is often compromised following exposure to stress,

and work from non-human animal studies showing that risk behaviors are altered by early

adversity (both abuse and deprivation) underscore the importance of examining decision-making

in the context of risk. The current manuscript describes a study focused on maternal deprivation,

which has been shown to increase risk-taking behavior (e.g., Arnold & Siviy, 2002; Higley,

Hasert, Suomi, & Linnoila, 1991). This rise in risk-taking may be associated with the increased

risk for externalizing problems following early-life stress (Merz & McCall, 2010) and weakened

ability to learn from previous failed trials (Patterson, Craske, & Knowlton, 2013). Importantly,

there is evidence that risk-taking can be atypically low (e.g., Spivey, Barrett, Padilla, &

Gonzalez-Lima, 2008); low risk-taking could be associated with the increased sensitivity to

negative events following maternal deprivation (Goff et al., 2012; Gee et al., 2013; Zeanah et al.,

2009). Taken together, the extant literature suggests exposure to early adversity may have

divergent consequences on risky decision-making.

Heterogeneity in risk-related behaviors following maternal deprivation may be due, in

part, to developmental differences in risk assessment. Massive changes in risk-taking occur

across development (Steinberg, 2004; Galvan et al., 2006; Somerville, Jones, & Casey, 2010),

suggesting the age at which risk-taking phenotypes emerge following early adversity may matter

greatly. Therefore, risk-taking phenotypes following early adversity may present very differently

depending on the age at which they are measured, representing potential poor distal outcomes not observed earlier in development.

Additionally, risky behavior may differ for males and females. In female rats, maternal separation was unrelated to voluntary ethanol intake (Gustafsson, Ploj, & Nylander, 2005; Roman, Ploj, & Nylander, 2004), but both decreased and increased ethanol intake was observed in male rats depending on the length of separation (Ploj, Roman, & Nylander, 2003). Similarly, maternal separation was related to increased risk-taking behavior on an elevated maze task only for male rats (and not female) (Llorente-Berzal et al., 2011). Maternal deprivation resulted in increased locomotion in male monkeys, whereas females were more self-directed "depression-like" (Spinelli et al., 2012). In humans, risk-taking was increased in men and decreased in women following stress (Lighthall, Mather, & Gorlick, 2009). These data highlight the importance of examining sex-differences in risky decision-making.

The present study aimed to examine the impact of maternal deprivation in humans across age and sex using a laboratory-based measure of risky decision-making (Humphreys, Lee, & Tottenham, 2013). The sample consisted of youth with and without a history of early maternal deprivation (in the form of institutional rearing), a population that has been characterized as high in *both* externalizing problems and sensitivity to negative events (McLaughlin et al., 2010; Sonuga-Barke, Schlotz, & Kreppner, 2010; Tottenham et al., 2009; Wiik et al., 2011). High externalizing problems may result in riskier decision-making (Humphreys & Lee, 2011), whereas sensitivity to negative events could result in very conservative decision-making. We predicted that these outcomes would vary as a function of age and sex. Specifically, we anticipated that males, who tend to exhibit more externalizing problems following maternal deprivation (Zeanah et al., 2009), would show riskier decision-making, whereas females, who

might be very sensitive to negative feedback, would show more conservative decision-making. It is anticipated that these sex-differences would be explained by deprivation-associated differences in learning and sensitivity to negative feedback. Lastly, because risky decision-making shows normative changes during adolescence (Somerville et al., 2010), we anticipated that risky decision-making following maternal deprivation would vary as a function of developmental stage.

Method

Participants

One-hundred thirty-eight (57 male, 81 female) youth were included from an ongoing longitudinal study. Of these, 91 were youth who had always lived with their biologically-related parents and 47 experienced institutional care followed by adoption by families in the United States (post-institutionalized: PI). Never-institutionalized comparison participants were required to be free of serious medical illness, including head trauma, seizure disorder, and have IQs >70. We purposefully selected a wide age range in order to address the aims of the paper, and our sample ranged in age from 6-15 years old (*M*= 10.11, *SD*= 2.76). The families of both the PI and comparison youth had an average household income well above the median annual household income in the United States ($58,172; US Census Bureau, 2010). Participant demographics by PI status are provided in Appendix Table 1. The protocol was approved by the Institutional Review Board at the University of California, Los Angeles.

Tasks and measures

Balloon Emotional Learning Task (BELT; Humphreys et al., 2013). All participants completed a computerized risky decision-making task in which participants would press a button to "pump up" balloons and earn points based on the number of pumps for each of the 27 balloon trials (i.e.,

more pumps earned more points). Similar to the Balloon Analogue Risk Task (Lejuez et al., 2002), too many pumps would result in balloon explosions. These explosions occurred at an initially unknown number of pumps, resulting in the loss of all points for that trial. Balloons appeared in three colors with different response contingencies, counterbalanced across participants. The BELT demonstrated good concurrent validity in young adults, with moderate positive correlations between sensation seeking and BELT outcomes of interest (Humphreys et al., 2013).

Child Behavior Checklist 6-18 (CBCL; Achenbach & Rescorla, 2001). The 113-item rating scale completed by the parent yielded measures of child psychopathology. Responses were scored on a 3-point scale, from 0 for "not true" to 2 for "very true or often true." The CBCL was normed on a large sample of youth ages 6-18 years old, and it possesses excellent test-retest and interrater reliability. We utilized the total score from the internalizing and externalizing problem scores, which are unadjusted for participant age or sex. Both scales show very high internal consistency and test-retest reliability (Achenbach & Rescorla, 2001).

International Adoption Inventory. This questionnaire was designed to obtain information on preadoptive placement, including duration of institutionalization and the quality of the institutional care. Quality of caregiving was assessed on a likert-scale from 1 for "very poor caregiving" and 10 for "very good caregiving."

Data Analysis

We employed linear mixed modeling using SPSS (version 20), specifying full maximum likelihood estimation for these analyses. Separate linear mixed model analyses were performed for three variables: 1) *pumps* (proportion pumps out of total possible pumps), a measure of risky decision-making, 2) *explosions* as a measure of decision-making errors, and 3) *points* (proportion

earned points out of total possible points) as a measure of successful decision-making. For pumps and points, the design was comprised of nested data, with 27 observations nested within each individual. The repeated command was used to include trial number and condition, and specified a random effect for slope. For the explosions outcome, explosions were summed across each third in order to create a continuous measure for this variable, specifying third in the repeated command. For all outcomes, autoregressive covariance matrices were used. Two additional metrics were examined using Univariate ANOVA: 1) *learning*, calculated as a change in points earned during the first third and the last third, and 2) *post-explosion pump reduction* (calculated by taking the difference in pumps made on the first exploded short balloon trial and the trial immediately following from the same balloon condition) as a measure of sensitivity to negative feedback. Group (PI vs. comparison), sex, and age (centered) were included in the models as fixed effects. Two-way and three-way interactions were also examined.

<div align="center">Results</div>

Participant characteristics. Given maternal deprivation has been characterized as high in both internalizing and externalizing problems (McLaughlin et al., 2010; Sonuga−Barke, Schlotz, & Kreppner, 2010; Tottenham et al., 2009; Wiik et al., 2011), we first examined the association of group and sex by the two major domains of psychopathology: internalizing and externalizing scores. PI youth had significantly higher internalizing scores compared to comparison youth, $F(1,114) = 3.70, p = .003$; Cohen's $d = .55$ (Figure 1). For externalizing scores, there was a significant interaction of PI status and sex ($F(1,113) = 12.35, p < .001$). Simple main effects analyses showed male PIs has significantly higher externalizing scores than male comparisons ($F(1,113) = 27.04, p < .001$; Cohen's $d = 1.16$), and no differences were found between female PIs and female comparisons ($F(1,113) = 0.88, p = .35$; Cohen's $d = .25$). Among PI youth,

months institutionalized ranged from 0.13 to 72 (M = 16.89, SD = 14.84) and quality of care

ranged from 1-10 (M = 6.83, SD = 2.75).

  BELT performance. We examined our predictors of interest on outcomes from the BELT

(See Figure 2A for visual display of the task). There was a positive correlation between pumps

with points ($r(138)$ = .32, p < .001) and explosions ($r(138)$ = .88, p < .001). In addition, there

was a marginal negative association between points and explosions ($r(138)$ = -.15, p = .08).

Pumps

For pumps, there were main effects of group, sex, and age. On average, PI youth made fewer

pumps than comparison youth (.48 [.01] vs. .54 [.01], $F(1,1357.53)$ = 35.89, p < .001), females

made fewer pumps than males (.49 [.01] vs. .53 [.01], $F(1,1307.53)$ = 19.57, p < .001), and there

were age-related increases in pumps ($F(1,1307.53)$ = 95.81, p < .001). However, these main

effects were qualified by significant two-way and three-way interactions. A significant group ×

age interaction was found ($F(1,1307.53)$ = 50.46, p < .001), such that PI youth had steeper age-

related gains in pumps than comparison youth. Additionally, a significant three-way interaction

was found ($F(1,1307.53)$ = 13.43, p < .001) (see Figure 2B). With the exception of the males in

the comparison group, all groups had significant age-related increases in pumps. Males in the PI

group had the steepest slope (Est. = 0.04), followed by females in the PI group (Est. = 0.02),

female comparisons (Est. = 0.01), and lastly male comparisons (Est.= 0.001). At younger ages,

PI participants pumped less than the comparison group, whereas at older ages, males in the PI

group made more pumps than any other group. Posthoc analyses, conducted by centering age and

examining analyses within pairs of groups, revealed that male PIs were significantly less

cautious in their decision to pump (p < .05) than female PIs by age 9, female comparisons by age

11, and male comparisons by age 13.

Explosions

Though pumps and explosions were highly correlated, high pumps does not necessitate explosions. For number of explosions there were main effects of group, sex, and age. On average, PI youth had fewer explosions than comparison youth (1.43 [0.13] vs. 1.78 [0.09], $F(1,414) = 4.85$, $p = .028$), males had more explosions than females (1.94 [0.13] vs. 1.27 [0.09], $F(1,414) = 18.34$, $p < .001$), and there were age-related increases in explosions ($F(1,414) = 13.28$, $p < .001$). A significant two-way group × age interaction was found ($F(1,414) = 8.64$, $p = .003$), such that PI youth had steeper age-related increases in explosions than comparison youth. A significant three-way interaction was also found ($F(1,414) = 7.13$, $p = .008$) (see Figure 2C). While all groups had a positive age-related increase in explosions, except for males in the comparison group, male PIs had a significant steeper slope (Est. = .32) than all other groups, and both female PIs (Est. = .09) and female comparisons (Est. = .07) had a steeper slope than the male comparisons (Est. = -.03). Posthoc analyses revealed that male PIs had significantly more decision-making errors compared to female PIs by age 9, female comparisons by age 11, and male comparisons by age 14 ($p < .05$).

Points

For points, there were main effects of group, sex, and age. On average, PI youth earned fewer points than comparison youth (.38 [.01] vs. .41 [.01], $F(1,1364.58) = 8.01$, $p = .005$), males earned fewer points than females (.38 [.01] vs. .41 [.01], $F(1,1364.58) = 6.13$, $p = .013$), and there were age-related increases in points ($F(1,1364.58) = 19.49$, $p < .001$). However, the main effects of group and age were qualified by significant two-way interaction ($F(1,1364.58) = 6.17$, $p = .013$). As can be seen in Figure 2D, though both PI and comparison youth had significant age-related increases in decision-making success, the slope for PI youth was significantly steeper

than that of the comparison youths. The three-way interaction was not statistically significant (p = .42).

