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Developmental differences in description-based versus experience-based decision making under risk in children



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ABSTRACT

The willingness to take a risk is shaped by temperaments and cognitive abilities, both of which develop rapidly during childhood. In the adult developmental literature, a distinction is drawn between *description-based* tasks, which provide explicit choice–reward information, and *experience-based* tasks, which require decisions from past experience, each emphasizing different cognitive demands. Although developmental trends have been investigated for both types of decisions, few studies have compared description-based and experience-based decision making in the same sample of children. In the current study, children ($N = 112$; 5–9 years of age) completed both description-based and experience-based decision tasks tailored for use with young children. Child temperament was reported by the children's primary teacher. Behavioral measures suggested that the willingness to take a risk in a description-based task increased with age, whereas it decreased in an experience-based task. However, computational modeling alongside further inspection of the behavioral data suggested that these opposite developmental trends across the two types of tasks both were associated with related capacities: older (vs. younger) children's higher sensitivity to experienced losses and higher outcome sensitivity to described rewards and losses. From the temperamental characteristics, higher attentional focusing was linked with a higher learning rate on the experience-based task and a bias to accept gambles in the gain domain on the description-based task. Our findings demonstrate the

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importance of comparing children's behavior across qualitatively different tasks rather than studying a single behavior in isolation.

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Introduction

A propensity for risk taking (e.g., an inclination to seek out novel or rewarding but potentially harmful experiences) is associated with maladaptive behavior during adolescence and adulthood, including smoking, drug use, and delinquency (e.g., Lejuez et al., 2002; Steinberg, 2007; but see also Duell & Steinberg, 2019, 2020). Although identifying the determinants of risk-taking propensity during childhood can provide valuable insight into the early development of risk-taking tendencies, most developmental research on risk taking has focused on adolescence and in particular whether risk-taking tendencies peak during that period (Rosenbaum & Hartley, 2019). This means that there is still much that is not known about the early development of decision making under risk. During childhood, temperaments emerge that later establish stable personality characteristics at a time that cognitive abilities (e.g., executive function) undergo rapid change (Rothbart, 2007; Somerville & Casey, 2010). It is likely that both developing temperaments and cognitive abilities influence emerging risk-taking behavior during childhood.

Studies of decision making under risk in adults have drawn a distinction between *description-based* decision tasks, which provide explicit choice-reward information, and *experience-based* tasks, which require decisions from past experience, emphasizing different cognitive demands (Brand & Markowitsch, 2010; Hertwig, Barron, Weber, & Erev, 2004; Rosenbaum & Hartley, 2019). In description-based tasks, participants may be asked to choose between a sure amount of \$5 and a lottery that offers a 50:50 chance to win \$10 or nothing. In experience-based tasks, participants must instead learn experientially that taking greater risks (e.g., by inflating a virtual balloon) is associated with greater potential reward but also greater potential loss. During adulthood, willingness to take a risk shows different developmental trajectories with age on experience-based and description-based tasks (Huang, Wood, Berger, & Hanoch, 2015; Mata, Josef, Samanez-Larkin, & Hertwig, 2011), and evidence is emerging that this is also the case with regard to developmental trajectories during adolescence (Rosenbaum, Venkatraman, Steinberg, & Chein, 2018, 2021). In the current research, we employed the distinction between description-based and experience-based decisions under risk to study age-related differences during childhood. Our aims were twofold: (a) to investigate age-related differences in experience-based and description-based tasks in the development of risky choice in children and (b) to investigate whether similar temperaments are associated with children's risky decisions from experience and description.

Description-based versus experience-based tasks

The distinction between experience-based tasks and description-based tasks is important for the study of the development of risk taking during childhood because research with adults suggests that these tasks make different demands on cognitive abilities (Henninger, Madden, & Huettel, 2010; Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008) and thus may show different developmental trajectories in risk taking. Consequently, a child who exhibits a propensity to take risks on one task might not necessarily exhibit similar risk-taking tendencies on another task, depending on the specific task demands. This means that studying children's behavior on a single decision task in isolation is likely to provide an incomplete account of the development of decision making under risk in children and miss valuable insights garnered from comparing behavior across qualitatively different tasks.

Description-based decision tasks provide explicit information about probabilities of gains and losses associated with choice options (Brand & Markowitsch, 2010; Glöckner & Pachur, 2012; Hertwig et al., 2004; Rolison & Pachur, 2017). Conversely, experience-based decision tasks do not

make explicit the outcome probabilities associated with choice options and emphasize decisions from past experience. For example, in the well-known Balloon Analogue Risk Task (BART), participants inflate a computer-generated balloon, earning a small reward for each pump they make (Lejuez et al., 2002). For any given pump made, however, the balloon may explode, and if participants have not already “cashed” their winnings, all earnings accrued on the balloon are lost and participants move on to inflate the next balloon. In the BART’s standard form, participants are not told the explicit choice–reward characteristics of the task, which they must learn from past experience.

Children’s performance on description-based tasks

In a series of studies, Levin and colleagues investigated developmental differences in children’s behavior on a description-based decision task (Levin & Hart, 2003; Levin, Hart, Weller, & Harshman, 2007; Levin, Weller, Pederson, & Harshman, 2007). In this task, children made choices between a sure amount and a lottery in the gain and loss domains. In their earlier studies, children chose between a sure gain (or loss) of one prize and a 50:50 chance to win (or lose) two prizes or nothing or a 20:80 chance to win (or lose) five prizes or nothing (Levin & Hart, 2003). Where individual differences in personality were also assessed, children (6–7 years of age) who were lower in shyness or higher in impulsivity, as reported by their parents, were more likely to choose the lottery, indicating a higher willingness to take a risk (Levin & Hart, 2003). Impulsivity is related to behavior on a variety of risky decision-making tasks during adolescence and adulthood (Lauriola, Panno, Levin, & Lejuez, 2014; Lejuez et al., 2002; Romer, 2010; Ryan, MacKillop, & Carpenter, 2013). Low shyness during childhood is likely to relate to higher openness to new experiences during adolescence and adulthood, where it is associated with greater risk-taking propensity (Lauriola & Levin, 2001; Nicholson, Soane, Fenton-O’Creedy, & Willman, 2005). Openness to experience can motivate risk-taking behavior through a greater willingness to explore or experiment and a greater acceptance of uncertainty and change (McCrae & Costa, 1997).

In a later study of description-based decision making, Levin et al. (2007) investigated whether children are sensitive to expected value differences between a sure amount (1 quarter) and a lottery, offering either a low ($p = .20$), medium ($p = .33$), or high ($p = .50$) probability of winning (or losing) a small (2 quarters), medium (3 quarters), or large (5 quarters) monetary amount, and thus offered an advantageous, equal, or disadvantageous alternative to the sure amount. This method afforded assessment of children’s ability to use expected value information to make adaptive decisions, precluded by earlier studies that compared a sure amount and a lottery of equal expected value (Levin & Hart, 2003; Reyna & Ellis, 1994; Schlottmann & Tring, 2005). Levin et al. (2007) observed that younger children (5–7 years) were less sensitive than older children (8–11 years) to expected value differences for risky gains and, to a lesser extent, for risky losses, indicating developmental age-related differences in children’s understanding of chance on a description-based decision task (see also Weller, Levin, & Denburg, 2011).

