Journal of Behavioral Decision Making, *J. Behav. Dec. Making*, **31**: 12–24 (2018)
Published online 31 August 2017 in Wiley Online Library (wileyonlinelibrary.com) **DOI:** 10.1002/bdm.2038

Children's Sensitivity to Cost and Reward in Decision Making across Distinct Domains of Probability, Effort, and Delay

LISA M. GATZKE-KOPP,[1]* NILAM RAM,[1,2] DAVID M. LYDON-STALEY[1] and DAVID DUPUIS[3]
[1]*Human Development and Family Studies, Pennsylvania State University, USA*
[2]*German Institute for Economic Research (DIW), Germany*
[3]*ScribbleLive Inc., USA*

ABSTRACT

Many behavioral paradigms used to study individuals' decision-making tendencies do not capture the decision components that contribute to behavioral outcomes, such as differentiating decisions driven toward a reward from decisions driven away from a cost. This study tested a novel decision-making task in a sample of 403 children (age 9 years) enrolled in an ongoing longitudinal study. The task consisted of three blocks representing distinct cost domains (delay, probability, and effort), wherein children were presented with a deck of cards, each of which consisted of a reward and a cost. Children elected whether to accept or skip the card at each trial. Reward–cost pairs were selected by using an adaptive algorithm to strategically sample the decision space in the fewest number of trials. Using person-specific regression models, decision preferences were quantified for each cost domain with respect to general tolerance (intercept), as well as parameters estimating the effect of incremental increases in reward or cost on the probability of accepting a card. Results support the relative independence of decision-making tendencies across cost domains, with moderate correlations observed between tolerance for delay and effort. Specific decision parameters showed unique associations with cognitive and behavioral measures including executive function, academic motivation, anxiety, and hyperactivity. Evidence indicates that sensitivity to reward is an important factor in incentivizing decisions to work harder or wait longer. Dissociating the relative contributions of reward and cost sensitivity in multiple domains may facilitate the identification of heterogeneity in suboptimal decision making. Copyright © 2017 John Wiley & Sons, Ltd.

KEY WORDS cost discounting; delay tolerance; reward sensitivity; measurement

Individuals differ in the extent to which the value of a potential reward is discounted by the costs associated with obtaining it. Steep discounting functions are often considered to be less optimal, and adverse consequences of suboptimal decision making can manifest in interpersonal, educational, and economic domains. Although little is known about the developmental emergence of trait differences in discounting tendencies, studies indicate that individual differences in discounting among children follow similar patterns of those in adults (Green, Myerson, & Ostaszewski, 1999a). Assessing children's decision-making preferences provides insight into behaviors that could place children at risk for adverse outcomes associated with impulsive or risky decision making. The majority of studies that assess the effects of discounting on decision making quantify individual differences in the decision outcome, with less research focused on the components that factor into the decision, such as how individuals weigh the relative contribution of the potential reward and cost and whether these computations differ across domains of costs (e.g., delay, probability, and effort). Greater understanding of the processes by which individuals arrive at suboptimal decisions could inform behavioral interventions aimed at improving developmental outcomes.

DOMAINS OF COSTS IN DECISION MAKING

Decision theory presumes that individuals seek to optimize the utility of decision outcomes, which involves adjusting the hedonic value of an available choice as a function of the costs associated with pursuing it to arrive at an expected value (Sanfey, Loewenstein, McClure, & Cohen, 2006). Because costs effectively discount the expected value of a reward, an individual can be motivated to select a less preferred item if the costs associated with a more preferred alternative are deemed to be too high. Individuals vary with regard to their sensitivity to rewards and costs, with studies showing that children exposed to maltreatment may be non-responsive to changes in expected value when making decisions (Weller & Fisher, 2013). Experimental research demonstrates that the neurocomputational estimates of reward and cost occur independently, such that the subjective estimate of cost can be pharmacologically manipulated without affecting the subjective reinforcement value of the reward (Ikemoto & Panksepp, 1999; Salamone, Correa, Farrar, Nunes, & Pardo, 2009). The independence of these computations suggests at least two dimensions in which individual differences could exist and influence decision outcomes.

Further complicating researchers' ability to characterize heterogeneity in decision making is the fact that "costs" exist in multiple, and somewhat distinct, domains. For example, imagine a teacher implements a behavioral incentive program in which children earn a star for appropriate school behavior. Stars are entered into a weekly drawing for the chance to win special privileges, incentivizing children to

*Correspondence to: Lisa M. Gatzke-Kopp, Human Development and Family Studies, Pennsylvania State University, 119 HHD University Park, PA 16802 USA. E-mail: lmk18@psu.edu

earn as many stars as possible. Multiple factors could contribute to a child being non-responsive to this program, and children may differ as to which factor is most salient for them. One child could fail to respond if she/he was not motivated by the available rewards (low reward sensitivity). Alternatively, another child could fail to respond if the task required to earn the star was deemed too aversive (low effort tolerance). Research indicates that humans discount for mental effort as well as physical effort, and children may find the cognitive demands of schoolwork unpleasant (Kool, McGuire, Rosen, & Botvinick, 2010). Others could fail to respond if they felt that it would take too long to get the reward (low tolerance for delay) or if the chances of actually getting the reward were considered too small (low tolerance for probability). Understanding why a given child is non-responsive is critical in determining what a more successful incentive program would entail for that child.

Neuroscience research indicates that costs across these three domains are computed in discrete neural processes, and thus, an individual's choices in one domain do not necessarily offer insight into their choices in other domains (Prevost, Pessiglione, Netereau, Clery-Melin, & Dreher, 2010; Schultz, 2004). Behavioral studies have also demonstrated that discounting tendencies for delay and probability are generally uncorrelated among normative adults (Green & Myerson, 2010; Green, Myerson, & Ostaszewski, 1999b) and typically developing adolescents (ages 9–23 years) (Olson, Hooper, Collins, & Luciana, 2007). This literature suggests that understanding how an individual's decisions are influenced by sensitivity to costs requires assessing each domain of cost independently.

Research on psychological characteristics associated with discounting further indicates specificity with regard to cost domain, particularly between delay and probability. Studies suggest that measures of intelligence and executive function are correlated with delay discounting (Basile & Toplak, 2015; Karalunas & Huang-Pollock, 2011; Shamosh & Gray, 2008) but not probability discounting (Basile & Toplak, 2015; Olson et al., 2007). Delay discounting is associated with the impulsive and hyperactive behaviors associated with attention deficit hyperactivity disorder (ADHD) (Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010) but was not found to characterize a sample of young adult gamblers who did demonstrate less probability discounting relative to non-gamblers (Holt, Green, & Myerson, 2003). In addition to the problems associated with a failure to discount for low probability (i.e. risk), studies also suggest that extreme discounting for probability (i.e. uncertainty intolerance) is associated with anxiety (Charpentier, Aylward, Roiser, & Robinson, 2017). Effort discounting has been studied less extensively than discounting in delay and probability but is an especially important component of decision making. In particular, willingness to engage in cognitive effort is an important trait associated with academic success in children beyond the contribution of intellectual ability (Chevalier, 2017). In young adults, less discounting for effort was associated with the personality trait of persistence (Malesza & Ostaszewski, 2013). These findings indicate that cost sensitivity has domain-specific implications for psychological outcomes.

MEASURING COMPONENTS OF THE DECISION PROCESS

The relative independence of discounting in each cost domain has important implications for quantifying individual differences in decision making. Because the internal computations underlying an individual's decision involve integrating the individually computed estimates of reward and cost across multiple domains, there exist a multitude of dimensions along which individuals may differ. Measuring individual differences in each of these domains can be made more feasible by experimentally restricting decisions to a single cost domain. However, even when decisions are reduced to a single cost domain, most paradigms do not dissociate individual differences in cost valuation from individual differences in reward valuation.