Learning

We examined the degree to which individuals improved over the course of the task as a metric of learning. A univariate ANOVA was conducted to test potential main effects, two-way, and three-way interactions of group, sex, and age on learning. There were no significant main effects of any independent variable on task learning when included in the same model ($ps > .27$). However, a significant group × sex interaction was found ($F(1,133) = 5.27$, $p = .023$) (Figure 3A). Comparison youth and female PIs had positive learning scores that significantly differed from zero ($ps < .05$), indicating that learning on the task occurred. Male PIs did not demonstrate learning on the task ($p = .57$). Group comparisons revealed that male PIs demonstrated significantly less learning than both male comparisons ($p = .028$) and female PIs ($p = .024$). The three-way interaction of group × sex × age was not significant ($F(1,130) = 0.25$, $p = .62$).

Sensitivity to Negative Feedback

Because decision-making under risk can be influenced by feedback from previous trials (Humphreys & Lee, 2011), we examined sensitivity to negative feedback (i.e., explosions) by calculating post-explosion pump reduction. Negative values indicated fewer pumps on the subsequent balloon, whereas a score of zero indicated no change in pumps following the balloon explosion. Seventeen youth were excluded (11 PI, 6 comparison), due to having exploded no balloons. The mean post-explosion pump reduction score was -1.89 ($SD = 1.56$), which differed significantly from zero ($t(120) = 13.36$, $p < .001$).

Univariate ANOVA assessed group, sex, and their interaction differences in sensitivity to negative feedback, while controlling for participant age. There was a significant group × sex

interaction ($F(1,116) = 5.17$, $p = .025$). Posthoc pairwise comparisons using Least Significance Difference for the four groups (male and female comparison youths, male and female PI youths) revealed that female PIs were significantly more reactive than all other groups ($p < .05$) (see Figure 3B). These results were repeated with the inclusion of number of explosions as a covariate and the group × sex interaction remained significant ($F(1,115) = 4.80$, $p = .03$).

Sensitivity to Negative Feedback as a Mediator of Group Differences

Given that females from the PI group were more sensitive to negative feedback, as well as made fewer pumps and explosions, we conducted two sets of mediation analyses to examine whether post-explosion pump reduction mediated the association between this group and decision to pump and decision-making errors. Per expert recommendations (Preacher & Hayes, 2008), a bootstrap approach was used with 5000 estimates of the indirect effect. This derives a point estimate of the indirect effect with 95% confidence intervals (CI). If the confidence interval does not include zero, the indirect effect is considered statistically significant. Female PIs were treated as one group whereas all other individuals were grouped together; age was included as a covariate. See Table 1 for the summary of the mediation analyses. For both analyses, the total effect indicated a significant association between female PIs and the two measures of decision-making under risk. The individual indirect effects (mediation effect of post-explosion pump reduction) were significant, and the 95% CIs did not include zero. The direct effects were no longer significant, indicating that our metric of sensitivity to negative feedback fully mediated the relationship between group and pumps and explosions. In order to perform a more stringent test, and use the serial nature of the data collected on this task, we reconducted the mediational analyses using only individuals who exploded a balloon in the first third of the task, and restricted the pumps measurement to the last two-thirds of the task. Again, mediation analyses

demonstrated a significant indirect effect of group status to pumps (95% CI 0.001, 0.02) and explosions (95% CI 0.01, 0.34) via sensitivity to negative feedback.

Internalizing and externalizing scores

We then examined whether internalizing and externalizing psychopathology predicted pumps, explosions, or points. In the stepwise regression, group, sex, and age were included in Step 1, followed by centered psychopathology total scores in Step 2. Internalizing total scores did not predict additional variance in either pumps ($\Delta R^2 = .01$, $p = .34$) or explosions ($\Delta R^2 = .01$, $p = .24$) above the effects in Step 1. Externalizing total scores also did not predict pumps over and above the effect of the variables in Step 1 ($\Delta R^2 = .02$, $p = .12$). However, externalizing scores significantly incremented predictions of explosions, a measure of decision-making errors ($t(113) = 2.06$, $\beta = .20$, $\Delta R^2 = .03$, $p = .042$). In order to examine the potential role of externalizing psychopathology in decision-making under risk, two sets of analyses were conducted. First, sex was examined as a potential moderator of the association between externalizing and pumps/explosions on the BELT. A significant sex by externalizing interaction was found for both pumps ($F(1,1196.45) = 17.81$, $p < .001$) and explosions ($F(1,352) = 8.32$, $p = .004$), after controlling for group and age. While externalizing was unrelated to these outcomes in females (pumps: Est. = -0.0002 [0.0008], $p = .81$; explosions: Est. = -0.004 [0.01], $p = .77$), the slope was significantly positively associated with pumps and decision-making errors in males (pumps: Est. = 0.004 [0.001], $p < .001$; explosions: Est. = 0.05 [0.02], $p < .001$) (Figure 4AB). Secondly, we examined whether, within the PI group, less cautious decision-making in males compared to females was mediated by externalizing scores, controlling for age. The indirect effect of sex via externalizing on pumps was 0.04 (0.04), and the 95% CIs included zero (95% CI -0.01, 0.16), and on explosions was 1.23 (1.41), and the 95% CIs included zero (95% CI -0.43, 5.15). Thus,

the effect of less cautious decision-making under risk in males from the PI group could not be completely explained by heightened externalizing score. However, the limited sample size of this analysis may have reduced our ability to detect a significant result.

Individual differences in Institutional Care

Given that length of institutionalization and quality of institutional care have previously predicted diverse outcomes in PI youth (Castle et al., 1999; Tottenham et al., 2009), we examined BELT outcomes by the number of months institutionalized and quality of care in the institution. For duration of institutional care, we observed a piecewise effect where the number of months in institutional care demonstrated a decrease in pumps with longer care for those who spent more than 24 months in care ($t(407.95) = -5.97$, $p < .001$), however, the slope was significantly less steep in youth who spent less than 24 months in care (interaction term: $t(407.95) = 2.15$, $p = .032$), indicating that although there was a general dose-response association between time in institutional care and pump decisions, the function of time spent institutionalized was different depending on early or late adoption. Explosions were relatively flat for the individuals who spent less than 24 months in institutional care and steeply declined with longer institutionalization. The linear effect of months in institutional care was -.01 for those who spent more than 24 months in care, compared to .0001 for those who spend less than 24 months in institutional care (interaction term: $t(416.90) = 3.29$, $p < .001$). Months spent in institutional care was not associated with points earned on the task. Quality of institutional care as reported by adoptive parents was unrelated ($ps > .35$) to all BELT outcomes.

Discussion

We examined decision-making under risk in a wide age-range of youth with and without a history of maternal deprivation. Results indicated that youth with a history of maternal

deprivation were, on average, more conservative in their decision-making than their comparison counterparts. We found linear age-related increases in pumps overall, but male PI youth demonstrated the steepest age-related increases in both pumps and decision-making errors (i.e., explosions). Adolescent males with a history of institutional care were significantly less cautious in their decision-making than all other groups, suggesting that this group may constitute a high-risk group for harmful risk-taking behavior. This is supported by evidence that male PIs did not show evidence of learning during the task, indicating that normative processes of learning from feedback to inform decision-making under risk were not found in this group. Female PIs were consistently more conservative than comparison youth, which appeared to be driven by an increased sensitivity to negative feedback. Following balloon explosion, members from this group were more sensitive to feedback, as indexed by decreased pumps following an explosion, which mediated the association between this group and more cautious decision-making behavior. Taken together, these findings suggest that decision-making under risk is altered by maternal deprivation, with observed effects dependent on age and sex.

Risky decision-making can result in both positive and negative outcomes. In the BELT, more pumps can result in more points, with earning the most points being the stated goal of the game. The comparison youth's pattern of decision-making appeared to be functionally adaptive, as this group also earned more points than the PI youth in early and mid childhood. Behavioral sets to either approach or avoid (risk-taking versus risk aversion) are contextually dependent, and are built in part on prior experience (e.g., conditional adaptation theory) (Boyce & Ellis, 2005). Thus, the present findings that PI individuals, on average, demonstrated a risk averse behavioral set is consistent with the increased rates of fear and anxiety in this population (Tieman, van der Ende, & Verhulst, 2005), and may be the product of a developmental adaptation suited for a

highly stressful environment. The heightened relative sensitivity to the first explosion encountered on the task found in female PIs is in line with risk aversion that may be an adaptation to harsh environments.

Sex differences in decision-making behavior were also found. Males were less cautious in the decision to pump than females, in concert with prior research indicating sex differences in risk-taking (Byrnes et al., 1999). This sex effect appeared to be magnified in adolescence following maternal deprivation. Several prior studies have documented sex differences in response to stress (e.g., Barna et al., 2003; De Bellis & Keshavan, 2003). The association between sex and decision-making was moderated by externalizing psychopathology, suggesting that increased externalizing is related to less cautious decision-making, but only in males. The observed sex difference for increased risky behavior in males is consistent with evolutionary theories of social dominance (Diamond, 2006), socially instilled values for risk-taking (e.g., Kelling, Zirkes, & Myerowitz, 1976), or differential beliefs in likelihood of success during the activity (see Byrnes, 1998), which merit further investigation within the high-risk PI population. Importantly, the non-human animal models of deprivation that documented increased risk-taking and related behaviors in males, but no change or even reduced risk-taking behaviors in females (e.g., Spinelli et al., 2012), mirrors our adolescent findings, and suggests the sex-specific response to maternal deprivation may be trans-species. Additionally, the divergent responses to maternal deprivation is in line with hypothesized "opposite sequelae" related to reduced responsiveness to reward, 1) increased anhedonic behaviors, and 2) compensatory reward-seeking behavior (Pechtel & Pizzagalli, 2011). Female PI responses may mirror the anhedonic response, whereas adolescent male PI responses may be compensatory reward seeking.

Less cautious decision-making among males in the PI group may be due to the increased

rates of externalizing scores relative to all other groups. Though externalizing did not reach

statistical significance as a mediator of the association between sex and decision-making under

risk among PI youths, preliminary evidence from this study suggests it may be a promising

avenue in future studies for children who experienced maternal deprivation. Indeed, we observed

an association between externalizing problems and decision-making errors (explosions). For the

male PIs, less cautious decision-making behavior did not emerge until adolescence. This may

represent a "sleeper effect," such that the impact of maternal deprivation appears at a

developmentally later age, perhaps due to the maturing of specific brain circuitry (Andersen &

Teicher, 2009; Galvan et al., 2006). Yet, this timing also coincides with age-typical increases in

risk-taking behavior (Steinberg, 2004). Adolescence is accompanied by significant changes in

neurotransmitter systems, especially increases in dopamine among males (Sisk & Foster, 2004;

Sisk & Zehr, 2005; Teicher, Andersen, & Hostetter, 1995), which is postulated to result in

increased risk-taking behavior (Steinberg, 2008). Moreover, a growing number of studies have

documented the negative impact of institutional rearing on brain regions associated with

decision-making under risk, including both limbic and cortical regions (Gee et al., 2013; Goff et

al., 2013; Matthews & Robbins, 2003; Mehta et al., 2009; Sheridan, Drury, McLaughlin, &

Almas, 2010; Tottenham et al., 2011). These structures are associated with reward learning and

motivation, which are relevant to constructs assessed in the present study. Future work should

continue to examine the role of developmental changes in the brain as it pertains to decision-

making and related behavior in youths who experienced maternal deprivation.

Given that numerous studies have documented a dose-response relationship between

length of institutionalization and important developmental and health outcomes (e.g., Drury et

al., 2011; Rutter et al., 2007; Tottenham et al., 2009), we included time spent in the institution as a predictor of decision-making and its functional outcome. Consistent with prior work, there was little effect of time spent in the institution for youth adopted prior to 24 months. Previously, 24 months has been used as an important cutoff for plasticity following deprivation (Nelson et al., 2007; Rutter, 1998). Interestingly, our findings suggest that after this period, months spent in institutional care beyond 24 months was associated with more conservative decision-making. The finding may appear counterintuitive, as most studies mark less cautious decision-making as maladaptive. However, in the present study the steep reduction in risk-taking behavior found in PI youths with longer institutionalization reflects a pattern of further deviation from normative behavior, where these youth may be overly conservative, and suggests either reduced reward-driven behavior or avoidance of negative feedback via balloon explosions.