Children’s performance on experience-based tasks

Do children show developmental differences on experience-based decision tasks? Lejuez et al. (2007) developed a youth version of the BART for younger participants. In the youth version (BART-Y), points earned by pumping a virtual balloon are represented on a visual meter rather than appearing in a numerical format and are exchanged for prizes rather than money at the end of the task. Research to date using the BART-Y has focused on adolescents and has shown, for example, that greater willingness to take a risk on the task is associated with substance use, sexual behavior, and delinquency as well as sensation seeking and impulsivity (e.g., Amstadter et al., 2012; Lejuez et al., 2007). Although a small number of studies have assessed risk taking of children using versions of the BART (e.g., Lahat et al., 2012; Morris, Hudson, & Dodd, 2014; Morrongiello, Kane, McArthur, & Bell, 2012; Nystrom & Bengtsson, 2016), these studies typically focused on a single child age (but see Heffer & Willoughby, 2020). Most recently, however, Bell, Imal, Pittman, Jin, and Wexler (2019) created a version of the BART for use with children—the BART-C—and employed it with a very large sample of children and adolescents ranging from kindergarten age up to eighth grade. Their measure

of risk behavior—the number of pumps on trials in which the balloon did not explode—showed very few differences between kindergarten and Grade 3 (but increased subsequently into adolescence). However, the authors also calculated an alternative measure of “recklessness,” which examined whether children took risks without a payoff, and found that levels of recklessness decreased over this age range. This contrast in findings indicates that the pattern of age-related changes on this task might depend on which measure is used.

Indeed, there is an existing recognition in research with adult samples of the need to avoid reducing performance on the BART to a single measure such as number of pumps. Although developmental studies in the past have typically used the overall number of pumps on the task as their index of willingness to take a risk (e.g., [Lahat et al., 2012](#); [Lejuez et al., 2007](#)), this in fact conflates the learning and risk-taking propensity components of the task. In research with adults, the BART has been modeled using computational modeling techniques to decompose behavior on the task, mapping its separable learning and risk-taking propensity components ([Rolison, Hanoch, & Wood, 2012](#); [van Ravenzwaaij, Dutilh, & Wagenmakers, 2011](#); [Wallsten, Pleskac, & Lejuez, 2005](#); [Wichary, Pachur, & Li, 2015](#)). The value of such an approach has been to demonstrate that it is specifically the risk propensity components that are predictive of self-reported tendencies to engage in real-life risky behavior. To the best of our knowledge, however, there is no analysis to date of children’s performance on a version of the BART that has teased apart learning and risk-taking propensity.

The description–experience gap

In the literature on adults’ decision making under risk, it has become apparent that key characteristics of people’s decision making under risk depend on whether the outcomes and probabilities of choice options are described or learned from experience (e.g., [Barron & Erev, 2003](#); [Hertwig et al., 2004](#); [Kellen, Pachur, & Hertwig, 2016](#); [Rakow, Demes, & Newell, 2008](#); [Wulff, Mergenthaler-Canseco, & Hertwig, 2018](#)). In experiential tasks, rather than receiving descriptions of the outcomes and probabilities, participants typically acquire samples of outcomes of the choice options as a method of training them on the payoffs associated with each option. For example, participants may click on respective buttons to retrieve sampling of outcomes associated with each choice option before making a choice based on their experiences ([Hertwig et al., 2004](#)). A key finding to emerge from comparisons of choice behavior when outcomes are described versus experienced is that adult participants choose as if they underweight low-probability outcomes when these are learned experientially, which contrasts with a tendency to choose as if they overweight low-probability outcomes when these are described. There are a variety of possible explanations for this description–experience gap in choice, including the suggestion that in experiential tasks people typically rely on only a small number of samples when making a choice due to either insufficient sampling or unduly relying on the most recently observed outcomes ([Hertwig & Erev, 2009](#); [Wulff et al., 2018](#)).

It has been hypothesized that both children ([Rakow & Rahim, 2010](#); see also [Van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012](#)) and adolescents ([Rosenbaum et al., 2018](#)) may show a larger description–experience gap for cognitive and/or motivational reasons. On the basis that children are more limited in their processing capacity than adults, [Rakow and Rahim \(2010\)](#) hypothesized that children would exhibit a larger description–experience gap in their choice behavior than adults because they might draw on even smaller samples. Although a significant age difference in a description–experience gap was not in fact observed among children (9–11 years of age), adolescents, and adults, children made riskier decisions (i.e., accepting the lottery option) irrespective of whether the decisions were from description or from experience. Pertinent to our current research interests, children also differed from adolescents and adults in their sampling behavior; in the pre-choice phase during which they collected observations of the outcomes, children frequently alternated between the two options, whereas older participants tended to systematically make observations separately for each option ([Rakow & Rahim, 2010](#)). We note, however, that there is some evidence that, when free to terminate sampling, children under 10 years of age (but not adolescents) tend to sample as much as adults ([van den Bos & Hertwig, 2017](#)). Taken together, then, these findings at least point toward the possibility that children might have less effective learning processes (but see [Hills & Hertwig, 2010](#)), and thus might learn about payoffs less effectively in experienced-based decision tasks, even if they

actually observe as many samples as adults. Furthermore, learning from feedback may be even poorer among even younger children (e.g., 5–9 years), a possibility investigated in the current study.

The fact that experience-based tasks tap into both learning processes and a person's risk propensity raises the issue of how developmental patterns of performance on such decision-making tasks during childhood relates to patterns on description-based tasks that do not have the former component. One possibility is that children exhibit similar age-related differences across experience-based and description-based tasks in their propensity to take risks independent of age-related differences in their tendency to adjust behavior from experience. That is, there may be a core tendency to engage in risky decision making that will manifest itself regardless of the type of task and that will show a single developmental trajectory as well as similarly relating to other individual differences variables. If this is correct, then temperament characteristics associated with children's risk-taking propensity on description-based tasks, namely shyness and impulsivity (Levin & Hart, 2003; Levin et al., 2007), would be expected to relate specifically to the risk propensity component of experience-based tasks. Examining this issue, however, requires separating out the risk propensity component from the learning component of the tasks.

The current study

In the current study, we investigated age-related differences in decision making under risk among children on experience-based and description-based tasks, both created for the purpose of this study but with structural similarities to tasks previously used with children and adolescents. We focused on children aged 5 to 9 years because risky decision making has been studied much less frequently in this age group than in adolescents despite considerable developmental changes in cognitive processes across this developmental period. Importantly, we employed computational modeling to decompose behavior on the two types of tasks to investigate commonalities and differences in children's experience-based and description-based decision making under risk. This allowed us to examine whether children show similar developmental differences in experience-based and description-based risk-taking propensity and whether similar temperament characteristics are associated with children's decision making under risk based on experience and description.

Method

Participants

A total of 112 children aged 5 to 9 years (57% female; mean age = 7.06 year, $SD = 1.43$; $n_{5 \text{ years}} = 22$, $n_{6 \text{ years}} = 20$, $n_{7 \text{ years}} = 24$, $n_{8 \text{ years}} = 21$, $n_{9 \text{ years}} = 25$) completed an experience-based decision task and a description-based decision task (see "Materials and procedure" section for details) across two testing sessions completed on separate days. The two tasks were completed in a counterbalanced order across the two sessions. Prior to testing, we targeted a sample size of 20 children per age (in years), resulting in a larger sample size than previous studies that have assessed age differences in children's decision making under risk (e.g., Levin et al., 2007). Children were recruited from schools local to the university of the last author and were tested in a quiet area of their school.