Individual differences in cost discounting typically entail having participants select between a higher-reward/higher-cost option and a lower-reward/lower-cost option. A discounting function is derived from the series of choices and quantified as the rate at which the reward value is discounted as a function of cost. Implicit in these paradigms is the assumption that the subjective valuation of a given reward is equal across individuals, and therefore, differences in preference are necessarily reflective of differences in internal weighting of the cost. Evidence challenging this assumption has begun to emerge. Through experimental modification, researchers have shown that impulsive decision strategies in a gambling paradigm could derive from less discounting for risk *or* greater valuation of reward, thus highlighting the mechanistic heterogeneity underlying risky decisions (Bechara, Dolan, & Hindes, 2002). Research examining delay discounting behavior has similarly proposed that steeper discounting functions in children relative to adolescents may be a function of heightened reward sensitivity (reward immediacy) rather than an actual aversion to delay (Scheres et al., 2006).

Heterogeneity has also been illustrated for the mechanisms driving seemingly advantageous decisions. Using an animal model, researchers demonstrated that flatter delay discounting (greater willingness to wait) could be driven by a higher tolerance of delay, *or* greater sensitivity to reward (Paglieri, Addessi, Sbaffi, Tasselli, & Delfino, 2015). A recent neuroimaging study with typically developing children found that flatter delay discounting functions correlated with greater neural activity during anticipation of reward, suggesting that reward regions of the brain are important in overcoming a normal aversion to delay (Benningfield et al., 2014). In other words, reward can incentivize delay just as delay can discount reward. Similarly, researchers have found that effort demands discount the perceived value of rewards, but reward can also incentivize effort (Massar, Lim, Sasmita, & Chee, 2016). These findings suggest that discounting as a trait encapsulates individual differences in preference for both cost and reward, which cannot be dissociated in paradigms where higher reward and higher costs are always yoked.

Measurement of children's aversion to specific cost domains may benefit from observation of decisions made in

DOI: 10.1002/bdm

the context of experienced as opposed to hypothetical costs. One study found that delay discounting among a sample of 7- to 12-year-old children diagnosed with ADHD only differed from typically developing peers during an experiential delay task, with no differences when delays were presented as hypothetical (Yu & Sonuga-Barke, 2016). Examination of patterns of electrical activity in the brain has demonstrated that both typically developing children (age 9–15 years) and those with ADHD show a reduction in slow frequency brain activity while working on a cognitive task relative to resting, but that only typically developing children demonstrate this same response when engaged in waiting (Hsu, Benikos, & Sonuga-Barke, 2015). This pattern suggests that waiting is an active state for most children, with inability to engage actively in this state associated with delay discounting and delay aversion in children with ADHD (Hsu et al., 2015). Although daily demands on children's patience frequently entail durations of time that are not reasonably studied in a laboratory context (e.g. hours), studies suggest that differences in delay tolerance emerge even when imposed delays are on the order of seconds, making experiential delay tasks effective and feasible (Scheres et al., 2006).

PRESENT STUDY

In the present study, we sought to develop an experimental paradigm to assess individual differences in children's decision making in the context of effort, delay, and probability domains. Within each domain, we quantify children's decision preferences using three distinct parameters: (a) general tolerance of cost domain, (b) sensitivity to incremental increases in reward, and (c) sensitivity to incremental increases cost. Several design considerations were made to accommodate children. First, this task is explicit with regard to the cost and reward conditions for each decision in order to bypass individual differences in implicit learning, known to drive age differences in performance (Crone, Bunge, Latenstein, & van der Molen, 2005; Crone & van der Molen, 2004). Second, this task employs experiential rewards and costs to avoid developmental concerns that children may not have the life experience necessary to estimate larger scales of hypothetical costs and rewards, with which they may have limited experience. We then examine whether decision preferences are associated with behavioral traits and whether these associations are independent of overall cognitive ability.

A sample of 403 children enrolled in a larger, ongoing, longitudinal study completed the three-block decision-making task when they were approximately 9 years of age.

(1) Consistent with literature on cost discounting, we predict that individuals' tolerance for delay and probability will be uncorrelated. Although fewer studies have examined effort tolerance, following animal research, we hypothesize that effort and delay tolerance will be modestly correlated. We hypothesize that sensitivity to reward will be specific to the context in which it is measured, with minimal correlations of reward sensitivity across domains.
(2) Consistent with the evidence that neural systems associated with assessing reward and cost parameters are anatomically distinct from brain regions associated with executive function, we hypothesize that behavioral preferences across domains will be independent of basic cognitive ability.
(3) We will examine whether decision preferences in each domain demonstrate specificity with regard to behavioral characteristics as reported by the children's teachers. Specifically, we anticipate that (i) less effort tolerance will be associated with lower academic motivation; (ii) less tolerance for probability (i.e. intolerance of uncertainty) will be associated with anxious behaviors; and (iii) less delay tolerance will be associated with restlessness/hyperactivity. We will also examine whether these associations occur independent of individual differences in cognitive capacity.

METHOD

Sample and procedure

The decision-making task was developed in conjunction with the Family Life Project (FLP), an ongoing epidemiological study of the effects of poverty and rurality on early child development. Extensive detail about the recruitment and maintenance of the entire FLP sample can be found elsewhere (Vernon-Feagans, Cox, & The Family Life Project Key Investigators, 2013). Briefly, the FLP has followed 1292 families, recruited at the time of the child's birth, in regions of Pennsylvania (n = 519) and North Carolina (n = 773). Only families from the Pennsylvania sample were invited to participate in the present study.

Families were initially assessed when the child was 2 months of age. At initial assessment, 59% of the sample was married, 37% single, and 4% separated, divorced, or widowed. On average, mothers were 25 years old (M = 24.54, SD = 6.43; range 15–43) and had given birth to M = 1.7 (SD = 1.09) children (range 1–6). Stratified recruiting efforts oversampled for poverty. Approximately 1/3 (36%) of participants reported receiving no forms of government assistance, 26% reported assistance in the form of Special Supplemental Nutrition Program for Women, Infants and Children and/or Medicaid, and 38% reported government assistance in addition to Special Supplemental Nutrition Program for Women, Infants and Children or Medicaid. Parent educational achievement ranged from not having completed high school (12% of mothers, 14% of fathers) to having completed a 4-year college degree or graduate degree (9% of mothers, 15.5% of fathers). The majority of participants (55% of mothers, 44% of fathers) earned a high school diploma or equivalent, and approximately 21% of both mothers and fathers reported some additional training beyond high school. Consistent with the demographics in the regions from which the sample was drawn, 93% of parents identified their child as primarily White, 6% identified their child as primarily Black, and the remaining 1% did not indicate a race.

DOI: 10.1002/bdm

Of the 428 Pennsylvania families with continued involvement in the project at child age 9, $n = 403$ participated in the decision-making assessment. The remaining families were not assessed due to active refusal of this visit ($n = 3$), passive refusal (e.g. non-responsive to scheduling attempts) ($n = 3$), lives too far for home visits ($n = 8$), child has been removed from the home ($n = 3$), child has known intellectual disability, and deemed incapable of understanding the task by the research assistant ($n = 8$). Children who did not participate in the decision-making task did not differ from those who did with regard to maternal age at birth F (1, 442) = .01, $p = .94$; mother's education F (1, 440) = .25, $p = .82$ or father's education F (1, 424) = .17, $p = .68$.

The decision-making task was completed on a laptop computer in the children's homes during the summer following third grade (mean age = 9.20 years, $SD = .28$, range = 8.67 to 9.92). Prior to the assessment, parents signed a consent form and children provided verbal assent. All procedures were approved by the local institutional review board. Families were provided a $50 gift card for their time, and children were awarded a prize in conjunction with the task (described in the subsequent texts).

Decision-making task

Task overview

Children were told that they would be playing a computer-based card game in which they would earn points that could be redeemed for a prize. Prior to the start of the game, children were shown a large selection of prizes (~$20 value) including toys, art projects, games, and play equipment, as well as a selection of menial prizes, such as small plastic farm animals that were relatively unappealing. Children were told that if they got "enough" points, they would be able to choose any prize, but if they did not earn enough points, they would only be able to select from the smaller prizes. This allowed children to identify their own most incentivizing reward and ensured that children were motivated to maximize their winnings.