We must acknowledge limitations in the present study. Our task, the BELT, a tool to assess risky decision-making, may not map onto real-world decision-making and risk-taking behavior, though similar laboratory based assessments have been positively correlated with real-world risk behaviors (Lejuez, Aklin, Zvolensky, & Pedulla, 2003). Secondly, we were limited by the available sample size among the PI youth. The present study consists of cross-sectional age-related analyses, and would be strengthened via examination of the same children longitudinally. Independent replication of these findings is warranted, and we believe these findings provide an initial study in the area of risk taking as a function of maternal deprivation, sex, and age. Additionally, due to the nature of international adoption, we do not have access to individual prenatal/developmental histories for previously institutionalized youth, and thus are unable to separate the effect of potential prenatal differences from the effects of institutional rearing. Our

measure of quality of institutional care did not provide predictive utility for any of the outcomes of interest, though individual caregiver knowledge of institutional care likely varied.

The results from the present study provide empirical evidence that maternal deprivation in humans is followed by aberrant decision-making under risk, which may be useful for making predictions about the developmental progression of mental health processes associated with risk-taking as a function of sex. There are potential adverse implications for risk-aversive behaviors demonstrated by PI, especially female PI, youth, as judicious risk-taking is a fundamental aspect of learning and optimal functioning (Humphreys et al., 2013). Conversely, males with a history of maternal deprivation may be less sensitive to feedback, less likely to learn from experience, and therefore more prone to maladaptive (less cautious) risk-taking behavior.

Figure 1. Internalizing and externalizing scores by group and sex.
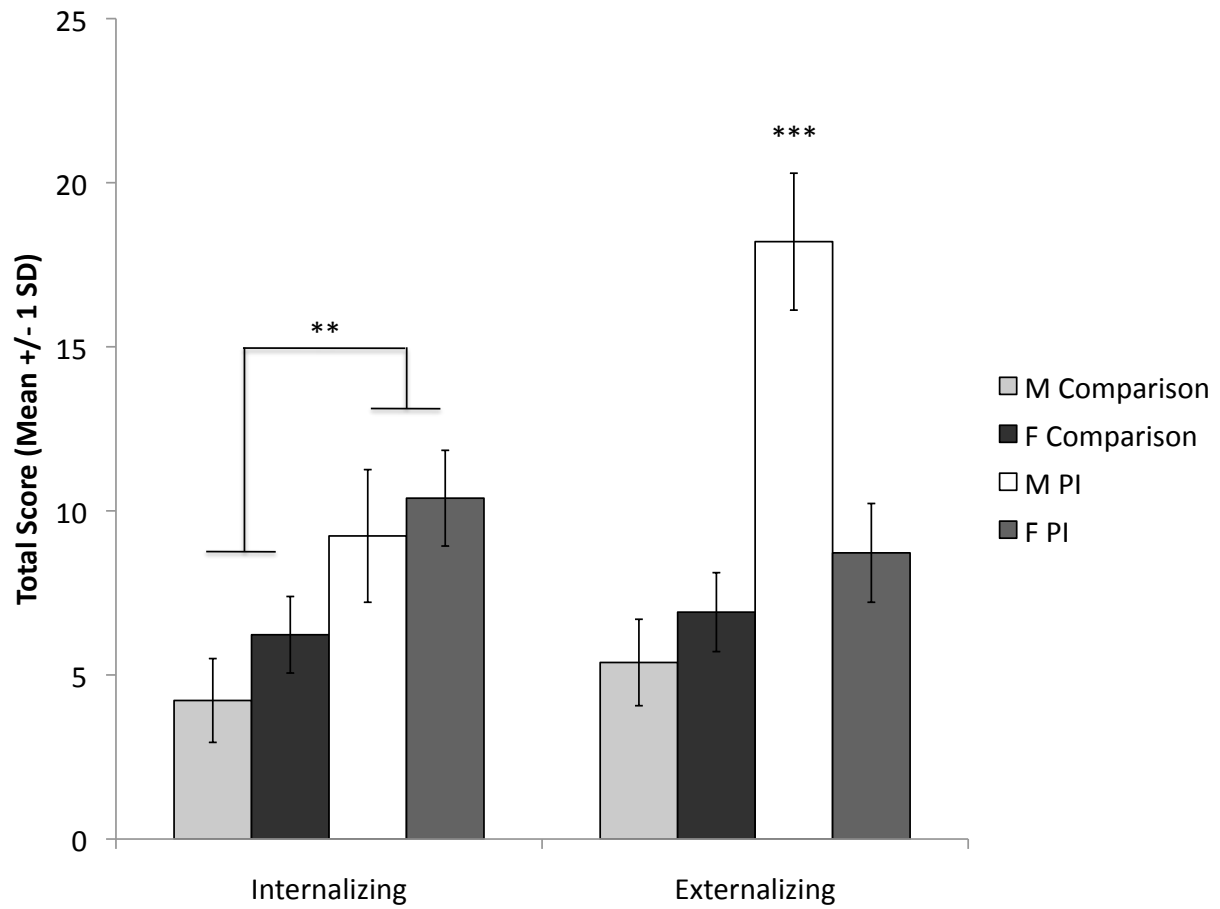
Note. Analyses included age as a covariate. ** $p < .01$. *** $p < .001$.

Figure 2. Balloon Emotional Learning Task (A), pumps (B), explosions (C), and points (D) by group, sex, and age. Note. M = male. F = female. PI = post-institutionalized. * *p* < .05, such that Male PI youth made significantly more explosions than all other groups by age 13 for pumps and age 14 for explosions.
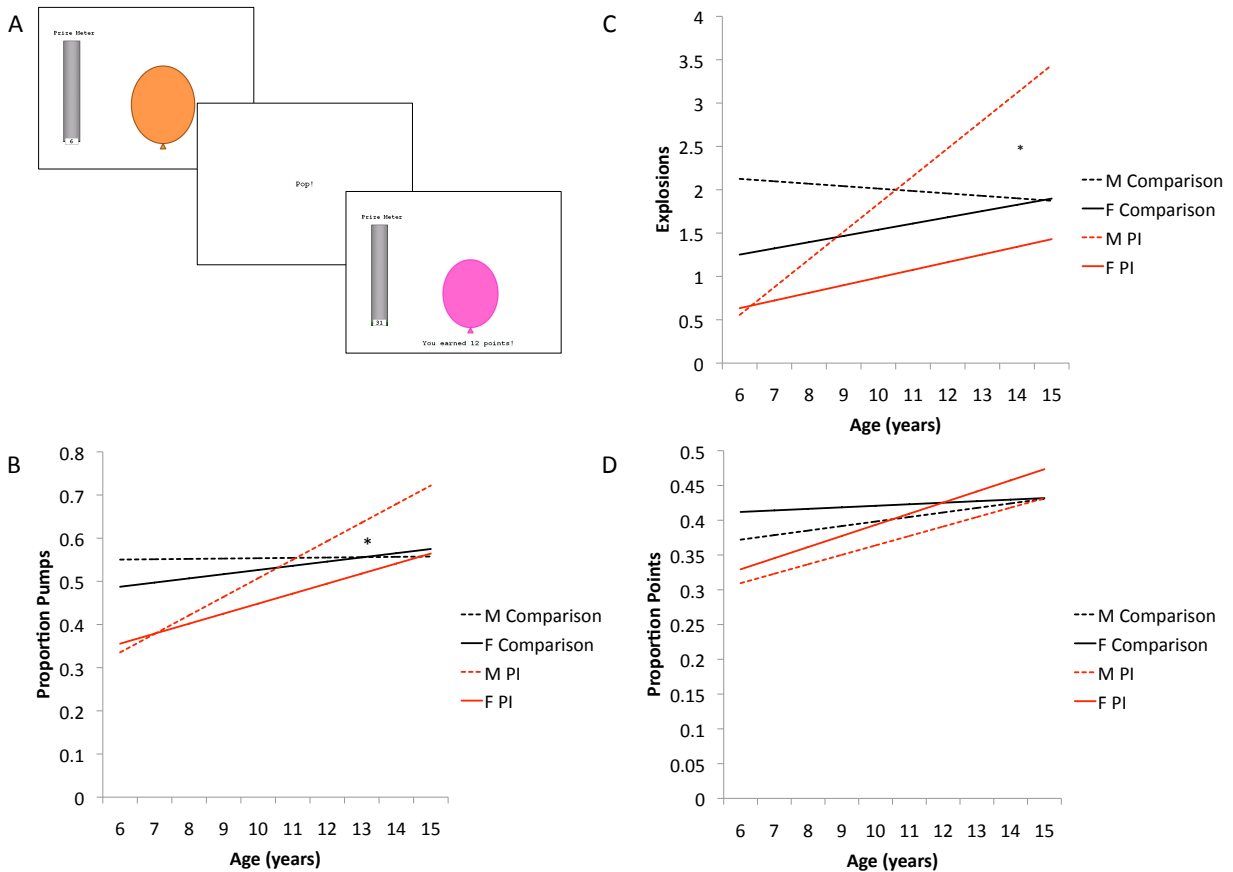
Figure 3. Task Learning (A) and Post-explosions pump reduction (B) by group and sex. Note. *

p < .05. M = male. F = female. PI = post-institutionalized.
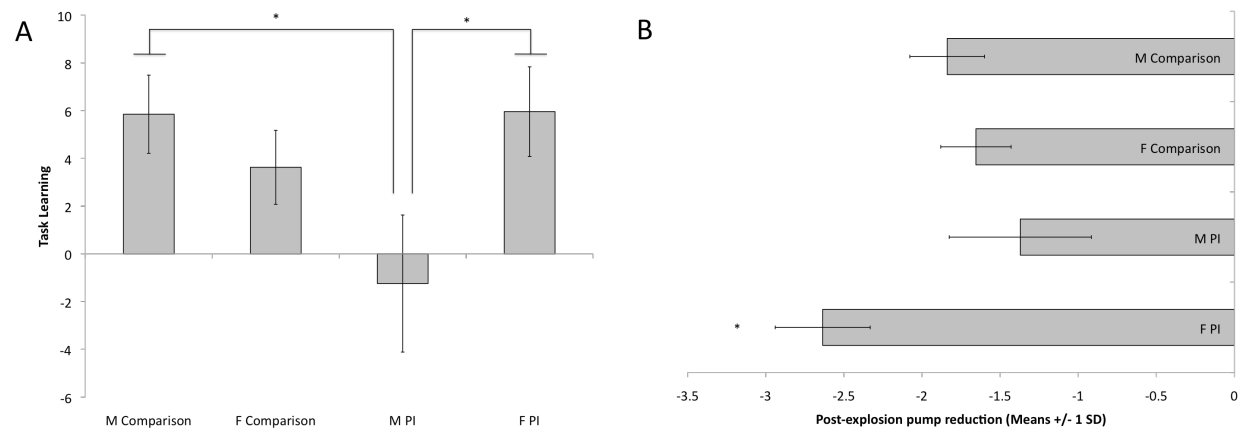
Table 1. Summary of mediator models for female PI group status (vs. other groups) and decision-making (*n*= 120; 5000 bootstraps)

Independent variable	Mediating variable	Dependent variable	Effect of IV on M	Effect of M on DV	Direct effect	Indirect effect (bias corrected intervals)		Total effect
(IV)	(M)	(DV)	(a)	(b)	(c')	(axb)	95% CI	(c)
Female PI Y/N	Post-explosion pump reduction	Pumps	-0.94**	0.04***	-0.02	-0.04	-0.07, -0.01	-0.06*
Female PI Y/N	Post-explosion pump reduction	Total Explosions	-0.94**	1.18***	-0.68	-1.10	-2.07, -0.37	-1.78*

Notes. PI = postinstitutionalized. * *p* < .05. ** *p* < .01. *** *p* < .001.