Materials and procedure

Experience-based decision task (Hungry Squirrel task)

To assess decisions based on experience, we developed an alternative to the BART suitable for children as young as 5 years. In the BART, participants inflate a virtual balloon (Lejuez et al., 2007), but it is possible that children find the inflation of the balloon itself to be rewarding. If so, the activity of inflating a balloon in the BART-Y may for young children obscure the intended trade-off between inflating the balloon for a secondary reward (e.g., a prize at the end of the task) and the loss of reward by bursting it. Consequently, an association between child temperament and pumps made to the balloon on the BART may reflect play behavior rather than risk-taking propensity. In addition, in the BART, par-

ticipants can inflate the virtual balloon with up to 128 pumps. Yet, counting abilities are still developing in young children (e.g., Manfra, Dinehart, & Sembianti, 2014), which will place significant limitations on their ability to keep track of their pumps to balloons and to adjust behavior in response to past experience.

In our alternative task, children engaged with a computer-based video game. On each of 60 trials, an animated character named “Hungry Squirrel” appeared at the foot of a “Wobbly Bridge” that joined two rocky cliffs (Fig. 1A). The bridge consisted of 30 steps, each holding a single acorn. An important advantage of implementing the task in this way was that it enabled children to see visually on-screen the full range of steps (i.e., opportunities to take a risk) on the task, such that children could visually adjust their risk-taking behavior as a position on the bridge (farther to the left or right) rather than needing to keep count of their steps taken (Fig. 1A).

Children were told that the Hungry Squirrel is collecting acorns for winter and wants their help in collecting acorns on the Wobbly Bridge (see Appendix for participant instructions). They were told that if they collected enough acorns by the end of the game, they would win a party bag containing gifts. In fact, all children received the same party gift bag regardless of their performance on the task. On each trial, pressing a red key on the computer keyboard moved the squirrel forward along the bridge, collecting a single acorn with each keypress. As each acorn was collected, it fell into a net hung

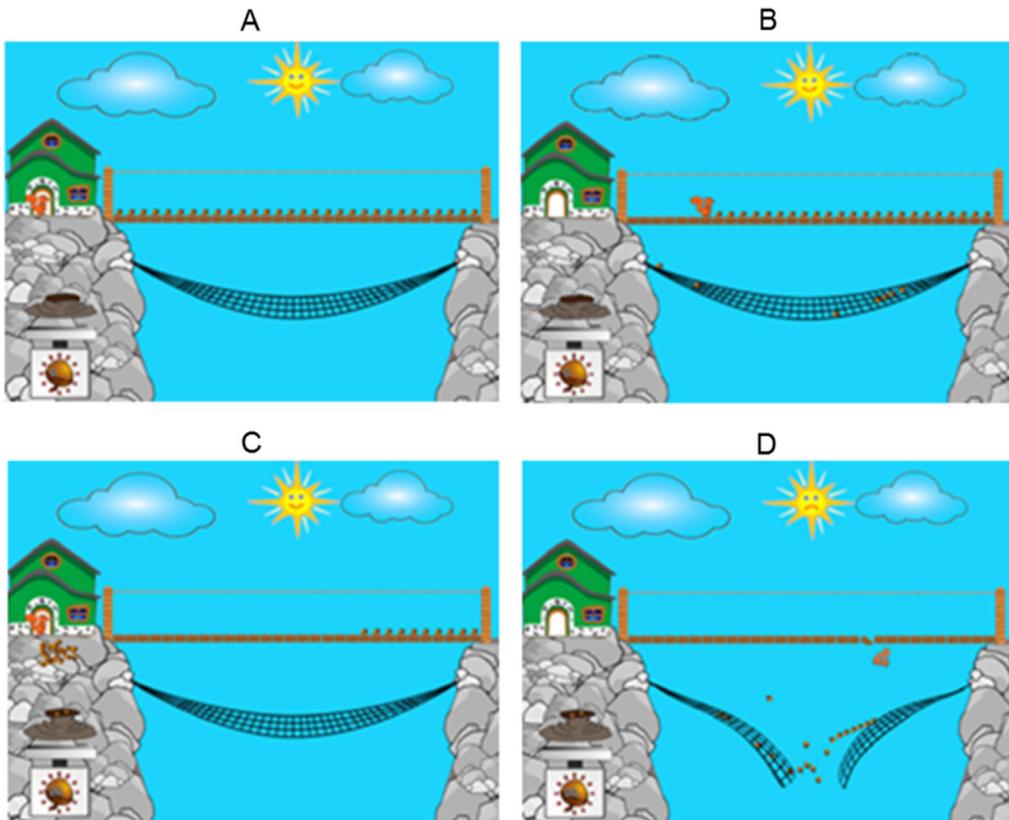


Fig. 1. Example displays of the experience-based decision task. (A) The animated squirrel appears at the foot of the Wobbly Bridge at the beginning of each trial. (B) A keypress is operated to move the squirrel along the steps of the bridge, collecting acorns that are caught in the net below. (C) The squirrel is returned to the base of the bridge with a keypress, banking the collected acorns in the sack and ending the trial. (D) If the squirrel is led onto a broken step, the squirrel falls from the bridge and the net breaks, dropping the acorns and ending the trial.

below the bridge (Fig. 1B). Pressing a green button returned the squirrel to the base of the bridge and banked the collected acorns in a sack, ending the trial (Fig. 1C). Each time acorns were banked, the sack filled and the counter below the sack updated. Children were told that on each trial one of the steps on the bridge might be broken and that if the squirrel is led onto a broken step, then all the acorns collected on the bridge would be lost. A broken step wobbled if stepped on, dropping the squirrel from the bridge, collapsing the net such that the collected acorns fell from the screen, and ending the trial (Fig. 1D). There were 60 trials, which included a broken step in each of the 30 positions on the bridge and 30 trials without a broken step. All children experienced the same 60 trials. Trials that did not have a broken step were included to ensure an adequate number of trials with which to assess children's unconstrained risk-taking on the task because losses constrain behavior. It was particularly important to avoid constraining behavior on the Hungry Squirrel task because the maximum number of steps (i.e., 30) was far lower compared with the BART (i.e., 128), substantially increasing the probability of a loss at low levels of risk taking. On the basis that on each trial any of the 30 steps could be broken, the optimal number of steps was 15. The trials were presented in a randomly generated order for each child with the exception that one of the trials without a broken step was always the first trial children experienced. This was done to ensure that children were not exposed to a loss at the outset of the first trial, which was likely due to the small number of steps contained on the bridge. An immediate loss on the first trial could discourage risk taking prior to an opportunity for learning.

Children received on-screen instructions and training to ensure that they understood the rules of the task (see Appendix). As part of the training, they were instructed to guide the squirrel across the bridge to collect 10 acorns to familiarize them with the computer controls. Children were then informed with on-screen instruction that one of the steps on the bridge may be broken on each trial and were shown three animated demonstrations. In the first animation, the squirrel stepped on a broken step following 10 steps, after which written instruction appeared explaining that the acorns were lost. In a second animation, the squirrel collected and banked 20 acorns, after which written instruction appeared explaining that the squirrel decided to return before reaching a broken step. In a final animation, the squirrel stepped on a broken step in the final step position, after which written instruction appeared reminding children that one of the steps may be broken. Children who were not able to read the on-screen instructions were read the instructions by the experimenter. The experimenter sat beside children during the testing to assist and answer questions.