Task presentation

Depictions of the task interface are shown in Figure 1, with open access for download and use at https://github.com/dkdupuis/aceTask#acetask. The task consisted of a virtual deck of cards, each with an associated reward for an associated domain-specific cost (delay, probability, and effort). Rewards were presented as the point value of the card ranging from 1 to 10, displayed numerically and visually (no. of stars). The cost associated with each card was presented on the left side of the screen and also ranged across 10 equally spaced increments. The specific presentation of costs differed by domain as described in the succeeding texts. In each trial, children were presented with a card and asked to choose whether to keep the card and be awarded the points according to the cost demands, or skip the card, forgoing the points and receiving a new card. Children were not told how many cards were available in the deck but were told that cards were limited and the game would end without warning,

Figure 1. Graphical user interface of the decision-making task. Sample screens for (A) delay block—the participant can receive eight points if they wait for 18 s, (B) probability block—the participant has an 80% probability of receiving eight points, and (C) effort block—the participant can receive eight points if they place a list of five non-sense words into alphabetical order. In all instances, the red shading depicts the cost associated with the given trial relative to the range of potential costs. [Colour figure can be viewed at wileyonlinelibrary.com]

encouraging children to consider each trial without reference to an unlimited possibility for future options.

The task was administered in three randomly ordered blocks. Before each block began, children completed a practice session of six trials. To ensure familiarity with the range of costs employed, card options in the practice sessions were pre-determined to be identical across participants.

Delay. During the delay, block costs were incurred as actual waiting time. As shown in Figure 1A, delay costs were depicted numerically and visually by using a circular clock,

DOI: 10.1002/bdm

the shaded portion of which indicated the number of seconds the child would have to wait for the points. If the child opted to keep a card, the shaded portion of the circle ticked down like the second hand on a clock. After the imposed time passed, the points were awarded and the next trial began. The 10 levels of delay cost, which ranged from 6 to 60 s in 6-s increments, were recoded as 1 to 10 for continuity of analyses across blocks.

Probability. During the probability block, costs were incurred through probabilistic awarding of points. As shown in Figure 1B, the probability of award was depicted numerically (e.g. 80%) and visually as a proportionally shaded rectangular bar. If the child opted to keep a card, the computer awarded the points at the indicated probability. If the child won the probabilistic draw, the screen displayed a thumbs-up sign and the word “success”. If the draw was not won, the screen displayed a thumbs-down sign, and the next trial began. To ensure that children understood that it was possible to not receive points even at high probabilities, one of the practice trials for this block was programmed to deliver a failure for a 90% probability card. The 10 levels of probability cost, which ranged from 10 to 100% in increments of 10%, were recoded as 1 to 10 with 1 indicating the lowest level of cost (i.e. 100% probability).

Effort. During the effort block, shown in Figure 1C, costs were incurred as cognitive effort. Children were asked to alphabetize a list of eight-letter non-sense words. Words were randomly generated by the computer with the requirement that at least two words in the list have identical letters in the first position. The amount of work required was depicted numerically (number of words to be alphabetized) and visually as number of shaded cells in a 3 × 4 table of rectangles. If the child opted to keep a card, they were presented the list of words and asked to place each in its appropriate position. The 10 levels of effort cost, which ranged from three words to 12 words in increments of 1, were recoded as 1 to 10, with 1 representing the lowest level of effort (alphabetizing three words). To dissociate the effects of time and effort, a standard inter-trial interval was enforced such that when participants selected a low effort cost option and were able to complete the task quickly, they were required to wait passively until the next trial.

Within each block, an adaptive algorithm was used to select the trial-by-trial reward–cost pairings from a 10 reward × 10 cost grid (100 possible combinations) in a way that maximized information about the child’s decision making function while minimizing task duration. Example decision data are illustrated in Figure 2. The first five cards were pre-determined to sample the four quadrants with the following reward/cost pairings (8/3, 3/8, 3/3, and 8/8) followed by the center pair of 5 points for the median level of cost. For each decision the child made, the algorithm assumed that the decision would apply to options that fell within that range (e.g. accepting an option of 4 points for 4 cost assumed acceptance of options >4 points for <4 cost). With each decision, regardless of whether the card was kept or skipped, the decision space was segmented into portions that still needed to be sampled, and portions that were assumed to be redundant with previous decisions. Using this approach, the entire 10 × 10 decision space could be inferred with fewer than 21 trials, enabling the entire three-block assessment to be completed in less than 30 min on average (M = 22.68, SD = 6.93; range = 7.82 to 47.73 min).

Task scoring

Each individual i’s binary decisions across t = 0 to 100 possible trials were then modeled as a function of the *costs* and *rewards* (each variable centered in a range from −4.5 to +4.5) using a “measurement model” that was structured as a person-specific logistic regression. Specifically, log odds of the child deciding to accept a card in a specific reward–cost scenario was parameterized for each cost domain as,

$$\log\left(\frac{P(acceptcard_{it}=1)}{1-P(acceptcard_{it}=1)}\right) = \beta_{0i}+\beta_{1i}cost_{it}+\beta_{2i}reward_{it}$$

Such that an individual’s decision tendencies are quantified in three ways: β_{0i} is a person-specific intercept term that indicates *general tolerance* in a specific cost domain (log-odds at the median cost and reward values); β_{1i} is a person-specific *cost-sensitivity* coefficient that indicates how sensitive the child’s decisions were to increases in effort, delay, or probability costs; and β_{2i} is a person-specific *reward-sensitivity* coefficient that indicates how sensitive the child’s decisions were to increases in reward in each domain. More positive general tolerance scores indicate greater willingness to accept an average offer, and more negative general tolerance scores indicate greater disinclination to accept the average offer. The cost-sensitivity and reward-sensitivity scores indicate the extent to which the probability of accepting a card changes with increases in cost and reward, respectively.

Cognitive ability

Multiples measures of cognitive functioning were assessed in participants’ homes at the pre-kindergarten visit (approximate age 5 years).

Executive function

Detailed information about the testing battery and the psychometric properties of the scores has been reported elsewhere (Willoughby et al., 2012). In brief, a composite executive functioning (EF) score was computed from a six-task battery that assessed working memory, inhibitory control, and attention shifting. Global EF scores derived from unidimensional item response models of the six tasks have good test–retest reliability (r = .95; Willoughby & Blair, 2011) and criterion validity (Willoughby et al., 2012). On average, females had higher EF scores (M = 1.66, SD = .73) than males (M = 1.31, SD = .74), F (1, 388) = 22.65, $p < .001$.