Figure 4. Sex moderates of the association of externalizing score for (A) proportion pumps and (B) explosions.

(A)

(B)
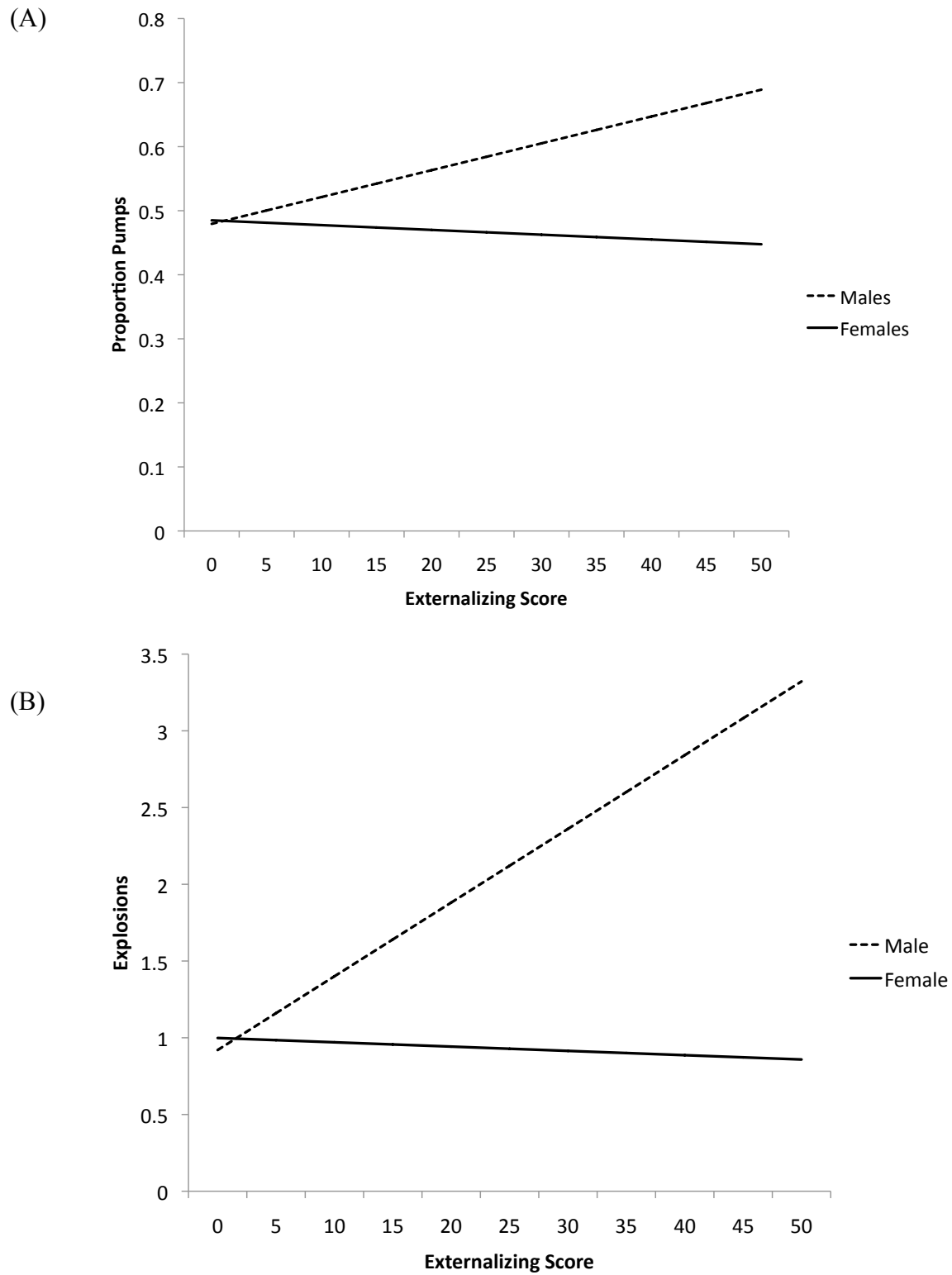
Appendix Table 1. Participant demographics

	PI	Comparison
Age	10.35 (2.62)	9.98 (2.84)
	Range: 6.18-15.71	Range: 6.00-15.93
Sex (% Male)	30%	47%
Country of Origin	Belarus (1)	
	China (17)	
	Guatemala (2)	
	Hungary (1)	
	Indian (1)	
	Kazakhstan (7)	
	Russia (13)	
	South Korea (2)	
	Taiwan (1)	
Age placed in	6.85 (14.83)	--
institution (months)	Range: 0.00-72.00	
Age adopted (months)	23.74 (27.43)	--
	Range: 0.13-120.00	
Months in institution	16.89 (14.84)	--
	Range: 0.13-72.00	

Means (SD). Note. PI = post-institutionalized.

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CHAPTER FIVE: RISKY DECISION-MAKING IN CHILDREN WITH AND WITHOUT

ADHD: A PROSPECTIVE STUDY.

Abstract

Objective: Children with ADHD have been shown to be more risk-taking than their non-ADHD counterparts, perhaps due to difficulties in appropriate decision-making in the context of risk. Successful decision-making under risk is important for adaptive functioning, as learning from feedback from prior decisions can guide future risky behavior. Method: We used a prospective design to examine whether ADHD diagnostic status predicted risky decision-making at a two-year follow-up. Using a well-characterized sample of 193 children with and without ADHD (aged 5-10 at Wave 1; 7-14 at Wave 2), we examined risky decision-making using the Balloon Emotional Learning Task (BELT), as computerized assessment of sequential risky decision-making that separately assesses risk-taking from its functional outcome. Results: Contrary to expectations, children with ADHD at Wave 1 were no more risk-taking than comparison (non-ADHD) youth as measured at Wave 2. ADHD diagnosis was also unrelated to success on the task and sensitivity to negative feedback. Notably, however, group differences were found in learning on the task. Though both youth with and without ADHD demonstrated learning on the task condition with a low threshold for punishment feedback, only non-ADHD youth demonstrated learning on the task condition with a high threshold for punishment feedback. Conclusions: The association between ADHD and risky decision-making is unclear. Learning during decision-making, particularly in high-punishment threshold contexts, may be deficient in children with ADHD. Successful functioning requires using feedback to guide future behavior, and thus negative outcomes in youth with ADHD may be partially explained by poorer learning from experience.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a childhood-onset disorder characterized by developmentally aberrant levels of inattention and hyperactivity (American Psychiatric Association, 2000). Nearly 60% of mental health visits to physicians for children in the United States involve attention problems (Hoagwood, Kelleher, Feil, & Comer, 2000) and the worldwide prevalence rate of ADHD has been estimated at 5.3% (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). Longitudinal studies suggest that children with ADHD exhibited elevated rates of functional impairment including poor academic achievement, social problems, and comorbidity (Lee, Lahey, Owens, & Hinshaw, 2008; Owens, Hinshaw, Lee, & Lahey, 2009).

ADHD is conceptualized as a disorder of disinhibition (Nigg, 2001), based partly on its prediction of outcomes characterized by poor inhibitory control such as alcohol and substance use disorders (Charach, Yeung, Climans, & Lillie, 2011; Lee, Humphreys, Flory, Liu, & Glass, 2011), risky driving, sexual behavior, gambling, and unintentional injury (Breyer et al., 2009; Garzon, Huang, & Todd, 2008; Thompson, Molina, Pelham, & Gnagy, 2007; Wymbs et al., 2013). Laboratory-based paradigms further substantiate the association between ADHD and risk-taking where children with ADHD had a greater number of pumps (indicating greater risk-taking) on an implicit risk-taking task, the Balloon Analogue Risk Task (BART; Lejuez et al., 2002, 2007), compared to healthy controls (Humphreys & Lee, 2011). A second study used a gambling task with explicit probabilities to minimize the impact of working memory and learning on performance, children with ADHD similarly exhibited greater risk-taking relative to a non-ADHD comparison group (DeVito et al., 2008). Taken together, childhood ADHD is reliably associated with increased risk-taking behavior with respect to both real-world outcomes (e.g., auto accidents, sexual behavior) and laboratory-based risk-taking tasks.

However, the decision to engage in risk-taking and learning are inter-related such that decisions are informed by feedback based on prior decisions, and thereby guide future behavior (Barto, Sutton, & Watkins, 1990). Capturing this process of feedback-guided decision-making has clear relevance, as well as detecting individual and developmental differences in learning from decisions. The Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, & Damasio, 2000) is an emotional decision-making task in which participants choose cards from four decks with different, initially unknown, average reward/punishment contingencies. As an implicit learning task, participants must learn from successive trials which decks produce advantageous versus disadvantageous outcomes over time. The IGT consists of two stages (Bechara, Damasio, Tranel, & Damasio, 1997; Brand, Recknor, Grabenhorst, & Bechara, 2007): the first stage is an exploratory period prior to determination of the pattern for each deck whereas the second stage follows the learning period. In a study using a child version of the IGT, non-ADHD children (n = 21) selected more cards from the advantageous deck over time, while children with "pure" ADHD (i.e., no anxiety or depression) (n = 11) did not select more cards from the advantageous deck across task trials (Garon, Moore, & Waschbusch, 2006). The study also uncovered significant variability among individuals with respect to task knowledge (i.e., which deck was advantageous) where children with ADHD were significantly less aware of the advantageous deck than comparison youth. Thus, ADHD and its associated deficits may negatively affect learning from experience. To date, although implicit learning from experience is necessary for adaptive decision-making on some tasks (e.g., IGT), few studies directly interrogate risky decision-making in sequential risk-taking in which participants control their risk-taking (as opposed to forced-choice tasks) (see Pleskac, 2008).

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Given that examining implicit learning is necessary to adequately characterize risk-taking, the present study used the Balloon Emotional Learning Task (BELT; Humphreys, Lee, & Tottenham, 2013), a risky decision-making task that incorporates implicit learning and differentiates adaptive and maladaptive risk-taking behavior. Similar to the BART, the BELT requires participants to pump of a series of balloons for a maximum of *n* pumps. Following each pump, participants choose to either stop playing to save points (number of pumps prior to saving = number of points earned) or continue to pump. Importantly, the each balloon explodes at an initially unknown number of pumps, resulting in zero points for that balloon trial. Thus, with increasing pumps, the individual incurs greater "risk" for losing all the points accumulated during that trial. However, crucially, unlike the BART, the BELT features two stable and one variable balloon condition. The stable balloon conditions consisted of a fixed explosion point (one low and one high threshold) to allow the individual to learn the explosion threshold via experience, thus guiding subsequent decisions about pumping behavior. However, the variable balloon condition, which is most similar to the original BART, consisted of three randomly ordered explosion thresholds, limiting the ability to detect the optimal strategy for pumps on this condition. Prior research suggests that both children and young adults learn the differences associated with the stable vs. variable balloon condition given that they earned more points with greater task experience (Humphreys, Lee, et al., 2014; Humphreys et al., 2013).

Theories on the etiology of ADHD, including the dynamic developmental behavioral theory (Sagvolden, Johansen, Aase, & Russell, 2005), propose that altered dopaminergic function, specifically hypofunctioning mesocortical dopamine branches, contributed to impaired learning and memory in ADHD. Stimulant medication is postulated to partially normalize this dysfunction. Methylphenidate, a stimulant, is the most commonly used treatment for ADHD and

principally target the dopamine transporter (Volkow et al., 1998). Given that the dopaminergic

system is essential for learning from reinforcement, and that methylphenidate ameliorated

deficient learning from external feedback in youth with ADHD (Groen, Mulder, Wijers,

Minderaa, & Althaus, 2009), examining differences in learning during decision-making may be

particularly relevant in individuals with ADHD.