Description-based decision task (Pirate task).

This task was structurally identical to the cups task developed by Levin et al. (2007), enabling us to assess children's sensitivity to expected value differences between a sure amount and a lottery. Children made risky choices in the domain of gains and losses set in the context of a computerized task involving a pirate (see Appendix for participant instructions). On gain sets (Fig. 2A), children could choose between a sure gain of one coin (Fig. 2A, left) and a gamble (Fig. 2A, right) that offered a low (five chests; $p = .20$), medium (three chests; $p = .33$), or high (two chests; $p = .50$) probability of winning a small (two coins), medium (three coins), or large (five coins) amount. The gamble amount was indicated by a thought bubble that appeared above the corresponding pirate. Choices were made by clicking on a chest. If coins were won, the selected chest and the chest in the center of the monitor, which contained the accrued coins, would open and the corresponding pirate moved to the center chest to deliver the earned coins. On loss sets (Fig. 2B), children chose between a sure loss and a gamble that offered a low, medium, or high probability of losing a small, medium, or large amount that corresponded to the amounts and probabilities on gain sets. Losses were represented by skulls, each equaling a loss of one coin. If a skull was revealed by selecting the sure loss or gamble, the corresponding pirate moved to the center chest and removed the corresponding number of coins. Gain and loss sets each consisted of the nine combinations of the three levels of amount and probability. The gain and loss sets were each presented three times in random order, with the exception that sets followed a gain then loss sequence. Children made 54 choices in total. In gain and loss sets, the lottery option was optimal for one third of trials, the sure option was optimal for one third trials, and for the remaining trials the lottery and sure option had equal expected values. Thus, an expected value maximizing strategy would predict the lottery option on half the trials. As in the experience-based decision task, children were told that if they earned enough coins by the end of the game, they would win a party



Fig. 2. Example displays of the description-based decision task. (A) On gain trials, children chose between a sure gain of one gold coin (left) and a two-, three-, or five-coin lottery gain (right). (B) On loss trials, children chose between a sure loss of one gold coin, represented by a skull (left), and a two-, three-, or five-coin lottery loss (right). The number of chests indicates the probability of a lottery gain or loss as two ($p = .50$), three ($p = 0.33$), or five ($p = .20$) chests.

bag containing gifts. All children in fact received the same party gift bag regardless of their performance on the task.

Teacher report

The teacher of each child completed the teacher version of the Children's Behavior Questionnaire (Putnam & Rothbart, 2006; Rothbart, Ahadi, Hershey, & Fisher, 2001) to assess children's temperament. We used a modified version of the scale for our current purposes by selecting the six most relevant subscales of the short version of the questionnaire (Putnam & Rothbart, 2006). Each subscale contained six statements. Teachers were asked to rate how well each statement described a child on a 7-point scale (1 = *extremely untrue of this child*, 2 = *quite untrue of this child*, 3 = *slightly untrue*

of this child, 4 = neither true nor false of this child, 5 = slightly true of this child, 6 = quite true of this child, 7 = extremely true of this child). The subscales assessed anger/frustration (Cronbach's $\alpha = .92$; e.g., gets angry when he/she has to remain still during rest time), attentional focusing (Cronbach's $\alpha = .87$; e.g., when practicing an activity, has a hard time keeping his/her mind on it), high-intensity pleasure (Cronbach's $\alpha = .80$; e.g., likes to play so wild and recklessly that he/she might get hurt), impulsivity (Cronbach's $\alpha = .73$; e.g., usually rushes into an activity without thinking about it), inhibitory control (Cronbach's $\alpha = .90$; e.g., can wait before entering into new activity if he/she is asked to do so), and shyness (Cronbach's $\alpha = .86$; e.g., is sometimes shy even around people he/she has known a long time). Mean scores were used as measures of temperament in each subscale.

Results

Experience-based decision making

Overall willingness to take a risk

We used children's mean adjusted number of steps taken on the task as a measure of overall risk taking. The mean adjusted steps excluded trials on which children lost their earnings because these trials constrain risk taking on the task (i.e., the number of steps that children could take). The same adjustment was used to measure overall willingness to take a risk on other versions of the BART (Bell et al., 2019; Lejuez et al., 2002, 2007). Fig. 3 shows the number of steps taken in each block of the Hungry Squirrel task separately for each age group. The dashed line indicates the number of steps expected under risk-neutral behavior, which optimizes earnings on the task (i.e., on the basis that on each trial any of the 30 steps could be broken; the optimal number of steps was 15). As can be seen, whereas in most age groups children took more steps than expected under risk neutrality—thereby indicating risk seeking—as they progressed across blocks the older children, but not the younger children, seemed to reduce the number of steps. To evaluate the patterns statistically, we conducted a

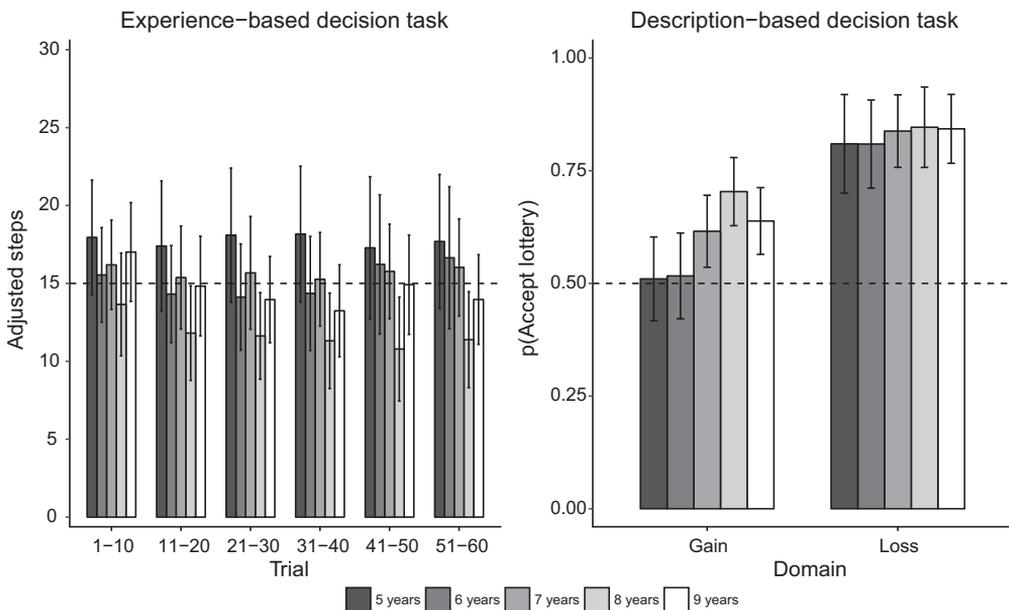


Fig. 3. Mean group adjusted steps taken on the experienced-based task (Hungry Squirrel) and mean group lottery acceptance on the description-based task (Pirate) according to child age in years. The dashed lines indicate risk-neutral (i.e., optimal) behavior. The vertical bars indicate 95% confidence intervals.

mixed-effects linear regression analysis on mean-adjusted steps, including age (continuous), gender (male or female), and block (10-trial blocks) as predictors. Continuous predictors were mean centered. Random intercepts were included for participants. In a second block, we included an interaction term involving age and block. There were no effects of age ($b = -0.91, t = 1.91, p = .059$), gender ($b = 0.18, t = 0.13, p = .898$), or block ($b = -0.13, t = 1.51, p = .133$). However, age interacted with block ($b = -0.15, t = 2.55, p = .011$). Simple slopes analysis revealed that older children (1 SD above mean age, $b = -0.35, t = 2.87, p = .004$), but not younger children (1 SD below mean age, $b = 0.09, t = 0.73, p = .465$), took fewer steps with experience. Consequently, whereas younger and older children did not differ in terms of the number of steps taken in the first block ($M_{\text{younger}} = 16.47, M_{\text{older}} = 14.34; b = -0.53, t = 1.06, p = .291$), older children took significantly fewer steps than younger children in the final block ($M_{\text{younger}} = 17.39, M_{\text{older}} = 12.22; b = -1.29, t = 2.58, p = .011$).