DOI: 10.1002/bdm

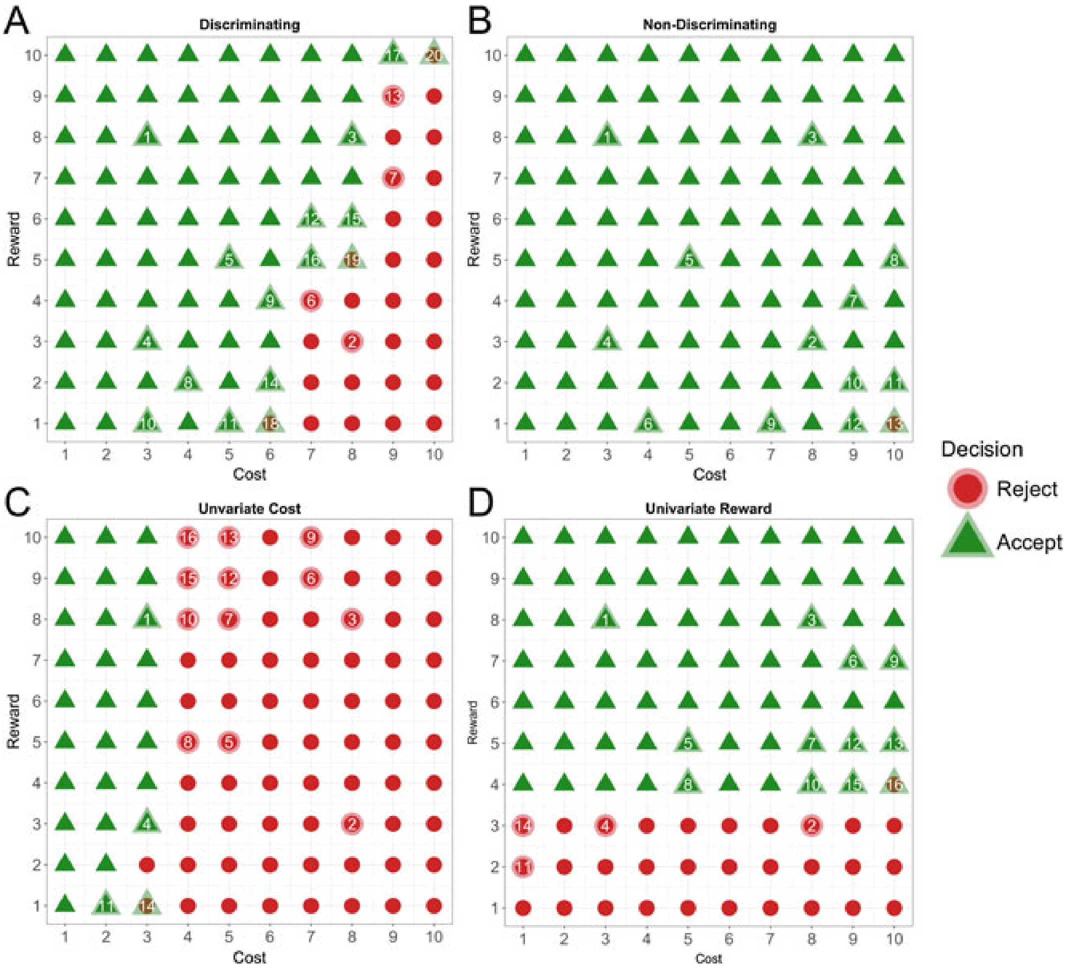

Figure 2. Each panel depicts exemplar cases of different decision strategies. All possible pairings of reward (*y*-axis) and cost (*x*-axis) are represented in the grid. Inferred decisions are depicted as red dots (rejects) and green triangles (accepts). Actual decisions are indicated by larger shapes, and numbered in order of presentation. The first five cards presented were fixed to sample the grid equally for all participants, with subsequent cards presented determined by the participant's previous choices. Decision strategies illustrated are (A) discriminating- incorporated reward and cost into decisions, (B) non-discriminating- accepted all cards, (C) univariate cost, and (D) univariate reward—Based decisions on only one factor. [Colour figure can be viewed at wileyonlinelibrary.com]

Non-verbal intelligence

Children's intelligence quotient (IQ) was measured by using the symbol search and coding subscales of the Wechsler Preschool and Primary Scale of Intelligence Third Edition (Wechsler, 2002). These scales were used to estimate IQ independent of verbal ability, which is known to be affected by socioeconomic status (Sameroff, Seifer, Barocas, Zax, & Greenspan, 1987). Standardized scores were averaged to obtain an overall IQ score (M = 98.07, SD = 13.12). On average, females had slightly higher scores (M = 100.08, SD = 13.01) than males (M = 96.33, SD = 13.00), F (1, 350) = 7.24, p = .007.

Verbal ability

A separate measure of verbal ability was estimated from the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007). Standardized scores (M = 101.45, SD = 14.62) did not differ between males and females, F (1, 367) = .99, p = .32.

Behavioral traits

Behavioral traits were measured by teacher reports, which were solicited from each child's teacher with the parents' permission.

Academic motivation

Teachers were asked to complete the Academic Achievement Motivation scale (Stinnett, Oehler-Stinnett, & Stout, 1991), a 10-item measure of *academic motivation*. Items, rated from 1 = *strongly disagree* to 5 = *strongly agree*, included positively phrased items (e.g. "shows pride in work") and reverse coded negatively phrased items (e.g. "often must be supervised to get the best performance on school work"). Scores across Grades 1 to 3 were correlated r = .63 to .74, ps < .001. Because of this relatively high stability, scores were averaged across all available years. Composite scores ranged from 1.15 to 5.00 (M = 3.73, SD = .88) and were normally distributed (skew = −.49, kurtosis = −.71). On average,

DOI: 10.1002/bdm

teachers rated girls ($M = 3.93$, $SD = .81$) higher in academic motivation than boys ($M = 3.57$, $SD = .91$), F (1, 388) = 16.47, $p < .001$.

Anxiety and hyperactivity

Anxiety and hyperactivity were extracted from teacher reports on the Social Skills Rating System (Gresham & Elliott, 1990), which consists of 48 items rated from 0 to 2. Scores from the third grade teacher were used to maximize proximity to the decision-making assessments. *Anxiety* was indexed from the six-item internalizing scale (e.g. "anxious in groups of children" and "easily embarrassed") (Cronbach $\alpha = .80$). Scores ranged from 0 to 10 ($M = 1.94$, $SD = 2.24$) and were normally distributed (skew = 1.20, kurtosis = .74). Scores did not differ between boys and girls, F (1, 347) = 1.09, $p = .30$.

Similarly, the *hyperactivity* scale consisted of six items (e.g. "interrupts others" and "easily distracted") (Cronbach $\alpha = .88$). Scores ranged from 0 to 12 ($M = 2.58$, $SD = 2.93$) and were normally distributed (skew = 1.12, kurtosis = .49). On average, boys were rated higher in hyperactivity (M = 3.35, SD = 3.13) than girls (M = 1.68, SD = 2.38) F (1, 348) = 30.57, $p < .001$.

Data analysis

We first evaluated whether children engaged meaningfully with the task and incorporated both reward and cost value into their decisions. We then examined within-domain and across-domain associations in children's decision preferences (*general tolerance*, *reward sensitivity*, and *cost sensitivity*) by using correlations to evaluate whether there was evidence of redundancy in children's rank order decision preferences. Paired t-tests were used to determine whether decision parameters were significantly different as a function of decision domain. Sex differences in decision parameters were examined by using a 3 (block) × 3 (domain) repeated measures ANOVA. Finally, we conducted regressions to test the hypotheses that decision preferences would demonstrate domain-specific associations with behavioral measures that were independent of cognitive ability. Three identical regression models were conducted predicting academic motivation, anxiety, and hyperactivity traits. In each model, sex and cognitive ability were entered in Step 1. Decision parameters were entered in Step 2 to determine whether these variables contributed significant additional variance. All nine decision parameters were entered simultaneously to test the specificity hypotheses.

RESULTS

Decision patterns

All children completed the delay block, and all but one child completed the probability block (due to a time constraint). However, seven children elected not to complete the effort block after finding the practice session too difficult, and the RA ended the block early for an additional four children who became too frustrated to continue. On average, children who did not complete the effort block ($n = 11$) had significantly lower IQ ($M = 80.94$, $SD = 6.94$) than children who did ($M = 98.46$, $SD = 12.98$), F (1, 350) = 14.43, $p < .001$).

Children's decision patterns were examined for validity. Decision patterns emerged in four different profiles, reported in Table 1 and depicted in Figure 2. The overwhelming majority of children displayed a *discriminating* profile, in which both accept and reject decisions were made. However, some children displayed a *univariate* profile wherein decisions were only influenced by the cost (e.g., accepting any card below a certain cost threshold regardless of value) or the reward (e.g., accepting any card above a certain value threshold regardless of cost). Univariate decision strategies were relatively rare in both the delay and effort blocks, but in the probability block, ~10% of children made decisions based entirely on the probability, irrespective of reward value. Finally, a small subset of children displayed a *non-discriminating* profile by accepting all cards ($n = 56$, 13.90% of the total sample). This profile could reflect an indiscriminate behavior meant to proceed obligatorily through the task rather than valid decision making. However, of the 56 children who completed a block without rejecting any cards, 43 did so in only 1 block, with far fewer doing so in 2 ($n = 10$) or all 3 ($n = 3$) blocks. McNemar tests indicated that the non-discriminating profile was less likely to occur in the effort block relative to both the probability ($\chi2 = 4.65$, $p = .03$) and delay ($\chi^2 = 10.32$, $p = .001$) blocks, which did not differ from each other ($\chi2 = .60$, $p = .44$). This suggests that children did engage validly with the task and that failures to reject any cards were likely a genuine indication that the costs presented in that domain were acceptable.