Study Rationale and Hypotheses

The goal of the present study was to examine whether childhood ADHD (i.e., ADHD

versus non-ADHD comparison youth) was prospectively associated with risk-taking behavior

and outcomes on the BELT. Given that ADHD is a risk factor for later risk-taking outcomes

(e.g., Jerome, Segal, & Habinski, 2006; Lee et al., 2011), we examined baseline (i.e., Wave 1)

ADHD diagnostic status [i.e., children with ADHD (n = 104) and non-ADHD comparison

children (n = 89)] as a predictor of risk-taking behavior on the BELT assessed at a two-year

prospective follow-up (i.e., Wave 2). While we hypothesized that youth with ADHD at Wave 1

would demonstrate greater risk-taking behavior than non-ADHD youth, a recent review indicated

that the association of ADHD and risky decision-making in children and adolescents was

inconsistent (Groen, Gaastra, Lewis-Evans, & Tucha, 2013). Second, given the instability of

ADHD over time (Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Valo & Tannock, 2010), we

also examined whether persistent ADHD (ADHD diagnosis at both timepoints as opposed to

only one timepoint) predicted risk-taking on the BELT. Considering evidence from the IGT

(Garon et al., 2006), and that an attentional construct (associative sensitivity) was positively

associated with learning on the BELT in young adults (Humphreys et al., 2013), we

hypothesized that children with ADHD would demonstrate less learning than non-ADHD

comparison youths. However, given the inconsistent evidence on the association between ADHD

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and sensitivity to negative feedback (Carlson, Mann, & Alexander, 2000; Carlson & Tamm, 2000; Humphreys & Lee, 2011), no directional hypotheses were made with respect to this outcome.

As a secondary, exploratory aim, we assessed implicit learning in the form of awareness of the advantageous balloon condition, as previous studies have done (Bechara et al., 1997). Specifically, we examined how often individuals selected the most advantageous balloon condition when asked to choose one balloon in which to play the game again, and whether that selection was predictive of greater gains (points) on the task. We hypothesized that children with ADHD would be less likely to select the advantageous balloon condition, given prior evidence of less implicit learning by children with ADHD on affective-decision making (Garon et al., 2006).

Methods

Participants

At baseline (i.e., Wave 1), participants were 193 5-10 year-old children (69 percent male) with (n = 104) or without (n = 89) ADHD. Approximately two years later (i.e., Wave 2), children were 7- to 14-years-old. Fifty percent of children were Caucasian, 7% African-American, 10% Hispanic, 3% Asian, 24% Mixed/Other, and 6% Missing. Families were recruited from a large metropolitan area in the Western United States using presentations to self-help groups for ADHD, advertisements mailed to local elementary schools, pediatric offices, clinical service providers, and some referrals from mental health clinics. English fluency was required for parents and children. Families were excluded if their child had a Full Scale IQ less than 70 or a current/previous diagnosis of an autism spectrum, seizure, or neurological disorder that prevented full participation in the study.

Procedures

At baseline (i.e., Wave 1; ages 5-10), study eligibility for interested families was determined through a telephone screening based on the inclusion and exclusion criteria listed above. Eligible families (n = 230) were then mailed rating scales (95% returned completed or partially-completed rating scales) and invited to our laboratory for in-person assessments. After obtaining parental consent and child assent, parents completed a structured diagnostic interview of child psychopathology and an interview about parenting; in a separate room, children's cognitive, academic, and social-emotional functioning were assessed. In addition, parents and children were videotaped during a parent-child interaction task. All interviewers were initially blind to the child's diagnostic status, although blindness was difficult to maintain following the completion of the DISC-IV. Approximately 85% of children were assessed in our laboratory without psychotropic medication (e.g., stimulants). If a child was normally medicated, we asked that parents provide ratings based on the child's unmedicated behavior.

Approximately two years after the baseline evaluation, families were invited back to the laboratory for a follow-up assessment (i.e., Wave 2; ages 7-14). Procedures for the follow-up visit were highly parallel to those of Wave 1 (e.g., structured diagnostic interviews for child and parent psychopathology). Approximately 91% of the initial Wave 1 sample participated in the Wave 2 follow-up assessment. Families who participated in the follow-up had a higher mean number of child ADHD symptoms than families who did not participate in Wave 2, $t(226) = -2.08$, $p = .04$, but there were no other significant demographic (i.e., child age and sex, parent race-ethnicity and sex) or clinical (i.e., parental ADHD and depression) differences between these two groups of families. In the final analyses of this study, 193 participants had complete data on the BELT. The IRB approved all study procedures.

Measures

Diagnostic Interview Schedule for Children, Version IV (DISC-IV; (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). At Wave 1 and Wave 2, we used the DISC-IV, a computer-assisted, fully structured diagnostic interview with the parent, to obtain child ADHD data based on the Diagnostic and Statistical Manual, 4th Edition (American Psychiatric Association [APA], 1994). The ADHD module of the DISC-IV has good psychometric properties, including high test-retest reliability (r = .79 after one year) and internal consistency (ICC = .84 for symptoms counts, ICC = .77 for criterion counts) among the parents from a large community sample (see (Shaffer et al., 2000).

Balloon Emotional Learning Task (BELT; Humphreys et al., 2013). At Wave 2, all participants completed a computerized task of risky decision-making in which participants pressed a button to "pump up" balloons and earn points based on the number of pumps for each of the 27 balloon trials (i.e., more pumps earned more points). As with the BART, a balloon exploded following too many pumps. Initially, these explosions occurred at an unknown threshold (i.e., number of pumps), resulting in the loss of all points for that trial. Balloons appeared in three colors with different explosion points (pink balloons exploded at 19 pumps [certain-long], orange balloons exploded at 7 pumps [certain-short], and blue balloons exploded variably at 7 pumps, 13 pumps, or 19 pumps distributed equally across each third of the task [variable]) with corresponding colors counterbalanced across participants. The BELT demonstrated concurrent validity in young adults, with moderate positive correlations between the number of pumps on the task and sensation seeking (Humphreys et al., 2013).

A subsample of the participants (n = 100) was asked, following task completion, which balloon each would choose if he or she were to play the game again, as well as how much he or she liked each balloon color (using a 1-5 likert scale).

Data Analysis

We employed generalized estimated equations (GEE) using SPSS (version 20), specifying negative binomial with log link distribution due to the count data (i.e., number of pumps). GEE analyze longitudinal or sequential data by appropriately accounting for correlated observations characteristic of repeated measures designs. Separate GEE analyses were performed for each condition (certain-long, variable, and certain-short) for: (1) *number of pumps,* a measure of risky decision-making, (2) *number of points earned,* a measure of successful decision-making, and (3) *number of explosions*, a measure of decision-making errors. For the number of pumps and points, the design consisted of nested data, with 27 observations nested within each individual. Trial number was used as the within-subjects variable. Robust estimator covariance matrices were used specifying an autoregressive structure given than we expected trials close together would be more correlated than those further apart. The number of explosions reflected the sum across each third of the task to create a continuous measure, specifying third in the repeated command and autoregressive covariance matrix. Wave 1 ADHD diagnostic status, sex, and age at testing were included in the models as fixed effects.

Two additional metrics were examined: (1) *learning,* calculated as a change in points earned across task trials (using the GEE analysis of points earned by trial), and (2) *post-explosion pump reduction* (i.e., the difference in the number of pumps made on the first exploded short balloon trial and the trial immediately following from the same balloon condition) as a measure of sensitivity to negative feedback. Wave 1 ADHD diagnostic status, sex, and age were included in the models as fixed effects.

Additional, exploratory analyses examined individual differences in which balloon condition participants preferred. A follow-up assessment was introduced to the procedure

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approximately halfway through data collection, in which trained examiners introduced a set of questions for participants to answer, following BELT completion. Therefore, a subset of the sample (n = 100) was asked to pick one balloon (from the set of the three balloon colors) if he or she were to play the game again, as well as how much he or she liked each balloon color (using a 1-5 likert scale). Both choice (i.e., certain-long, uncertain, certain-short) and likert scale ratings were examined as independent variables associated with learning for each balloon type.

Results

BELT performance. We examined Wave 1 ADHD diagnostic status (i.e., ADHD versus non-ADHD comparison), sex, and age as predictors of BELT outcomes (Table 1). There was a positive correlation among pumps, points, and explosions. In addition, there was a marginal negative association between Wave 1 ADHD diagnosis and points.

Number of Pumps. We employed GEE to examine the association of Wave 1 ADHD diagnosis with the number of BELT pumps at Wave 2. Each balloon condition was examined separately. Controlling for sex, age, and trial number, Wave 1 ADHD diagnostic status was unrelated to pumps on the certain-long condition (Wald χ^2 = 0.59, 95% CI [-0.16, 0.08], p = .59), variable condition (Wald χ^2 = 1.33, 95% CI [-0.12, 0.03], p = .25), and certain-short condition (Wald χ^2 = 0.20, 95% CI [-0.06, 0.04], p = .65). Sex was similarly unrelated to pumps on all conditions whereas age was positively associated with greater pumps only on the certain-short condition (Wald χ^2 = 4.18, 95% CI [0.001, 0.03], p = .04).

Number of Points. As with the number of pumps, we examined the association between Wave 1 ADHD diagnosis and the number of points earned on the BELT at Wave 2. Controlling for sex, age, and trial number, ADHD was unrelated to points earned on the certain-long condition (Wald χ^2 = 0.44, 95% CI [-0.13, 0.06], p = .51). A marginal association was found

between Wave 1 ADHD and points on the variable condition (Wald χ^2 = 3.07, 95% CI [-0.10, 0.01], p = .08), however, where children with ADHD earned marginally fewer points per trial than non-ADHD comparison youth. Wave 1 ADHD diagnosis was unrelated to points earned on the certain-short condition (Wald χ^2 = 0.13, 95% CI [-0.10, 0.07], p = .72). Sex was unrelated to points on all conditions, and age was associated with greater points only on the variable condition (Wald χ^2 = 4.44, 95% CI [0.001, 0.04], p = .035)

Number of Explosions. For explosions, GEE was used specifying repeated thirds. All conditions were considered together given the relatively low rate of explosions. Once again controlling for sex, age, and third number, Wave 1 ADHD diagnostic status was unrelated to the number of explosions on the BELT (Wald χ^2 = 0.03, 95% CI [-0.21, 0.18], p = .87). Neither sex nor age was related to number of explosions.

Learning. We examined individual differences in improved performance over the course of the task to estimate learning. The same GEE models that examined points on the task were used, although an interaction term (Wave 1 ADHD diagnostic status × trial) was added to test whether group differences existed in changes (e.g., improvements) in points earned across the task. Again, this interaction was examined within each condition. For the certain-long condition, following a significant ADHD × trial interaction (Wald χ^2 = 4.68, p = .03) (see Figure 1A), we examined the association of trial with the number of points earned separately in youth with versus without ADHD. Whereas non-ADHD comparison youth earned more points across the trials (Wald χ^2 = 9.82, 95% CI [0.003, 0.01], p = .002), suggestive of learning on the condition, among children with ADHD, the number of points earned did not vary across the trials (Wald χ^2 = 0.15, 95% CI [-0.003, 0.01], p = .70), suggesting impaired associative learning on this condition. For the variable condition, the ADHD x trials interaction was unrelated to points

earned on the task (Wald $\chi^2 = 0.31$, $p = .58$), and there was no evidence of learning on this condition (Wald $\chi^2 = 2.41$, 95% CI [-0.001, 0.01], $p = .12$). In contrast to the variable condition, there was strong evidence overall of learning on the certain-short condition (Wald $\chi^2 = 50.15$, 95% CI [0.01, 0.02], $p < .001$), but this effect was not significantly moderated by ADHD status (Wald $\chi^2 = 0.74$, $p = .39$) (see Figure 1B). Posthoc analyses of learning on the certain-short condition within each group revealed that children with and without ADHD had similar levels of learning (both 95% CI [0.01, 0.02], $p < .001$). In order to rule-out the possibility the differences in IQ may explain the group difference found in learning on the certain-long condition, analyses were reconducted using full-scale IQ as a covariate. Notably, this group by learning interaction remained significant even after statistically controlling for estimated full-scale IQ.