We conducted the mixed-effects linear regression analysis also on the number of losses (i.e., broken steps stepped on) children experienced on the task. This analysis showed a significant effect of age ($b = -0.16, t = 2.02, p = .046$), such that older children (1 SD above mean age, $M = 2.38$) experienced fewer losses than younger children (1 SD below mean age, $M = 3.03$) per 10-trial block. This finding reflects younger children's tendency toward taking more steps (see Fig. 2), although this effect was not significant in our above analysis of adjusted steps. There was also a significant effect of block ($b = 0.07, t = 2.50, p = .013$) and no significant effect of gender ($b = 0.03, t = 0.11, p = .911$). As with children's adjusted steps, age interacted with block ($b = -0.05, t = 2.39, p = .017$). Simple slopes analysis showed that although younger and older children did not differ significantly in the number of losses they experienced in the first block ($M_{1 \text{ SD below mean age}} = 2.61, M_{1 \text{ SD above mean age}} = 2.43; b = -0.04, t = 0.46, p = .646$), older children experienced significantly fewer losses than younger children in the final block ($M_{1 \text{ SD below mean age}} = 3.46, M_{1 \text{ SD above mean age}} = 2.33; b = -0.28, t = 2.98, p = .004$). These latter findings dovetail with our analysis of children's number of adjusted steps, such that younger children experienced more losses than older children in the final block as a consequence of their greater risk seeking.

Computational modeling

To decompose the cognitive processes contributing to children's behavior on the task, we used a computational model developed by Wallsten et al. (2005) for the BART, which is structurally very similar to the Hungry Squirrel task. We refer to this model (which was the best-performing Model 3 in Wallsten et al.'s model comparison) as the *Wallsten model*. Applied to the Hungry Squirrel task, the Wallsten model assumes that for each step made on the bridge there is a constant subjective probability that the step will wobble (i.e., of losing). This subjective probability (or belief) on a given bridge h , q_h , is represented as a beta distribution and the mean of the distribution q_h , which is summarized by the two parameters $a_h > 0$ and $b_h > 0$ (see Pleskac, 2008; Pleskac & Wershba, 2014):

$$\hat{q}_h = \frac{a_h}{a_h + b_h}. \quad (1)$$

The initial belief at the first bridge—that is, q_1 —is estimated from the data (based on estimated values of a_1 and b_1). The variance of the beta distribution, which can be interpreted as indicating the decision maker's uncertainty in the belief, is defined as

$$\delta_h = \frac{a_h b_h}{(a_h + b_h)^2 (a_h + b_h + 1)}. \quad (2)$$

Larger values of δ translate into a greater adjustment after experiencing the trial outcome (i.e., whether the step wobbles or not); therefore, the δ parameter can be viewed as a learning rate, with larger values indicating stronger learning. The δ values were log-transformed for ease of interpretation.

The Wallsten model further assumes that for each trial (i.e., bridge) there is a target number of steps, G_h , which is determined based on q_h and a risk aversion parameter γ^+ :

$$G_h = \frac{-\gamma^+}{\ln(\hat{q}_h)}. \quad (3)$$

Higher values of γ^* indicate a greater tendency to take another step. The probability of taking another step at step i , p_i , is a function of the difference between the target number of steps and the number of steps taken so far:

$$p_i = \frac{1}{1 + e^{\phi(i-G_n)}}, \quad (4)$$

where ϕ is a free parameter representing how consistently participants follow their target number of steps (i.e., G_n). Lower values of ϕ indicate that the decision maker's tendency to take another step is sensitive to other information besides his or her targeted number of steps (or is just noisy) and that thus the behavior will be more variable.

The Wallsten model further assumes that after each trial the subjective probability of a step wobbling is updated based on the experience at the previous trial (i.e., the number of steps taken and whether the final step wobbled or not). This updating is implemented within the beta distribution as follows: After each trial h , parameter b in Eq. (1) is increased by 1 if the final step wobbled (i.e., $b_{h+1} = b_h + 1$). Otherwise, b_h is not increased (i.e., $b_{h+1} = b_h$). The parameter a in Eq. (1) is increased by the total number of steps that did not wobble on the previous trial, c_h : $a_{h+1} = a_h + c_h$. If the final step on trial h did wobble, a is increased as $a_{h+1} = a_h + c_h - 1$.

To estimate the parameters of the Wallsten model, we used a Bayesian hierarchical approach. With the Bayesian approach, prior distributions for the model parameter estimates are updated in light of the observed behavior to produce posterior distributions for the parameters (see Lee & Wagenmakers, 2014). In a hierarchical model, the individual-level parameters are drawn from a group-level distribution (separately for each model parameter). The group level of our model spanned all age groups. An advantage of a hierarchical approach is that the individual-level parameter estimates are constrained by the group distribution, producing more reliable individual-level estimates than if the model were estimated separately for each participant. The model parameters were estimated with Monte Carlo Markov chain (MCMC) sampling implemented in JAGS called from the R package *R2jags* (Sturtz, Ligges, & Gelman, 2005). We took a total of 1,000,000 samples on each of 15 chains, with every fifth sample recorded. A burn-in period discarded the first 2,000 samples of each chain. Visual inspection of the MCMC samples indicated that the chains mixed well, also confirmed by \hat{R} values < 1.01 , indicating convergence (Gelman & Rubin, 1992). The number of effective samples was at least 10,000 for 92.2% of the estimated individual-level parameters (with a median of 150,000 samples).

To statistically evaluate whether there are age differences in the model parameter values, we conducted a multiple linear regression analysis for each individual-level parameter, including age (as continuous) and gender (male or female) as predictors. There were no age differences in the q_{init} parameter, that is, the prior beliefs about the probability that a step would wobble on the first trial (1 SD above and below mean age, $M_{younger} = .979$, $M_{older} = .980$; $b = 0.00$, $t = 1.19$, $p = .239$) nor on the learning rate [$\log(\delta)$; $M_{younger} = -11.51$, $M_{older} = -11.28$; $b = 0.08$, $t = 0.44$, $p = .660$], behavioral consistency (ϕ ; $M_{younger} = 0.48$, $M_{older} = 0.31$; $b = -0.06$, $t = 1.82$, $p = .069$), and risk aversion (γ^* ; $M_{younger} = .62$ vs. $M_{older} = .53$; $b = -0.03$, $t = 1.83$, $p = .070$). Note that the age differences visible in the children's behavior in Fig. 3 might be "smeared out" across the behavioral consistency and the risk aversion parameters, which are often structurally interdependent (e.g., Krefeld-Schwab, Pachur, & Scheibehenne, 2022; van Ravenzwaaij, Dutilh, & Wagenmakers, 2011). There were no gender differences on any of the parameters.