An examination of the parameter estimates for individuals with univariate or non-discriminating profiles indicated the logistic model used for task scoring adequately captured the (lack of) influence of reward and cost on the child's decisions. For instance, individuals who focused only on cost had reward-sensitivity scores near zero. Individuals with the non-discriminating profile had near zero sensitivity scores for both reward and cost. A repeated measures ANOVA indicated no differences between boys and girls across domains (domain × sex, F (2, 388) = 2.19, $p = .11$), individual parameters

Table 1. Prevalence of decision-making profiles in each cost domain

Cost domain	Univariate: cost	Univariate: reward	Non-discriminating	Discriminating
Delay ($n = 403$)	7 (1.74%)	11 (2.73%)	33 (8.19%)	352 (87.34%)
Effort ($n = 392$)	2 (.51%)	5 (1.28%)	12 (3.06%)	364 (92.86%)
Probability ($n = 402$)	39 (9.70%)	2 (.50%)	27 (6.72%)	321 (79.85%)

Note. Univariate decision makers selected cards with regard to only one factor. Non-discriminating decision makers accepted all cards presented. Discriminating decision makers incorporated both reward and cost in decisions.

DOI: 10.1002/bdm

(parameter × sex, F (2, 388) = .19, p = .83), or domain × parameter × sex, F (4, 388) = 1.50, p = .20.

Association of decision tendencies within cost domains

Descriptive data for children's decision-making parameters for each cost domain are presented in Table 2. Mean tolerance scores were positive for the probability and delay blocks, indicating that, on average, children were generally tolerant of uncertainty and generally willing to wait. However, mean tolerance in the effort block was negative, indicating that, on average, children were disinclined to work for the median level of reward. As expected, all participants had positive reward-sensitivity scores in all three blocks, indicating that increases in reward value consistently increased the probability of participants accepting the card, with individual differences in the magnitude of sensitivity to reward. Comparably, all participants had negative cost-sensitivity scores, indicating that increases in cost consistently decreased the probability of accepting the card, with individual differences in the magnitude of sensitivity to cost.

Within-domain correlations are seen in the bolded portions of Table 2. Correlations between tolerance and cost sensitivity indicate that individuals with higher effort tolerance were less likely than other children to reject a card as effort demands further increased. The same pattern emerged with regard to delay. Thus, within the effort and delay domains, general tolerance and cost sensitivity appear to capture similar intra-individual characteristics. There was also a modest association between higher sensitivity to effort costs and higher sensitivity to reward, $r = -.17$. Within the probability block, tolerance was unrelated to sensitivity to cost (risk), but those with higher tolerance for uncertainty showed greater sensitivity to increases in reward. Higher reward sensitivity was also modestly associated (r = .14) with less cost sensitivity.

Association of decision tendencies across cost domains

Correlations in the non-bolded portion of the lower triangle in Table 2 indicate how decision preferences in one cost domain related to preferences in the other cost domains. Tolerance scores were all positively correlated, with the largest association between delay and effort (r = .35). Children who were generally more willing to wait were generally more willing to work. Smaller correlations were observed between tolerance of probability and that of delay (r = .12) and effort (r = .18). Cost sensitivity to delay was associated with cost sensitivity to effort (r = .23), but neither were correlated with cost sensitivity to probability. Reward sensitivity in the delay block was modestly associated with reward sensitivity in the effort (r = .14) and probability blocks (r = .11), which were not related.

The pattern of associations among children's decision making tendencies indicates a very modest degree of rank order similarity in tolerance among cost domains, with some additional associations with cost and reward sensitivity also emerging as significant. However, the magnitude of these associations was small and may have only achieved

Table 2. Associations among decision parameters (general tolerance, reward sensitivity, and cost sensitivity) across cost domains

	Delay n = 403			Effort n = 392			Probability n = 402		
	1a. Tolerance	1b. Reward	1c. Cost	2a. Tolerance	2b. Reward	2c. Cost	3a. Tolerance	3b. Reward	3c. Cost
1a.	–			2.48***			−2.53***		
1b.	**.05**	–			.20**			.79***	
1c.	**.29*****	**−.01**	–			.29***			.96***
2a.	.35***	.02	.22***	–			−5.13***		
2b.	−.14**	.14**	.06	**−.04**	–			.61***	
2c.	.11*	.21***	.23***	**.44*****	**−.17*****	–			.67***
3a.	.12*	−.08	.06	.18***	−.04	.13*	–		
3b.	−.05	.11*	.09	−.07	.09	.09	**.22*****	–	
3c.	−.04	.07	−.08	−.12*	.06	.01	**−.07**	**.14****	–
Mean (SD)	1.62 (5.26)	2.18 (1.08)	−1.94 (1.06)	−.99 (5.10)	2.00 (.91)	−2.23 (1.15)	4.16 (5.52)	1.39 (.85)	−2.89 (1.60)
Range	−18.70 – 15.90	.34 – 5.78	−6.05 – −.34	−18.86 – 14.71	.50 – 5.76	−6.14 – −.34	−11.29 – 22.73	.34 – 5.67	−6.14 – −.34

Means, standard deviations (SD), and observed ranges for each of the decision parameters in each cost domain are presented in the bottom rows. Values in the lower triangle are correlations among task scores. Values in the upper right triangle are t-values from the paired t-tests of mean difference between domains.
Note.
*$p < .05$.
**$p < .01$.
***$p < .001$.

DOI: 10.1002/bdm

significance due to the relatively large sample size, suggesting that preferences across the domains are largely unique. Paired sample *t*-tests, reported in the upper triangle of Table 2, further support that preferences in each domain significantly differ from one another.

Association of decision tendencies with cognitive ability

Bivariate correlations between decision preferences and all cognitive measures are reported in Table 3. None of the probability decision preferences were associated with IQ, verbal ability, or EF. No associations were observed with delay tolerance. However, greater sensitivity to reward in incentivizing delay was associated with higher scores on all three cognitive measures. Higher effort tolerance was associated with better EF and verbal ability, but not with IQ. However, greater reward sensitivity and less cost sensitivity in the effort context were associated with higher IQ and EF scores. Although significant, the magnitude of these correlations again suggests that decision-making tendencies are not purely a function of general cognitive ability.

External and discriminant validity of cost domain decisions

Correlations among all decision preferences and behavioral traits are also reported in Table 3. Higher academic motivation was associated with higher effort tolerance and less sensitivity to effort costs, as well as higher sensitivity to reward in incentivizing both effort and delay. Anxiety and hyperactivity were only associated with preferences in the effort domain. Children rated higher in anxiety were generally more tolerant of effort, but also more sensitive to costs, meaning that anxious children's tolerance for effort dropped off more quickly as effort demands increased. Children rated higher in hyperactivity were less tolerant of effort, less sensitive to the incentivizing effects of reward, and more sensitive to increases in effort demand.

Finally, three regression models were used to examine the unique associations between children's decision tendencies and behavioral traits. In Step 1, sex, IQ, verbal ability, and EF were entered as control variables. The nine scores derived from the decision-making task were entered in Step 2. Despite correlations among some of the predictors, tolerance values were relatively high (.57 to .93) and variance inflation factor values were relatively low (1.08 to 1.76) indicating that variables were appropriately independent. Results are shown in Table 4.

Academic motivation was significantly associated with being female and higher cognitive function across measures (Step 1 (F (4, 336) = 32.08, $p < .001$). Prediction was improved with Step 2 (ΔF (9, 323) = 2.50, $p = .009$). Greater academic motivation was uniquely associated with more

Table 4. Regression models examining discriminant validity of decision parameters

	Academic motivation	Anxiety	Hyperactivity
Step 1 R^2	.28***	.06***	.19***
Sex	−.10*	.02	.22***
IQ	.23***	−.18**	−.07
EF	.21***	−.08	−.26***
Verbal	.19***	−.04	−.07
Step 2 ΔR^2	.05**	.06*	.05*
Delay			
Intercept	−.02	.14*	.03
Reward	.02	−.06	.00
Cost	−.11*	.00	.17**
Effort			
Intercept	.13*	−.09	−.11
Reward	.14**	.01	−.05
Cost	.02	−.09	−.09
Probability			
Intercept	−.07	.09	.04
Reward	.02	.00	−.01
Cost	.04	−.12*	−.07

Values are standardized β parameters.
Note.
*$p < .05$.
**$p \leq .01$.
***$p \leq .001$.