Sensitivity to Negative Feedback

Because decision-making under risk can be influenced by feedback from previous trials (Humphreys & Lee, 2011; Humphreys et al., 2013), we estimated sensitivity to negative feedback (i.e., explosions) by calculating the change in the number of pumps following a balloon explosion. Negative values indicated fewer pumps on the subsequent balloon, whereas a score of zero indicated no change in pumps following the balloon explosion. Seventeen youth were excluded (11 ADHD, 6 comparison), due to having exploded no certain-short balloons. The mean post-explosion pump reduction score was 1.79 (SD=1.48), which differed significantly from zero ($t(175)$=16.05, $p<.001$). A generalized linear model specifying Poisson distribution for post-explosion pump reduction revealed that Wave 1 ADHD diagnostic status, controlling for youth age and sex, was unrelated to sensitivity to negative feedback (Wald $\chi^2 = 0.13$, 95% CI [-0.27, 0.18], $p = .72$).

Balloon ratings. For a subset of the sample (n = 100), we introduced a measure following completion of the BELT to assess implicit balloon preferences. This subset of the sample (n = 100) did not differ from those in the first half in the percentage with respect to ADHD, percentage male, pumps, points, or explosions (ps > .10). There was a marginal effect of age ($t(190) = 1.74$, $p = .08$), such that those included in follow-up analyses were marginally younger (10.17 [0.13] vs. 10.52 [0.15]).

Participants were asked to choose one balloon if they were to play the game again and to rate how much they liked each color balloon using a 1-5 likert scale (1 = Not at all, 3 = Neutral, 5 = Very much). The certain-long balloon was chosen by 48% of participants, the variable balloon was chosen by 42%, and the remaining 10% chose the certain-short condition. Controlling for the task version used, participants reported the highest ratings for the certain-long balloon (M = 4.00 [0.15]), followed by the variable balloon (M = 3.32 [0.13]), and then the certain-short balloon condition (M = 2.74 [0.13]). Ratings for all three conditions significantly differed from one another (ps < .01). Thus, we observed significant individual differences with respect to participants choosing which balloon condition was the most rewarding and most enjoyable.

Next, we tested whether participants who earned more points were more likely to choose the certain-long balloon (the most "advantageous" condition) relative to the certain-short and variable balloon conditions. Univariate ANOVA suggested that controlling for task version, individuals who chose the certain-long condition earned significantly more points on the task ($F(1,94) = 11.11$, $p = .001$, M = 132.25 [3.45] vs. M = 116.88 [3.48]. There was also a significant effect of the balloon condition chose on gains made on the task (last third minus first third) ($F(1,94) = 7.49$, $p = .007$), such that those who selected the certain-long balloon

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demonstrated gains on the task (M = 7.53 [1.95]), whereas those who selected either of the other

two conditions did not (M = 0.40 [1.97]). The number of points earned was also significantly

positively correlated with subjective ratings of how much they reported "liking" the certain-long

balloon ($r(100) = .25, p = .01$).

Although individuals with ADHD were less successful at learning on the certain-long

condition than non-ADHD comparison youth, there was no group difference with respect to the

selection of the certain-long condition (Wald = 0.88, B = 0.40 [0.42], $p = .35$). Similarly, there

was no group difference in the rating of the certain-long balloon condition by ADHD status

($F(1,95) = 0.73, p = .39$). Given that an ADHD by learning effect was found on the certain-long

condition, we investigated whether a similar interaction was present in the association between

selection of the certain-long balloon and learning on the certain-long condition. A GEE model

was conducted, as above, with certain-long points as the repeated measure and Wave 1 ADHD

status, selection of the certain-long balloon, and trial as main effects, along with two- and three-

way interactions. Though there was only a main effect of the binary variable: selection of

certain-long balloon (Wald $\chi^2 = 11.00$, 95% CI [0.09, 0.36], $p = .001$), but findings were

qualified by significant two-way interaction of selection of the long balloon by trial (Wald $\chi^2 =$

5.81, $p = .016$). Individuals who selected the certain-long balloon earned more points overall,

and showed greater gains over the course of the task. However, this effect was again qualified by

a significant three-way interaction with selection of the certain-long balloon, trial, and Wave 1

ADHD status (Wald $\chi^2 = 8.60, p = .003$) (see Figure 2). As can be seen in the Figure, there was

no learning observed among children with Wave 1 ADHD, regardless of whether the certain-

long balloon was selected. However, among comparison youth, the selection of the certain-long

balloon significantly predicted learning on this condition. Thus, the significant association of

selection of the certain-long balloon with respect to learning was specific to non-ADHD youth only.

Association of Wave 2 ADHD Diagnostic Status and BELT

Given that persistent ADHD may be differently associated with negative outcomes than ADHD at a single timepoint (e.g., Miller, Miller, Newcorn, & Halperin, 2008; Rabiner, Carrig, & Dodge, 2013) we included additional analyses to examine this possibility in the present dataset. Of the 104 children with ADHD at Wave 1, 70% met full diagnostic criteria for ADHD at Wave 2. Alternatively, 89% of non-ADHD comparison youth at Wave 1 were similarly negative for ADHD at Wave 2. We re-analyzed the association of ADHD diagnostic status with respect to key BELT variables, but differentiated youth with stable ADHD (i.e., positive diagnosis at Wave 1 and Wave 2), variable ADHD (i.e., positive diagnosis at Wave 1 or Wave 2), or non-ADHD at both time points. However, differentiating ADHD caseness based on relative persistence did not significantly change the pattern of findings with respect to risk-taking, points earned, sensitivity to negative feedback, or selection of the certain-long balloon following the game. Nevertheless, both ADHD groups demonstrated diminished learning on the certain-long balloon condition, and all three groups demonstrated learning on the certain-short condition. However, whereas the selection of the certain-long balloon condition was unrelated to the total number of points earned overall ($\beta = .09$, $p = .64$) in youth with persistent ADHD, among children with variable ADHD ($\beta = .56$, $p = .01$) and non-ADHD youth ($\beta = .34$, $p = .02$), selection of this balloon was positively associated with the number of overall points earned.

Discussion

The present study examined the concurrent and prospective association of childhood ADHD diagnostic status and risky decision-making in large and ethnically-diverse sample of

youth followed over two years. Given that ADHD is reliably associated with poor decision-making and inappropriate risk-taking (Barkley, 1997), we anticipated that youth with a history of ADHD would similarly exhibit impaired risk-taking behavior and related outcomes on the BELT, a computerized test of risky decision-making. However, youth with a history of ADHD exhibited, on average, similar levels of risk-taking on the BELT relative to non-ADHD comparison youth. That is, both groups made comparable pumps, exploded similar numbers of balloons, and earned comparable points. We additionally explored two components previously associated with risk-taking behavior: learning and sensitivity to negative feedback (Humphreys, Telzer, et al., 2014). While no group differences were identified in sensitivity to negative feedback, youth with and without ADHD at Wave 1 differed in learning. Though both groups demonstrated learning on a low punishment threshold condition, only individuals without ADHD demonstrated learning on the high punishment threshold condition.

Contrary to some prior work, risk-taking behavior did not significantly differentiate children with versus without ADHD. Groen and colleagues (2013) reviewed 14 studies and concluded that the association of ADHD and risky decision-making in children and adolescents was substantially inconsistent, with only half of the 14 studies having detected aberrant risk-taking in youth with ADHD. Significant variability in demographic factors, rates of comorbidity, methylphenidate use, and form of reward offered by the task may contribute to this variability. Although this is the first study to examine the association of ADHD and the BELT, relevant personality factors and early life adversity were linked to altered risky decision-making behavior on the BELT in young adults (Humphreys et al., 2013; Humphreys, Lee, et al., 2014). The multiple decisions within each task trial of the BELT (choice of whether to continue to pump or to save after each pump) is different from other of studies on implicit learning in the context of

risk, which require a more simple forced-choice decision to be made prior to trial-based feedback is provided (e.g., IGT). This requirement for some degree of exploration within each trial makes the task structurally more similar to the BART than gambling tasks. We previously reported (Humphreys & Lee, 2011) moderately increased risky behavior in youth with ADHD on the BART, but the largest effect was among children with comorbid ADHD and oppositional defiant disorder. Previous studies failed to find ADHD group differences with respect to the overall number of pumps on the BART, although these studies consisted of ADHD in adults (Mäntylä, Still, Gullberg, & Del Missier, 2012; Weafer, Milich, & Fillmore, 2011). Finally, as reviewed by Groen et al. (2013), risky behavior is uniformly associated with worse outcomes. However, a key asset of this study (and the BELT in particular) is that some level of risk-taking is necessary to improve performance; thus, the BELT uniquely considers how "risky" behavior can be adaptive, provide learning opportunities, and result in better outcomes.

The specific deficits associated with ADHD may also contribute to the absence of group differences observed in this study. Impaired inhibitory control is often thought to underlie elevated risky behavior among youth with ADHD (Barkley, 1997). The BELT may not have elicited individual differences in impulsivity as participants were allowed to "cash out" following each pump and move onto the next balloon. Thus, impulsivity may have been expressed in multiple ways, including excess pumping (e.g., balloon explosion) but also prematurely cashing out when additional pumps would have been adaptive. Given that ADHD was associated with deficient learning on the certain-long condition, the impulse to cash out on this balloon condition may have been more potent than the prospect of delaying through more pumps (despite being able to earn more points). Delay aversion, an individual difference variable regarding the desire to avoid delays, as well as delay discounting, the preference for immediate small rewards over

larger delayed rewards, have been implicated in youth with ADHD (e.g., Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Paloyelis, Asherson, & Kuntsi, 2009; Wilson, Mitchell, Musser, Schmitt, & Nigg, 2011), indicating that failed exploration may be related to a preference for immediate gains or the desire to avoid delays.

We also considered sensitivity to negative feedback, which declined across development and linked to overall points on the BELT (Humphreys, Telzer, et al., 2014). Given the mixed findings on sensitivity to negative feedback in ADHD (Carlson et al., 2000; Carlson & Tamm, 2000; Humphreys & Lee, 2011), *a priori* hypotheses were not made with respect to group differences. Unlike Drechsler, Rizzo, and Steinhausen (2008), the present findings did not indicate either an increased sensitivity for the magnitude of the reward or insensitivity to negative reinforcement. However, similar behavioral expressions of risk taking among youth with versus without ADHD may belie underlying neural differences. For example, decision-making was similar among adults with and without ADHD, but differences in regional cerebral blood flow were observed during the task (Ernst et al., 2003). Specifically, hippocampal activation was greater in comparison than ADHD participants, which the authors proposed was essential in decision-making. Given the centrality of the hippocampus in learning (Whitlock, Heynen, Shuler, & Bear, 2006), unmeasured patterns in neural activation may contribute to individual differences in success on the BELT.

Similar to risk-taking and sensitivity to negative feedback, and contrary to expectations, ADHD diagnostic status was unrelated to overall success on the BELT, although a marginal effect was found for the variable balloon condition in which children with ADHD earned fewer points. Given that learning on the long-condition was specific to non-ADHD comparison youth only, additional trials may have been necessary to elicit significant group differences for

decision-making success. Despite the lack of group differences on points earned, improvements in task performance were observed, consistent with prior work on the BELT (Humphreys et al., 2013; Humphreys, Lee, et al., 2014; Humphreys, Telzer, et al., 2014), as both participants with and without ADHD gained points across task trials on the certain-short condition. The condition, which has the lowest explosion point and therefore quickest opportunity for feedback about the limits of this balloon condition, appears to be most easily learned. The fact that children with ADHD, who previously exhibited impaired learning (Chang et al., 1999), showed gains on this condition suggests that ADHD is not universally associated with deficient use of experience to guide behavior. However, learning on the certain-long condition was impaired within the ADHD group.