Teacher reports

To test for associations between children's temperament and their behavior on the experience-based decision task, we conducted partial Pearson r correlations including the six temperaments (i.e., anger/frustration, attentional focusing, intensity pleasure, impulsivity, inhibitory control, and shyness), adjusted steps on the task, and the parameters of the Wallsten model. The partial correlations controlled for child age and gender. In inspecting Table 1, shyness (but not other temperaments) was associated with overall adjusted steps on the task, with greater shyness associated with taking fewer steps. Significant correlations also emerged for the model parameters. The temperamental variable attentional focusing was positively associated with a higher learning rate [$\log(\delta)$] but less consis-

tent behavior (ϕ). Higher impulsivity was associated with a lower learning rate. Finally, higher inhibitory control was associated with a higher learning rate and less consistent behavior.

Description-based decision making

First, we examined children's acceptance rates for the lottery option as an index of willingness to take a risk. Fig. 3 displays the mean lottery acceptance rate in the gain and loss domains separately for each age group and separately for the gain and loss domains. On an equal number of trials, the lottery option had a higher, lower, or equal expected value to the sure option, and thus the optimal rate of lottery acceptance was .50. The acceptance rate increased with age in the gain domain but not in the loss domain (Fig. 3). Overall, nearly all age groups showed clear indication of risk-seeking behavior, as indicated by an acceptance rate that exceeded .50. We conducted a mixed-effects logistic regression analysis on children's choices, including age (continuous), gender (male or female), and domain (gain or loss) as predictors. Continuous predictors were mean centered. Random intercepts were included for participants to account for repeated measurements within participants. In a second block, we included an interaction term involving age and domain. Children were significantly more likely to accept the lottery option in the loss domain ($M = .86$) than in the gain domain ($M = .61$) ($b = 1.33, t = 20.41, p < .001$). Older children were more likely than younger children to accept the lottery option (1 *SD* above and below mean, $M_{\text{younger}} = .69, M_{\text{older}} = .81; b = 0.15, t = 2.59, p = .010$). There was no significant effect of gender ($b = 0.06, t = 0.37, p = .715$). Age interacted with domain ($b = -0.14, t = 3.08, p = .002$). Fig. 3 provides the mean probability of lottery acceptance in the gain and loss domains according to child age. Likelihood of lottery acceptance increased with age in the gain domain but not in the loss domain (Fig. 3). Follow-up analysis confirmed that older children were significantly more likely than younger children to choose the lottery option in the gain domain ($b = 0.22, t = 3.55, p < .001$) but not in the loss domain ($b = 0.06, t = 0.43, p = .668$).

To test whether higher lottery acceptance among older children reflected higher decision quality, we conducted our mixed-effects logistic regression analysis on whether children chose the advantageous choice option on trials where the lottery and sure amount differed in their expected values (18 gain trials or 18 loss trials). Age (continuous), gender (male or female), and domain (gain or loss) were included as predictors, and continuous predictors were mean centered. Random intercepts were included for participants. In a second block, we included an interaction term involving age and domain. Children exhibited significantly higher decision quality in the gain domain ($M = .58$) than in the loss domain ($M = .51$) ($b = -0.28, t = 4.40, p < .001$). Older children exhibited significantly higher decision quality than younger children (1 *SD* above and below mean, $M_{\text{younger}} = .51, M_{\text{older}} = .58; b = 0.07, t = 2.98, p = .003$). There was no significant effect of gender ($b = 0.02, t = 0.34, p = .734$) and no significant interaction between age and domain. Thus, older children's higher likelihood of accepting the lottery option appears to partially reflect higher decision quality.

Computational modeling

We decomposed children's behavior on the description-based task with an expected utility (EU) model. According to the model, the subjective valuation of an Option A (which has N outcomes) is determined as $V(A) = \sum_{i=1}^N u(x_i) \times p_i$, where x is the outcome and p is the probability of the outcome. The utility u of an amount x is determined by the utility function (applied separately for gains and losses), such that

$$u(x) \begin{cases} x^\alpha, & \text{if } x \geq 0 \\ -|x|^\beta, & \text{if } x < 0 \end{cases} \quad (5)$$

where α and β are free parameters that define the shape of the utility function for gains and losses, respectively. In the gain domain, a value of 1 of the α parameter indicates a neutral (i.e., unbiased) attitude toward risk and hence indifference between a sure amount and a lottery of the same magnitude of expected value. Values above 1 indicate a risk-seeking attitude, and values below 1 indicate a risk-averse attitude. Conversely, in the loss domain, values below 1 indicate a risk-seeking attitude, and values above 1 indicate a risk-averse attitude. The valuations of a risky option R and a safe option S

Table 1
Pearson correlations between the different measures.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<i>Teacher report</i>																
1. Anger/frustration	-															
2. Attentional focusing	-.51 ^{***}	-														
3. High-intensity pleasure	.28 ^{**}	-.34 ^{***}	-													
4. Impulsivity	.50 ^{***}	-.57 ^{***}	.58 ^{***}	-												
5. Inhibitory control	-.60 ^{***}	.84 ^{***}	-.44 ^{***}	-.65 ^{***}	-											
6. Shyness	-.15	.16	-.32 ^{**}	-.54 ^{***}	.26 ^{**}	-										
<i>Experience-based task</i>																
7. Adjusted steps	-.05	-.08	.01	.11	-.12	-.23 [*]	-									
8. γ^+	-.01	-.04	.15	.09	-.01	-.08	.53 ^{***}	-								
9. q_{init}	-.01	.05	.03	.00	-.03	.00	-.22 ^{**}	-.45 ^{***}	-							
10. $\text{Log}(\delta)$	-.07	.29 [*]	-.07	-.29 ^{**}	.28 ^{**}	.16	-.50 ^{***}	-.12	-.02	-						
11. ϕ	.13	-.30 ^{**}	-.06	.16	-.28 ^{**}	-.18	.54 ^{***}	-.11	-.05	-.62 ^{***}	-					
<i>Description-based task</i>																
12. Number of accepted gambles	-.15	.17	-.02	-.13	.12	-.06	.01	-.02	-.08	-.04	.01	-				
13. α	.04	.10	.06	.01	.03	-.04	.08	.03	-.14	-.08	.08	.32 ^{**}	-			
14. β	-.14	.06	-.08	.01	.03	-.02	-.06	-.19 [*]	.02	.14	.11	-.19 [*]	.09	-		
15. b^+	-.18	.19 [*]	.02	-.05	.13	-.22 [*]	.03	-.07	.00	-.01	-.01	.74 ^{***}	.26 ^{**}	.01	-	
16. b^-	-.08	.07	-.06	-.16	.06	.11	-.04	.02	-.09	-.02	.01	.79 ^{***}	.08	-.26 ^{**}	.18	-
17. ϕ	.07	.02	.02	.03	.02	.01	.01	-.07	-.11	-.08	.17	.11	.75 ^{***}	.36 ^{***}	-.03	.08

Note. All correlations controlled for individual differences in child gender and age.