Table 3. Correlations between decision parameters and cognitive abilities or behavioral traits

Task scores	IQ	Verbal ability	Executive function	Academic motivation	Anxiety	Hyperactivity
Delay						
Tolerance	.01	.02	.06	−.04	.07	.01
Reward sensitivity	.17**	.12*	.16**	.14**	−.10	−.09
Cost sensitivity	.08	.00	.07	−.03	−.02	.08
Effort						
Tolerance	.09	.11*	.23***	.17***	−.12*	−.19***
Reward sensitivity	.15**	.08	.22***	.23***	−.07	−.11*
Cost sensitivity	.16**	.16**	.19***	.12*	−.18***	−.15**
Probability						
Tolerance	.03	.07	.05	−.02	.07	.03
Reward sensitivity	.02	−.02	−.03	.03	−.05	.01
Cost sensitivity	−.05	.05	−.03	.03	−.10	−.06

Positive correlations with cost sensitivity indicate less influence of increasing costs on the probability of rejecting a card.
Note. N = 350–402.
*$p < .05$.
**$p < .01$.
***$p < .001$.

DOI: 10.1002/bdm

sensitivity to delay costs (β = −.11), higher overall effort tolerance (β = .13), and greater sensitivity to reward in incentivizing effort (β = .14).

Anxiety ratings were uniquely and negatively associated with IQ in Step 1 (F (4, 301) = 4.98, p = .001). Model prediction was improved with Step 2 (ΔF (9, 288) = 1.94, p = .03). Higher anxiety ratings were associated with higher tolerance of delay (β = .14) and greater sensitivity to probability costs (β = −.12).

Hyperactivity ratings were uniquely associated with being male and having lower EF (Step 1 F (4, 279) = 17.20, $p < .001$). Prediction was significantly improved with Step 2 (ΔF (9, 266) = 1.88, p = .048). Children rated higher in hyperactivity were less sensitive to increases in delay costs (β = .17).

DISCUSSION

Results of the present study support hypotheses that children's sensitivity to how rewards and costs influence their decisions can be meaningfully dissociated and that individual differences in sensitivity to rewards and costs differ across delay, probability, and effort domains. Children's decision preferences in each cost domain demonstrated unique associations with behavioral traits, indicating that individual differences in how children make domain-specific decisions provide unique and meaningful information about more global aspects of behavior. These findings offer insight into potential sources of heterogeneity within suboptimal decision outcomes, such as risk taking and impulsivity. Differentiating between the contributions of reward and cost sensitivity could have implications for how behavioral interventions are tailored for individual children.

Distinguishing among tolerance, sensitivity to costs, and sensitivity to reward

The objective of this study was to dissociate the relative contributions of sensitivity to reward from sensitivity to cost in decision making, which can be conflated in measures of discounting functions (Paglieri et al., 2015). Using person-specific logistic regressions, we were able to estimate an intercept term as a standardized index of general tolerance, enabling the comparison across individuals with reference to a standard reward/cost tradeoff. In addition, we quantified sensitivity to incremental increases in reward and cost in the decision to accept an offer. Results supported the hypotheses that these metrics capture distinct information about individual differences in decision preferences. The strength of correlation among the three decision parameters differed across cost domains but was generally low. The highest correlation was observed in the effort domain. Individuals who were less tolerant of effort were more sensitive to additional increases in effort demand, indicating that tolerance and cost sensitivity each captured some degree of effort aversion. It is possible that this association is a function of the minimal increments of cost increase in this paradigm, where each additional cost unit represented only one additional word to be alphabetized. Larger incremental increases might facilitate greater dissociation between these variables. Furthermore, this correlation may be inflated by the influence of cognitive ability on both variables. When entered simultaneously into a regression with cognitive function controlled, only tolerance contributed uniquely to child behavior.

Results also supported the distinction between sensitivity to reward and sensitivity to costs. Within-domain correlations between reward and cost sensitivity were below .2. Furthermore, tolerance was uncorrelated with reward sensitivity in both the delay and effort domains, suggesting that individual differences in sensitivity to reward are unique from individual differences in aversion to cost in these contexts. Only within the probability block did greater reward sensitivity correlate with a higher tolerance for uncertainty, although the magnitude of this correlation was also small. In addition to reward sensitivity being relatively independent from aversion to costs, correlations of reward sensitivity across domains were small, despite reward being administered in an identical manner in all blocks. These findings are consistent with neuroimaging research that found differential patterns of brain activation in response to reward estimated in the context of delay versus effort (Massar, Libedinsky, Weiyan, Huettel, & Chee, 2015).

A confluence of evidence indicates that individuals' discounting tendencies in response to delay are independent of their discounting for probability (Green & Myerson, 2010; Green et al., 1999a; Green et al., 1999b). Our results generally support this dissociation, although small positive correlations were observed between delay tolerance and uncertainty tolerance and between reward sensitivity in the delay and probability domains. This discrepancy is likely a function of the relatively larger sample size providing increased power to detect small effects. However, it is possible that by extracting reward sensitivity from sensitivity to costs, some shared variance emerged that is not easily detected when quantifying discounting.

Far less research has sought to examine associations between delay and probability discounting with discounting in the effort domain. Some studies have suggested that discounting for effort is correlated with discounting for delay, although each still retains unique associations with other traits (Malesza & Ostaszewski, 2013). Our results were consistent with evidence of a modest correlation between domains. It is possible that this correlation reflects the extent to which waiting itself is an effortful task for children (Hsu et al., 2015). Future research should examine whether correlations between delay and effort diminish with age.

Decision preferences and general cognitive ability

Previous research suggests that cognitive ability is not uniformly associated with the ability to make advantageous decisions across all domains. Results from the current study are consistent with previous findings that IQ is correlated with decisions related to delay, but not probability (e.g. Basile & Toplak, 2015; Karalunas & Huang-Pollock, 2011). Interestingly, intellectual and cognitive measures were not correlated with sensitivity to delay, but rather were correlated with sensitivity to the incentivizing properties of

DOI: 10.1002/bdm

reward in overcoming delay aversion. The ability to dissociate sensitivity to reward and cost in the current task therefore provides an additional level of specificity to how IQ relates to lower levels of delay discounting. Sensitivity to reward may be adaptive in facilitating behavioral flexibility to override trait-level tolerance when appropriately incentivized to do so (Benningfield et al., 2014).

Decision making in the effort context also evidenced associations with non-verbal IQ, EF, and verbal ability. Unlike the delay context, however, these associations were not unique to reward sensitivity. Higher scores on all three cognitive measures were generally associated with more tolerance for effort, more responsiveness to reward, and less responsiveness to cost. Given the nature of the task, which targeted cognitive effort specifically, these associations are not surprising. Although the task makes use of non-sense strings of letters in the alphabetizing task to avoid privileging children's verbal ability, more fluency with letters is likely to make performance easier. In addition, the task placed at least some demand on working memory. The modest magnitude of the associations implies that a substantial portion of the interindividual differences in decision making are not determined by cognitive ability.

Validity of decision preferences

The final hypotheses posited that children's decision preferences had domain-specific implications for their behavioral traits. In order to account for shared variance, all nine decision parameters were examined simultaneously as predictors of behavioral traits while also controlling for cognitive ability. As hypothesized, higher levels of teacher-rated academic motivation were associated with higher levels of effort tolerance, as well as greater sensitivity to reward. These results indicate that the present task captured variance associated with children's academic behaviors in the classroom beyond variance accounted for by intellectual ability. The effort block was the only domain in which the average tolerance scores were negative, and the only domain that children refused or became too dysregulated to complete. Emergence of such frustration provides a glimpse into the challenges teachers face in engaging students in learning behaviors. Willingness to exert cognitive effort is known to be an important component of learning and predicts academic achievement independent of intelligence (Biggs, 1999). The finding that both tolerance of effort and sensitivity to reward contributed unique variance in predicting academic motivation suggests that children differ in terms of both their general willingness to work and how readily they respond to incentives to motivate effort. The ability to identify different preferences among students characterized broadly by academic or behavioral challenges in school may help teachers and parents select the most appropriate behavioral strategy for a given child.