The most notable finding of the present study may be the lack of learning among ADHD youth on the certain-long condition. Crucially, whereas comparison youth demonstrated steady gains in point for both of the certain/stable conditions, children with ADHD remained consistent in the number of points earned across the task for the certain-long condition. This lack of learning may be related to poor attention and general adaptive control processes used to distinguish the balloon conditions. Adaptive control processes are thought to be negatively influenced by the poorer error processing in youth with ADHD (Shiels & Hawk, 2010). Detecting errors and changing behavior in response to feedback is an important part of learning, and recent psychophysiological work indicates that children with ADHD may monitor environmental feedback less effectively (Crone, Jennings, & van der Molen, 2003; Groen et al., 2009; Luman, Oosterlaan, Hyde, van Meel, & Sergeant, 2007; Luman, Oosterlaan, Knol, & Sergeant, 2008).

Previous work on associative learning and explicit gambling paradigms suggested that, compared to non-ADHD youth, children with ADHD did not improve across trials. For example, Drechsler et al. (2008) used the Game of Dice Task and found that adolescents with and without ADHD performed similarly on the first run, but during the same game, non-ADHD youth demonstrated significant improvement in the financial outcome whereas youth with ADHD had worse outcomes and made more risky decisions. Interestingly, working memory, flexibility, or planning was unrelated to the performance deficits associated with ADHD, underscoring the need for future work to consider what underlies or mediates differences in task performance. Similarly, in a study of two conditional associative learning tasks, in which fixed mappings of stimulus-response pairs are learned through trial and error, Gitten, Winer, Festa, and Heindel (2006) found no differences between ADHD and comparison youth. However, performance on spatial learning task revealed a group difference, as children without ADHD improved across the course of the task (e.g., made fewer errors over time) whereas children with ADHD did not improve. These findings were characterized as deficient strategic processing.

Given the prior work on awareness of the game's structure during implicit decision-making tasks (e.g., Bechara et al., 1997), a portion of the sample was asked to describe their preferred balloon conditions. Awareness of the qualitative differences in the balloon conditions appeared to predict performance, as the selection of the "advantageous" certain-long balloon resulted in more points overall and learning on the task. Prior work with the IGT found children with ADHD were significantly less aware of the task structure (Garon et al., 2006). However, the association of ADHD and implicit learning was less clear in the current study given the absence of group differences with respect to the selection of the certain-long balloon condition and preference for this condition. However, selection of this balloon was unrelated to overall success

on the task among children with persistent ADHD. Thus, although implicit learning appeared to be associated with overall task performance, the role of ADHD as a moderating factor is unclear. Even within the IGT, ADHD is inconsistently associated with deficient task performance, with some finding impaired performance in children and adults with ADHD (Ernst et al., 2003; Garon et al., 2006; Toplak, Jain, & Tannock, 2005), while others found no differences (Geurts, van der Oord, & Crone, 2006).

The findings from the present study should be considered in light of limitations. First, as mentioned above and in prior work (Humphreys et al., 2013), additional trials may have elicited more learning opportunities and, potentially, diagnostic group differences in task success. Second, whereas the BELT simultaneously presents rewards (points) and punishment (removal of points),and given evidence of diminished reward anticipation in children with ADHD (Scheres, Milham, Knutson, & Castellanos, 2007), unmeasured differences in the salience of the reward on the BELT may have been relevant. Third, motivational differences may also be influential given that ADHD-related differences in intrinsic motivation have been reported (Luman, Oosterlaan, & Sergeant, 2005). Finally, ADHD is associated with a wide array of co-occurring problems, including comorbid learning disabilities (Pastor & Reuben, 2008). Thus, deficits associated with ADHD complicate inferences of specificity; although we note that inclusion of IQ in relevant models did not alter the results.

In conclusion, childhood ADHD diagnostic status was unrelated to risk-taking and sensitivity to negative feedback. However, given the opportunity to learn from experience on an instrumental learning task on risky decision-making, children with ADHD demonstrated aberrant learning. Consistent with previous work with the BELT (Humphreys et al., 2013), overall individuals learned and subsequently were more successful in their decision-making. Future

work should consider how exploration-based learning may be impaired in individuals with

ADHD, and if replicated, how these deficits may be treated.

Table 1. Descriptive statistics and correlation matrix among ADHD, sex, age, and primary BELT outcomes.

	ADHD	Sex	Age	Pumps	Points	Explosions
ADHD	1	.14†	-.13	-.07	-.12†	-.01
Sex (Male = 1)		1	-.001	.06	-.01	.09
Age			1	.14t	.17*	.07
Pumps				1	.75***	.85***
Points					1	.33***
Explosions						1
% or Mean (SD)	54%	69%	10.35 (1.41)	164.81 (43.18)	127.88 (23.69)	4.69 (3.16)
Range	0-1	0-1	7.86-14.35	55-288	55-209	0-16

Note. ADHD = attention-deficit/hyperactivity disorder.

†*p* < .05. **p* < .05. ***p < .001.

Figure 1. Learning on the (A) certain-long and (B) certain-short balloon condition by Wave 1
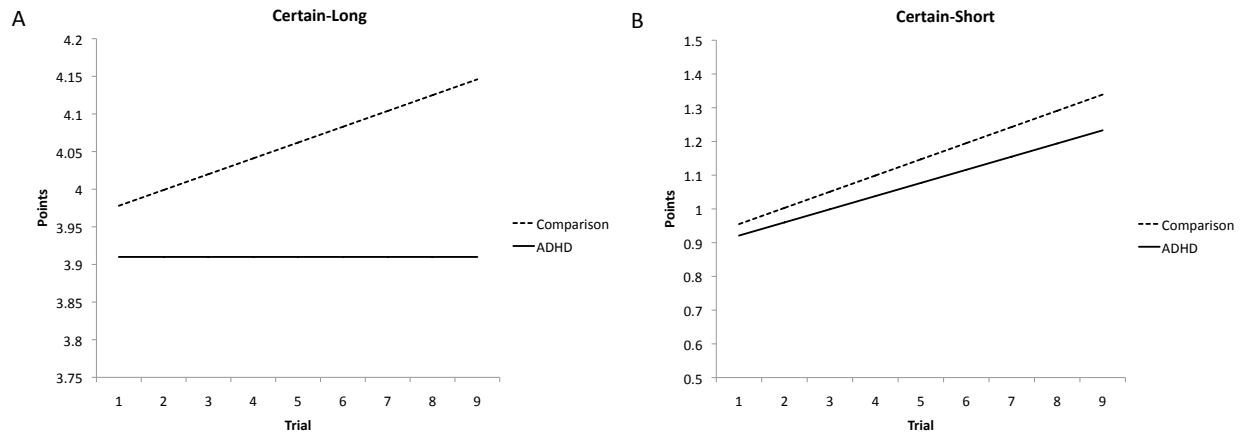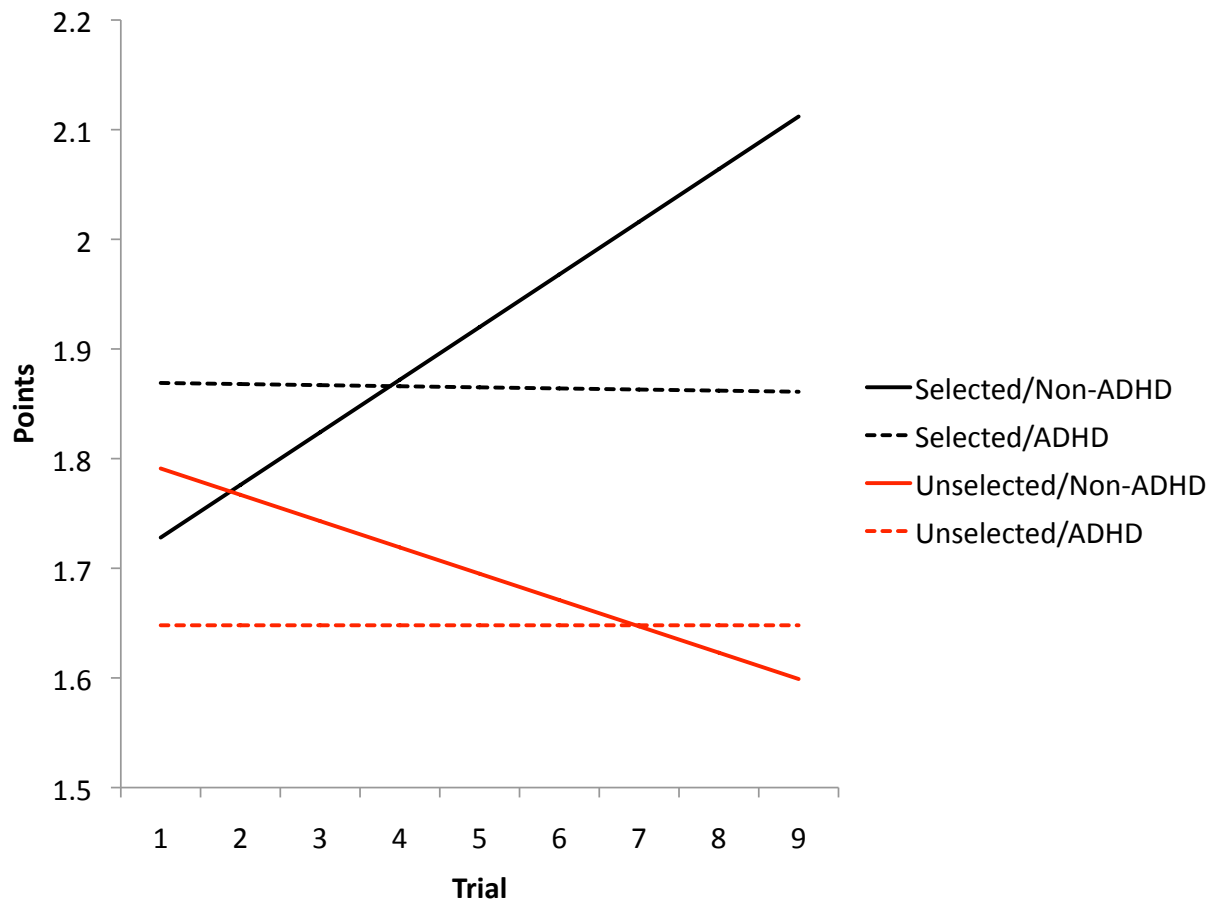
ADHD status.

Figure 2. Three-way interaction of Wave 1 ADHD status, selection of the certain-long balloon, and trial on points earned on the certain-long balloon.

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CHAPTER SIX: CONCLUSIONS

The goal of this investigation was to examine risky decision-making and related outcomes in four separate studies using the Balloon Emotional Learning Task (BELT), a task created for the purpose of sequentially assessing risk-taking behavior and the outcome of that behavior. The four studies that comprise the current investigation provide substantial support for its use, and each examined the association between individual and developmental differences (i.e., personality/temperament, age, early adversity, and attention-deficit/hyperactivity disorder [ADHD]) with risk-taking behavior and the success of that behavior. Instrumental exploratory behavior, as measured by the number of pumps made on the task, was necessary in order to gain points. Thus, unlike most risky decision-making tasks, the risk-taking behavior was required and adaptive in order to achieve a successful outcome. However, too much risk-taking would result in the loss of accrued points on that trial (explosion), and thus a balance of not being overly risky nor overly conservative under risk was necessary. Several key variables of interest emerged from the investigation, including how sensitivity to negative feedback and learning impact risk-taking and successful decision-making.