- ^{*} $p \leq .05$.
- ^{**} $p \leq .01$.
- ^{***} $p \leq .001$.

in a choice problem were entered into a choice rule to determine the choice probability of choosing the more risky option:

$$p(R, S) = \frac{1 + |b|}{1 + e^{-\phi(V(R) - V(S))}} + \max(0, b), \quad (6)$$

where ϕ is a choice consistency parameter, with higher values indicating more consistent choices, and b is a response bias parameter, $b \in [-1, 1]$. It allows capturing a bias to choose the risky or the safe option irrespective of the valuation of the options (cf. Rutledge, Skandali, Dayan, & Dolan, 2015). A positive value of b indicates a bias toward choosing the risky option, whereas a negative value of b indicates a bias toward choosing the safe option. b was estimated separately for the gain and loss domains. Overall, thus, the EU model had five parameters (α , β , ϕ , b^+ , and b^-).

As for the computational modeling analysis of the Hungry Squirrel task, the parameters of the EU model were estimated using a Bayesian hierarchical approach, with a group-level distribution estimated across children of all age groups. For parameter estimation, we used MCMC sampling implemented in JAGS called from the R package *R2jags* (Sturtz et al., 2005). We took a total of 1,000,000 samples on each of 12 chains, with every fifth sample recorded. A burn-in period discarded the first 2000 samples of each chain. Visual inspection of the samples indicated that the chains mixed well, also confirmed by \hat{R} values < 1.01 , indicating convergence (Gelman & Rubin, 1992). The effective sample size was at least 14,000 for each estimated parameter (with a median of 310,000 samples).

To assess age differences on the EU model parameters, we conducted multiple linear regression analyses on each parameter, including age (continuous) and gender (male or female) as predictors. Older children exhibited significantly higher α values than younger children (1 SD above and below mean, $M_{\text{younger}} = 1.12$, $M_{\text{older}} = 1.36$; $b = 0.08$, $t = 12.04$, $p < .001$), indicating greater risk-seeking tendencies among older children than among younger children in the gain domain. Older children also exhibited significantly higher β values (1 SD above and below mean age, $M_{\text{younger}} = 1.01$, $M_{\text{older}} = 1.09$; $b = 0.03$, $t = 5.51$, $p < .001$), indicating greater risk aversion among older children than among younger children in the loss domain. Furthermore, male children exhibited a greater risk-seeking tendency than female children in the gain domain (α , $M_{\text{male}} = 1.27$, $M_{\text{female}} = 1.22$; $b = 0.05$, $t = 2.54$, $p = .011$).

Regarding response bias (i.e., b^+ and b^-), older children exhibited a stronger tendency to accept the lottery option than younger children in both the gain domain (1 SD above and below mean age, $M_{\text{younger}} = 0.02$, $M_{\text{older}} = 0.19$; $b = 0.06$, $t = 8.46$, $p < .001$) and the loss domain (1 SD above and below mean, $M_{\text{younger}} = 0.66$, $M_{\text{older}} = 0.71$; $b = 0.02$, $t = 1.99$, $p = .046$). Male children were more likely than female children to accept the lottery option in the gain domain ($M_{\text{male}} = 0.14$, $M_{\text{female}} = 0.07$; $b = 0.07$, $t = 3.52$, $p < .001$) but were less likely to accept the lottery option in the loss domain ($M_{\text{male}} = 0.65$, $M_{\text{female}} = 0.71$; $b = -0.07$, $t = 2.83$, $p = .005$).

Finally, behavioral consistency (ϕ) increased with age (1 SD above and below mean age, $M_{\text{younger}} = 0.33$, $M_{\text{older}} = 0.41$; $b = 0.03$, $t = 9.67$, $p < .001$) and was higher among male children ($M = 0.39$) than among female children ($M = 0.36$) ($b = 0.03$, $t = 3.90$, $p < .001$).

Teacher report

Table 1 reports the partial correlations between child temperament and description-based decision making, controlling for age and gender. There was an association between attentional focusing and response bias (b^+) in the gain domain, whereby higher attentional focusing was associated with higher tendencies to accept the lottery option. In addition, higher shyness was associated with lower response bias in the gain domain (b^+) and thus lower tendencies to accept the lottery option. The teacher-reported temperament showed no association with any other measure of behavior in the description-based task.

Associations between experience-based decision making and description-based decision making.

In inspecting Table 1, lower risk aversion (γ^+) on the experience-based task was associated with a more risk-seeking attitude in the loss domain (β) on the description-based task. There were no other significant associations between the two tasks.

Discussion

Decision making under risk is investigated with both description-based tasks, where all relevant information about the options is directly provided to the decision maker, and experience-based tasks, where relevant properties of the options need to be learned from experiential sampling. Previous studies on decision making under risk have typically probed children's behavior on each of these tasks in isolation, making it difficult to directly contrast potential age trends across these tasks and also to determine whether individual differences in one type of task will map on to those in the other type. Given that description-based and experience-based tasks impose partially different requirements on the decision maker, developmental trends might not manifest in the same way across both types of tasks. We compared age-related differences in behavior on experience-based and description-based tasks to identify commonalities and differences in children's risky decision making across qualitatively different tasks. Our experience-based task was an alternative to the BART (Lejuez et al., 2002, 2007), which we designed for use with young children. Our description-based task was based on the cups task, a task developed for young children by Levin et al. (2007) that assesses children's risky choices of a lottery over a sure amount. In both instances, the tasks were set in a narrative context to facilitate children's understanding of and engagement with the task. We used a computational modeling approach in order to more closely inspect developmental patterns of performance on our tasks.

Although in both tasks the children showed, on the aggregate level, risk-seeking behavior, there was also a considerable discrepancy in children's behavioral tendencies and age trends across the two tasks. On the experience-based task (Hungry Squirrel), older children took fewer risks than younger children, reducing their risk taking with experience on the task. Computational modeling suggested that younger and older children had similar initial beliefs about the probability that risk taking would lead to a loss. One interesting possibility is that younger children's greater risk taking on the Hungry Squirrel task may partly reflect more extensive search behavior. Developmental studies indicate that young children are more inclined to *explore* new environments than *exploit* them for their potential rewards, reflecting a desire to learn about their environment (Liquin & Gopnik, 2022; Sumner, Steyvers, & Sarnecka, 2019). This curiosity-driven exploration is important for a child's learning and development (Liquin & Lombrozo, 2020) but may appear as a risk-seeking tendency in novel risky environments such as the Hungry Squirrel task.

Our computational modeling did not reveal age differences in the learning rate, as may have been suggested by older children's reduction in risk taking with experience (see left-hand side of Fig. 3). In the computational model, the learning rate parameter captures behavioral adjustments toward optimal (i.e., risk-neutral) behavior. Analysis of the behavioral data showed that across trials older children reduced their risk taking *below* the optimal level, exhibiting more risk-averse behavior with experience of the task. Hence, the behavioral data suggest that older children were more sensitive to experienced losses relative to experienced gains than prescribed by an optimal model. Conversely, younger children continued to exceed the optimal level of risk taking even with experience of the task, indicating little sensitivity to experienced gains and losses. Thus, in the experience-based decision task, children showed an age-related *decrease* in risk-taking propensity, albeit in the direction of risk-averse behavior rather than optimal behavior.

On the description-based task (Pirate task), conversely, older children more frequently accepted the lottery option than younger children, implying an age-related *increase* in risk taking. However, the effect of age interacted with domain; older children were more likely than younger children to choose the lottery option in the gain domain but not in the loss domain. This finding was reflected in our expected utility model analysis with respect to the estimated curvature of the value function for children's risky choices. Age differences in the value function indicated that older children were more sensitive than younger children to anticipated gains and losses, associated with more risk-seeking attitudes with age in the gain domain and more risk-averse attitudes with age in the loss domain. Analysis of children's decision quality (i.e., whether they chose the choice option with the higher expected value) also indicated higher decision quality among older children. This latter finding resonates with that of Levin et al. (2007; see also Weller et al., 2011), who found that older children were more sensitive than younger children to expected value differences between choice options.