Results further supported the hypothesis regarding decisions in the context of uncertainty and children's symptoms of anxiety. Specifically, children rated higher in anxiety were less inclined than their peers to choose a card as chances of winning decreased, indicating that their decisions were more affected by risk than by reward. Although discounting for low probability can be adaptive, intolerance of uncertainty can result in an excessive tendency to withdraw from opportunities simply because success cannot be guaranteed. In the current task, there was no condition in which points could be lost, making the level of risk fairly minimal. A child presented with a card worth six points at 70% probability must decide to accept the offer (an expected value of 4.2), or reject the offer (an expected value of 0). In other words, a child who rejects this offer is trading a 30% chance of getting no points for a 100% chance of getting no points. Such a decision is consistent with the theory that anxiety is associated with an aversion to uncertainty (Carleton et al., 2012; Charpentier et al., 2017). Although the behavioral assessments were not designed to identify anxiety disorders, the findings are consistent with the hypothesis that uncertainty intolerance is associated with anxious tendencies. Future research can examine whether preferences in decision making exhibited in childhood portend development of more significant anxiety-related problems as children transition into adolescence.

Unlike the predictions for the effort and probability blocks, associations with decision preferences in the context of delay were not entirely consistent with hypotheses. Specifically, delay was the only context in which decision preferences showed a significant association with each of the three behavioral measures, and several of these associations ran counter to predictions. Following studies associating greater delay discounting among individuals with ADHD (Scheres et al., 2010), we hypothesized that an aversion to delay would be associated with symptoms of hyperactivity. In contrast, hyperactivity was associated with *less* sensitivity to delay. Furthermore, in addition to the predicted associations with decisions related to effort, higher academic motivation was predicted by *greater* sensitivity to delay. This discrepancy from the findings in discounting tasks may be a function of important differences in task design. Delay discounting tasks often ask children to select between two options, both with at least some level of reward. In the present study, however, a decision to decline to wait means forgoing the opportunity for any reward on that trial and thus captures delay aversion more specifically. The pattern of findings here suggests that children rated higher in hyperactivity are not averse to waiting passively if incentivized but are significantly less tolerant of effort. These findings suggest a potential value in dissociating the influences of time and effort, which are often confounded in real-world decisions.

It is also important to note that the unpredicted adaptive associations with delay aversion emerge only when all decision preferences are modeled simultaneously, while controlling for cognitive ability. It is possible that delay aversion is associated with maladaptive behaviors only in the context of lower cognitive ability. One study, for instance, found that the association between ADHD and delay discounting was no longer evident once IQ was accounted for (Wilson, Mitchell, Musser, Schmitt, & Nigg, 2011). Thus, delay aversion may only be problematic when accompanied by lower cognitive ability. The present findings further support recommendations made by other researchers regarding the importance of incorporating measures of intellectual ability in the study of decision making in the context of delay (Olson et al., 2007).

DOI: 10.1002/bdm

SUMMARY AND LIMITATIONS

Several aspects of the sample and study design warrant consideration. First, although larger sample size is typically preferred in behavioral research, our sample size was markedly larger than most decision-making studies, and as such, our power to detect smaller associations was greatly increased. Thus, discrepancies between our findings and others in the literature may be a function of power rather than a true inconsistency. Secondly, the age of the present sample may limit generalizability to other developmental stages. Future research is needed to determine whether there is rank order stability in decision preferences across childhood and whether decision preferences are prospectively associated with psychological outcomes. In addition, the children in this study were measured at a time when hormonal changes begin in preparation for the physical changes of pubertal development (Mundy et al., 2015). Given the substantial individual differences in the timing of puberty, more developmental heterogeneity may exist in this sample than is evident from chronological age alone. Although no evidence of sexual dimorphism emerged in the present study, sex-specific patterns could emerge later in development as pubertal processes continue to influence ongoing brain development.

Finally, several aspects of the task design may limit generalizability. Although a large body of research has examined discounting tendencies from a trait-perspective, several studies have documented state-related influences on discounting including sleep deprivation (Reynolds & Schiffbauer, 2004) and affect (Hewig et al., 2011). Developmental research is needed to determine whether children are more affected by state-level fluctuations in their decisions than adults. In addition, in an effort to reduce assessment time, the use of an adaptive algorithm employed the assumption that all decisions could be inferred on the basis of previous decisions. Research in adolescents indicates that consistency is not characteristic of all participants (Olson et al., 2007). Future studies should expand the decision task to assess empirically the extent to which children adhere to consistent decision rules and whether inconsistency, in and of itself, is a meaningful index of neuroeconomic processes.

In sum, the present study examined a novel decision-making task designed to dissociate sensitivity to reward from sensitivity to cost across three different domains of cost. Findings demonstrate that children's decisions in the context of delay, effort, and probability domains are associated with psychological and behavioral traits and that decision preferences account for unique variance beyond cognitive ability. These findings also offer insight into ways to assess and operationalize heterogeneity in impulsive decision making.

ACKNOWLEDGEMENTS

The Family Life Project is funded by NICHD P01HD039667 with co-funding from the National Institute of Drug Abuse. This study was funded by a grant from the National Science Foundation, SES-1150844, to the first author. Additional support was provided by the National Institutes of Health in support of the second author (R01 HD076994, R24 HD041025, and UL TR000127) and the third and fourth authors (T32 DA017629). The third author was also supported by an ISSBD-JJF Mentored Fellowship for Early Career Scholars. The authors also wish to thank the Social Science Research Institute at Penn State for its instrumental support in project development. This study was made possible by the work of the Family Life Investigators including Lynne Vernon-Feagans, Mark Greenberg, Clancy Blair, Margaret Burchinal, Martha Cox, Patricia Garrett-Peters, Jennifer Frank, Roger Mills-Koonce, and Michael Willoughby.

REFERENCES

Basile, A. G., & Toplak, M. E. (2015). Four converging measures of temporal discounting and their relationships with intelligence, executive functions, thinking dispositions, and behavioral outcomes. *Frontiers in Psychology*, *6*.

Bechara, A., Dolan, S., & Hindes, A. (2002). Decision-making and addiction (part II): Myopia for the future or hypersensitivity to reward? *Neuropsychologia*, *40*, 1690–1705.

Benningfield, M. M., Blackford, J. U., Ellsworth, M. E., Samanez-Larkin, G. R., Martin, P. R., Cowan, R. L., et al. (2014). Caudate responses to reward anticipation associated with delay discounting behavior in healthy youth. *Developmental Cognitive Neuroscience*, *7*, 43–52.

Biggs, J. (1999). What the student does: Teaching for enhanced learning. *Higher Education Research & Development*, *18*, 57–75.

Carleton, R. N., Mulvogue, M. K., Thibodeau, M. A., McCabe, R. E., Antony, M. M., & Asmundson, G. J. G. (2012). Increasingly certain about uncertainty: Intolerance of uncertainty across anxiety and depression. *Journal of Anxiety Disorders*, *26*, 468–479.

Charpentier, C. J., Aylward, J., Roiser, J. P., & Robinson, O. J. (2017). Enhanced risk aversion, but not loss aversion, in unmedicated pathological anxiety. *Biological Psychiatry*, *81*, 1014–1022.

Chevalier, N. (2017). Willing to think hard? The subjective value of cognitive effort in children. *Child Development*, *(epub ahead of print)*.

Crone, E. A., Bunge, S. A., Latenstein, H., & van der Molen, M. W. (2005). Characterization of children's decision making: Sensitivity to punishment frequency, not task complexity. *Child Neuropsychology*, *11*, 245–263.

Crone, E. A., & van der Molen, M. W. (2004). Developmental changes in real life decision making: Performance on a gambling task previously shown to depend on the ventromedial prefrontal cortex. *Developmental Neuropsychology*, *25*, 251–279.

Dunn, L. M., & Dunn, D. M. (2007). PPVT-4: Peabody picture vocabulary test. Pearson Assessments.