Untempered risk-taking on the task, as in most contexts, would result in negative outcomes. Balloon explosions, considered a decision-making error, served as an indicator of limits within each balloon condition, and provided crucial opportunities to learn the optimal number of presses for each balloon type. Participants who demonstrated a more conservative approach to the task – characterized by less willingness to explore – were therefore unlikely to find the "boundary" or limit for each balloon condition. This resulted in less opportunity to exploit each balloon condition to the full potential. In all three studies that involved children, a minority of the participants did not explode a single balloon, indicating that very high levels of

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cautiousness were present among a portion of the sample in this developmental period. The findings suggest that the willingness to explore, which brings potential risk for negative outcomes, increases across development.

Remarkably, even among very young children and 'at-risk' groups of participants, gains were made across the task on the certain-short condition, indicating that the task provided a consistently identified condition for learning. This relatively low bar for learning was in stark contrast to that set by the certain-long condition. Learning on this stable condition was less frequently observed, as the willingness to test the boundaries that governed the certain-long condition required more exploration. Young adults, on average, demonstrated learning on this condition. Similarly, a lack of learning on this condition was seen among preadolescent children and individuals with diagnosed with ADHD.

Another contribution from this set of studies is the use of the BELT to identify potentially unique periods in development for risk-taking. The study presented in chapter 3 suggests that risky decision-making is impacted by two distinct systems that demonstrate age-related changes. Learning from experience demonstrated an increase across participant age, and was associated with better decision-making under risk. Conversely, sensitivity to negative feedback, which is necessary for learning but can result in overly inhibited behavior, declined across participant age from early childhood into young adulthood. The confluence of changes on these two processes across development led to an intriguing finding about the adolescent period. Adolescence emerged as a developmental "sweet spot" for the certain-short condition, which has with the lowest explosion point and thus earliest opportunity to learn the limit for this condition. Individuals in adolescence outperformed both children and young adults on the certain-short condition. Adolescents were more likely than the younger participants to explore the

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environment (i.e., made more pumps), and this increased exploration may have provided those learning opportunities that led to greater success on the task. Yet the heightened sensitivity to negative feedback in adolescence, as compared to adulthood, may have resulted in more sensitive detection of the limits of the certain-short balloon condition, allowing for greater exploitation of available points.

Among youth who experienced maternal deprivation, adolescence may also signify a transitional stage. On average, children who were previously institutionalized were more conservative in their behavior, making fewer pumps than comparison youth. This pattern of risk averse behavioral style may be counterintuitive given the heightened attentional and externalizing problems found in this population. Though there was a general pattern of conservative decision-making behavior in PI youth, an age-related shift was observed in adolescence for PI males. While overall, and consistent with the findings from the normative development study, pumps made on the task increased across development. However, growth was the steepest in PI males. These youth were significantly more risk-taking, making more pumps on the task and incurring more decision-making errors than other groups. Notably, males from the PI group did not appear to learn from this heightened exploration, as there were no changes in points across the task for this group. Female PIs, in contrast, did show learning despite their more conservative approach to the task. A heightened sensitivity to negative feedback appeared to mediate the association between females in the PI group and lower numbers of pumps and explosions. The differential pattern of findings among males and females in the PI group suggests that the increased in risk-taking following maternal deprivation may amplify existing sex differences in risk-taking noted in typical populations.

One additional finding about developmental period was related to the amount of time spent in institutional care. Consistent with other work identifying 24 months of age as a potential "sensitive period" among PI youth (Fox, Almas, Degnan, Nelson, & Zeanah, 2011; Marshall & Reeb, 2008), the study presented in chapter 4 observed that children who spent more than 24 months spent in institutional care were extremely conservative in their decision-making. There was a linear decline in risk-taking (deviating further from typical children's behavior) on the task with greater months spent in institutionalization, suggesting that more time spent in institutional care past 24 months may result in more atypical behavioral patterns.

Task Review

The BELT consisted of 27 trials, within which 9 trials always exploded at 19 pumps (certain-long condition), 9 trials always exploded at 7 pumps (certain-short condition), and the remaining 9 trials exploded at either 19, 13, and 7 pumps, equally distributed by task third (uncertain/variable condition). Primary metrics of interest on the task include the number of pumps made, the number of points earned, associative learning on the task, and post-explosion pump reduction as a measure of sensitivity to negative feedback. Each of these measures has the potential to be examined within each balloon condition, and temporally across the task. The major findings from each study are reviewed below.

Chapter 2

In the first study, a sample of young adults was employed to validate the BELT and to examine personality/temperament traits in the prediction of risk-taking behavior, learning, and successful decision-making on the task (Humphreys, Lee, & Tottenham, 2013). This study found that risk-taking declined on the variable balloon condition and that stable conditions allowed for learning (i.e., increase in points earned, avoidance of explosions). Additionally, high sensation

seeking in combination with the temperament trait known as associative sensitivity was associated with the greatest with learning.

Chapter 3

In the second study, the use of a cross-sectional sample of individuals ages 3 to 26 years were used to examine age-related changes in risk-taking behavior, successful decision-making, associative learning, and sensitivity to negative feedback (Humphreys, Telzer, et al., 2014). Far from being reckless and unsuccessful, as some theories about adolescent risk-taking contend, individuals in adolescence performed at an intermediate level on the task, faring less well than young adults, though better than children, on the overall number of points earned. In fact, on the balloon condition with the lowest threshold for negative feedback, the certain-short balloon, adolescents outperformed both children and young adults. Though overall, the decreased sensitivity to negative feedback appeared to result in advantageous outcomes on the task (i.e., more points), adolescents intermediate level of sensitivity to negative feedback appeared to result in especially attuned performance on the certain-short condition. In support of the concept of heightened attunement during this developmental period, adolescents learned more on this condition (i.e., showed greater gains in points earned) than both younger and older participants.

Chapter 4

The third study examined risky decision-making in youth with and without a history of early adversity in the form of maternal deprivation due to orphanage rearing (Humphreys, Lee, et al., 2014). Youth with a history of maternal deprivation were, on average, more conservative on the BELT, pumping less than comparison youth. However, adolescent males with a history of institutional care were significantly less cautious in their decision-making than all other groups,

and unlike other youths did not show evidence of learning on the task, suggesting that this group may be at-risk for harmful behavior.

Chapter 5

The final study in this investigation examined risky decision-making in a prospective sample of children with and without a diagnosis of ADHD at an assessment two years prior (Humphreys, Tottenham, & Lee, 2014). Contrary to expectations, children with and without ADHD behaved similarly in terms of risk-taking and sensitivity to negative feedback. Importantly, however, children with ADHD demonstrated a lack of learning on the certain-long condition compared to gains observed in the comparison youth. A second component of this study examined preferences for balloon condition (certain-long, variable, certain-short) if given the opportunity to play the game again, as well as ratings of each condition. Children with ADHD were as likely as children without ADHD to select the certain-long balloon condition. However, only among children without ADHD did this selection predict learning on that balloon condition.

Future Directions

The four studies provide a solid foundation for use of the BELT, and together indicate evidence for validity of the task in probing risky behavior, success and failure, and mechanisms that may govern changes in risky decision-making over time. Future work may consider using the BELT in other populations, particularly for use in measuring the ability to learn from exploration (as opposed to tasks in which learning occurs after passively being presented stimuli), and may be helpful in interrogating decision-making that requires rapid, implicit learning. This work may have direct applications, including use as a screening instrument for academic or occupational positions. Similarly, applications for targeting high-risk groups for

intervention or prevention are another potential future direction. Given the findings from the first study of individuals high on sensation seeking, the BELT or similar tasks may usefully differentiate high-risk-takers, which could be useful for distinguishing healthy or adaptive risk-taking behavior from unhealthy/maladaptive risk-taking behavior. A second future direction involves modifications to the task. It should be noted that the BART (Lejuez et al., 2002) was the initial inspiration for the BELT, and prior to the BART the Devil's Task (Slovic, 1966) was a tool to measure risk behavior. Further extensions or modifications to the task, including changing the number of trials, the number or types of conditions, and the reward and punishment structure of the task, provide the ability to assess additional questions of interest related to learning, motivation, and sensitivity to different types of feedback. Similarly, experimental manipulations to directly assess the role of external factors on risky decision-making as measured by the BELT, can provide an important complement to quasi-experimental work. For example, manipulations of stress, sleep, and cognitive load may all yield interesting insights into processes related to behavior on the BELT. Use of the BELT or similar tasks concurrent with neuroimaging may allow for identification of the relevant neural correlates of the association between learning from exploration and resulting behavioral changes.

The role of changes in risky decision-making across development was an important feature of the second and third studies, yet only the final study involved a longitudinal component, and even so it did not include a baseline measure of risky decision-making. An important future direction is to examine intra- and inter-individual change across time on the BELT, and to study predictors of trajectories within individuals longitudinally. A prospective study is currently underway to examine how behavior on the BELT changes within individuals

across development, and to examine whether outcomes from the BELT predict future risky behavior and decision-making.

Limitations

Limitations to each study were included within each chapter, however the broader limitations to the full set of studies are reviewed briefly here. All studies used the BELT to interrogate risky decision-making, but there are important differences that limit generalizability across the studies. First, data collection for each study took place in different spaces within the same university (three different lab spaces were used), and therefore the testing environment differed within the samples. Related to this point, the broader goals of the studies that provided the samples for the three sources of participants differed. This adult sample was recruited for the Stress Impulsivity Study (PI: Kathryn Humphreys), which was conducted to examine the impact of stress on risk-taking behavior, and the BELT was provided in the first of a two-session visit. The youth for studies examined in chapters 3 and 4 were participants in a longitudinal study within the Developmental Affective Neuroscience Laboratory (PI: Nim Tottenham), conducted to examine behavior and neural development following maternal deprivation, and participants completed many tasks as part of this larger project. The participants from chapter 5 were taking part in a longitudinal study within the UCLA ADHD and Development Lab (PI: Steve Lee), focusing on genetic and environmental correlates of ADHD and disruptive behaviors. All participants had come to the lab on two occasions, approximately two years apart. The BELT was administered during the Wave 2 assessment, along with several other measures.

In addition to the participants' different testing environments and testing batteries, incentives for participations also differed. Adults received additional chances to win movie tickets for points earned on the task, children from the ADHD and Development Lab earned

stickers for their performance, which could be used to earn prizes at the end of testing. Participants from the Developmental Affective Neuroscience Lab earned no explicit rewards for earning points, and thus the experimenters relied on intrinsic motivation and reward in the form of praise to encourage performance. It is unclear how these different rewards impacted performance, and how motivational differences may have affected the validity of the present findings.

Lastly, the role of explicit and implicit knowledge of the task structure is not known. The final study included a measure of implicit preferences, but no information was obtained to directly assess participant knowledge of the task parameters. Research from the Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, & Damasio, 2000), indicated that "hunches" about task conditions can be affectively felt, and may occur before explicit awareness. The use of items to obtain implicit and explicit knowledge before, during, and after the task may be useful in examining the role of learning during sequential decision-making tasks in the future.

Significance

This investigation provides support for measurement of risky decision-making using a task that separately and sequentially assesses risk-taking and the result of that behavior. In some contexts, high levels of what may be seen as "high-risk" behavior may be adaptive and result in an optimal outcome. However, in other contexts repeatedly pushing the limits is maladaptive and suboptimal. Exploration was a necessary feature of adaptive performance, as the learning opportunities afforded via exploratory experiences could be used to guide future behavior. The present set of studies indicates there are important individual and developmental differences in

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risk-taking and successful outcomes. In addition, the role of learning and sensitivity to negative

feedback appear to meaningfully shape behavior following exploration.

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