Green, L., & Myerson, J. (2010). Experimental and correlational analyses of delay and probability discounting. In G. J. Madden, & W. K. Bickel (Eds.), *Impulsivity: The behavioral and neurological science of discounting* (, pp. 67–92). American Psychological Association.

Green, L., Myerson, J., & Ostaszewski, P. (1999a). Discounting of delayed rewards across the life span: Age differences in individual discounting functions. *Behavioural Processes*, *46*, 89–96.

Green, L., Myerson, J., & Ostaszewski, P. (1999b). Amount of reward has opposite effects on the discounting of delayed and probabilistic outcomes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 418–427.

DOI: 10.1002/bdm

Gresham, F. M., & Elliott, S. N. (1990). *Social skills rating system: Manual*. Circle Pines, MN: American Guidance Service.
Hewig, J., Kretschmer, N., Trippe, R., Hecht, H., Coles, M., Holroyd, C. B., et al. (2011). Why humans deviate from rational choice. *Psychophysiology*, *48*, 507–514.
Holt, D. D., Green, L., & Myerson, J. (2003). Is discounting impulsive? Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes*, *64*, 355–367.
Hsu, C.-F., Benikos, N., & Sonuga-Barke, E. J. (2015). Spontaneous activity in the waiting brain: A marker of impulsive choice in attention-deficit/hyperactivity disorder? *Developmental Cognitive Neuroscience*, *12*, 114–122.
Ikemoto, S., & Panksepp, J. (1999). The role of nucleus accumbens dopamine in motivated behavior: A unifying interpretation with special reference to reward-seeking. *Brain Research Reviews*, *31*, 6–41.
Karalunas, S. L., & Huang-Pollock, C. L. (2011). Examining relationships between executive functioning and delay aversion in attention deficit hyperactivity disorder. *Journal of Clinical Child and Adolescent Psychology*, *40*, 837–847.
Kool, W., McGuire, J., Rosen, S., & Botvinick, M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, *139*, 665–682.
Malesza, M., & Ostaszewski, P. (2013). Relations between Cloninger's dimensions of temperament and steepness of delay and effort discounting of monetary rewards. *Psychological Reports*, *112*, 694–705.
Massar, S. A., Libedinsky, C., Weiyan, C., Huettel, S. A., & Chee, M. W. (2015). Separate and overlapping brain areas encode subjective value during delay and effort discounting. *NeuroImage*, *120*, 104–113.
Massar, S. A., Lim, J., Sasmita, K., & Chee, M. W. (2016). Rewards boost sustained attention through higher effort: A value-based decision making approach. *Biological Psychology*, *120*, 21–27.
Mundy, L. K., Romaniuk, H., Canterford, L., Hearps, S., Viner, R. M., et al. (2015). Adrenarche and the emotional and behavioral problems of late childhood. *Journal of Adolescent Health*, *57*, 608–616.
Olson, E. A., Hooper, C. J., Collins, P., & Luciana, M. (2007). Adolescents' performance on delay and probability discounting tasks: Contributions of age, intelligence, executive functioning and self-reported externalizing behavior. *Personality and Individual Differences*, *43*, 1886–1897.
Paglieri, F., Addessi, E., Sbaffi, A., Tasselli, M. I., & Delfino, A. (2015). Is it patience or motivation? On motivational confounds in intertemporal choice tasks. *Journal of the Experimental Analysis of Behavior*, *103*, 196–217.
Prevost, C., Pessiglione, M., Netereau, E., Clery-Melin, M., & Dreher, J. (2010). Separate valuation subsystems for delay and effort decision costs. *The Journal of Neuroscience*, *30*, 14080–14090.
Reynolds, B., & Schiffbauer, R. (2004). Measuring state changes in human delay discounting: An experiential discounting task. *Behavioural Processes*, *67*, 343–356.
Salamone, J. D., Correa, M., Farrar, A. M., Nunes, E. J., & Pardo, M. (2009). Dopamine, behavioral economics, and effort. *Frontiers in Behavioral Neuroscience*, *7*, 3–13.
Sameroff, A. J., Seifer, R., Barocas, R., Zax, M., & Greenspan, S. (1987). Intelligence quotient scores of 4-year-old children: Social-environmental risk factors. *Pediatrics*, *79*, 343–350.
Sanfey, A. G., Loewenstein, G., McClure, S. M., & Cohen, J. D. (2006). Neuroeconomics: Cross-currents in research on decision-making. *Trends in Cognitive Sciences*, *10*, 108–116.
Scheres, A., Dijkstra, M., Ainslie, E., Balkan, J., Reynolds, B., Sonuga-Barke, E., et al. (2006). Temporal and probabilistic discounting of rewards in children and adolescents: Effects of age and ADHD symptoms. *Neuropsychologia*, *44*, 2092–2103.
Scheres, A., Tontsch, C., Thoeny, A. L., & Kaczkurkin, A. (2010). Temporal reward discounting in attention-deficit/hyperactivity disorder: The contribution of symptom domains, reward magnitude, and session length. *Biological Psychiatry*, *67*, 641–648.
Schultz, W. (2004). Neural coding of basic reward terms of animal learning theory, game theory, microeconomics and behavioral ecology. *Current Opinion in Neurobiology*, *14*, 139–147.
Shamosh, N. A., & Gray, J. R. (2008). Delay discounting and intelligence: A meta-analysis. *Intelligence*, *36*, 289–305.
Stinnett, T. A., Oehler-Stinnett, J., & Stout, L. J. (1991). Development of the teacher rating of academic achievement motivation. TRAAM. *School Psychology Review*, *20*, 609–622.
Vernon-Feagans, L., Cox, M., & The Family Life Project Key Investigators (2013). The Family Life Project: An epidemiological and developmental study of young children living in poor rural communities. *Society for Research in Child Development Monographs*, *78*, 1–150.
Wechsler, D. (2002). *WPPSI-III administration and scoring manual*. Psychological Corporation.
Weller, J. A., & Fisher, P. A. (2013). Decision-making deficits among maltreated children. *Child Maltreatment*, *18*, 184–194.
Willoughby, M., & Blair, C. (2011). Test-retest reliability of a new executive function battery for use in early childhood. *Child Neuropsychology*, *17*, 564–579.
Willoughby, M. T., Blair, C. B., Wirth, R. J., Greenberg, M., & The Family Life Project Key Investigators (2012). The measurement of executive function at age 5: Psychometric properties and relationship to academic achievement. *Psychological Assessment*, *24*, 226–239.
Wilson, V. B., Mitchell, S. H., Musser, E. D., Schmitt, C. F., & Nigg, J. T. (2011). Delay discounting of reward in ADHD: Application in young children. *Journal of Child Psychology and Psychiatry*, *52*, 256–264.
Yu, X., & Sonuga-Barke, E. (2016). Childhood ADHD and delayed reinforcement: A direct comparison of performance on hypothetical and real-time delay tasks. *Journal of Attention Disorders*, DO.

Authors' biographies:

Lisa M. Gatzke-Kopp is an associate professor in Human Development and Family Studies. Her research focuses on the development of dopamine systems in the brain and implications for impulsive and risky behaviors.

Nilam Ram is a professor of Human Development and Family Studies and the director of the Quantitative Developmental Methods Research Group at Penn State. His research focuses on design and analysis of longitudinal data for study of within-person change.

David M. Lydon-Staley is a doctoral student in Human Development and Family Studies at Penn State and a predoctoral fellow with the Prevention Research and Methodology Centers. His research interests are in the area of reward processing and decision making related to smoking behavior.

David DuPuis received his PhD in Neuroscience from Penn State during which time he was a predoctoral fellow with the Prevention Research and Methodology Centers. He currently works as a data scientist for ScribbleLive.

Authors' addresses:

Lisa M. Gatzke-Kopp, Human Development and Family Studies, Pennsylvania State University, USA.

Nilam Ram, Human Development and Family Studies, Pennsylvania State University, USA; German Institute for Economic Research (DIW), Germany.

David M. Lydon-Staley, Human Development and Family Studies, Pennsylvania State University, USA.

David DuPuis, ScribbleLive Inc., USA.

DOI: 10.1002/bdm