Taken together, our findings imply a general age-related difference underlying behavior on both the experience-based task and the description-based task. In general, older children appear to be more sensitive than younger children to differences in the experienced outcomes in the experience-based task and the anticipated outcomes in the description-based task. Hence, the apparent disparity in age-related differences in decision making under risk between the experience-based task and the description-based task appears to reflect an age-related difference in sensitivity to outcomes. An advantage of the computational modeling approach is that it allows reaching a more nuanced conclusion about developmental patterns on decision-making tasks rather than using a single measure from each task (steps or lottery choices) to infer the developmental profile of risk taking.

The commonalities and differences we observed between experience-based and description-based tasks are informative to future developmental research. First, using a single decision task in isolation as a proxy for willingness to take a risk may provide an incomplete account of a child's risk propensity. This point echoes words of caution in the literature on risk preferences in adults where only weak correlations have been reported between behavioral decision-making tasks (e.g., Frey, Pedroni, Mata, Rieskamp, & Hertwig, 2017) and in the adolescent literature where inconsistent developmental patterns have been reported across different tasks (Rosenbaum et al., 2018). In research with children, where it is important to identify early precursors to later development of maladaptive behaviors during adolescence (e.g., Rose, Picci, & Fishbein, 2019), future research is likely to benefit from using more than one measure of risk preference. For instance, different measures of risk taking across different decision-making tasks may map onto distinct developmental trajectories of maladaptive behaviors (e.g., substance use, delinquency) or be differentially related to cognitive, motivational, or affective factors developmentally (Rosenbaum et al., 2018). Indeed, we found that individual differences in experience-based and description-based decision making under risk were associated with different aspects of child temperament. Second, computational modeling provided insights into fine-grained components of children's behavior that complemented our inspections of the behavioral data. This approach also enabled us to explore associations between components of behavior (e.g., willingness to take a risk) that were common to both the experience-based and description-based tasks. Although several studies have employed computational modeling to decompose adult decision making under risk (e.g., Rolison, Hanoch, & Gummerum, 2013; van Ravenzwaaij et al., 2011; Wallsten et al., 2005; Wichary et al., 2015), this approach has not been exploited to the same extent in the child development literature. Our findings show that computational modeling provides a promising and fruitful method for better understanding how decision making under risk develops during childhood.

It is important to note that in both tasks children of all ages did not exhibit the typical pattern of risk-averse behavior usually observed among adults (Hertwig et al., 2004; Rolison et al., 2012). Levin et al. (2007) similarly observed that children, even as old as 9 to 11 years, made riskier choices than adults on the description-based task used here (see also Rakow & Rahim, 2010). Risky choices among children may partly reflect poor calibration of the weighting of outcome probabilities for the lottery option (Harbaugh, Krause, & Vesterlund, 2002). Developmental differences in the weighting of outcome probabilities may also help to explain why we did not observe the typical risk-averse pattern of adults' behavior on the experience-based task. In addition, in our modified version of the BART, which we tailored for studying experience-based decisions among young children, optimal (i.e., risk-neutral) behavior was achieved by making 15 steps on an animated bridge rather than 64 pumps to a virtual balloon (i.e., the BART; Lejuez et al., 2002, 2007) or 38 puffs to a virtual bubble on the BART-C (Bell et al., 2019). This task feature is likely to have shifted behavior closer to the optimal level given that it was achieved with far fewer steps on the bridge than pumps to the balloon in the standard BART.

A strength of directly contrasting experience-based and description-based tasks within the same sample of children is that this enabled us to also test for associations in risk-taking behavior between these two types of decision tasks. Our behavioral measures of overall willingness to take a risk did not reveal any associations between the two tasks (i.e., adjusted steps did not correlate with number of times the lottery option was chosen). However, our computational modeling revealed that higher risk-taking propensity (γ) on the experience-based task was associated with a more risk-seeking attitude in the loss domain (β) on the description-based task. This finding suggests that risk taking on the experience-based task among children with a high risk-taking propensity may reflect a general

disposition to take greater risks despite large potential losses, as indicated by their risk-seeking tendencies in the loss domain when making decisions from description. This finding also further supports our conclusion of a general underlying age-related difference in sensitivity to gains and losses. As discussed earlier, older children's reduction in risk taking with learning on the experience-based task implies greater sensitivity to experienced losses relative to experienced gains than prescribed by an optimal model.

Our conclusions regarding developmental differences in sensitivity to gains and losses resonate with reinforcement sensitivity theory (RST; Gray, 1982). According to RST, two neurological systems are separately activated by rewarding and aversive stimuli and undergo developmental changes during childhood and adolescence. The Behavioral Approach System (BAS) reacts to rewarding or appetitive stimuli, whereas activity in the Behavioral Inhibition System (BIS) is instead triggered by aversive stimuli. Activation of the BAS, triggered by rewards, is associated with impulsive and approach behavior. Conversely, activation of the BIS, triggered by aversive stimuli, is associated with avoidance behavior and inhibition. A large body of research, using self-report and parent-report scales, has identified associations between BAS activation and externalizing problems (e.g., hyperactivity) and BIS activation and internalizing problems (e.g., anxiety) in children and adolescents (e.g., Blair, Peters, & Granger, 2004; Muris, Meesters, De Kanter, & Timmerman, 2005; Sportel, Nauta, de Hullu, & de Jong, 2013). In one study, Pagliaccio et al. (2016) observed age-related increases in BIS and BAS activation from 6 years of age to young adulthood but relatively larger age-related increases in BIS activation than in BAS activation. The age-related decrease in risk-taking behavior we observed on the experience-based task may reflect the relatively larger increases in BIS activation than in BAS activation with age. The age-related increases in sensitivity to gains and losses on the description-based task may reflect associated developmental changes in BIS and BAS activation. Future research could seek to examine whether individual differences in BIS/BAS activation are associated with experience-based and description-based decision making among children.

Do similar temperaments correlate with children's decisions based on experience and description? Using teacher ratings, we found that higher attentional focusing was associated with a higher learning rate and less consistent responding on the experience-based task as well as a stronger bias to accept lotteries in the gain domain on the description-based task. That higher attentional focusing was associated with lower choice consistency may reflect apparent inconsistent behavior that results from adjusting behavior in response to experienced outcomes. Children who fixate on a constant target on the experience-based task, rather than adjusting their behavior in response to experienced gains and losses, are likely to exhibit more consistent behavior. Although higher attentional focusing was associated with a higher learning rate on the experience-based task and a bias to accept gambles in the gain domain on the description-based task, these two features of children's risk-taking behavior were not associated with each other. As such, attentional focusing appears to have separable influences on the learning rate in the experience-based task and on lottery acceptance in the description-based task.

On the basis that lower shyness and higher impulsivity have been found to be associated with choosing the lottery option in studies of description-based decision making (Levin & Hart, 2003), we expected that shyness and impulsivity would be associated with behavior based on both description and experience. On the description-based task, shyness was associated with lower response bias in the gain domain (b^+) and thus lower tendencies to accept the lottery option, indicating a lower propensity for shy children to take risks. On the experience-based task, shyness was associated with the overall behavioral measure of risk taking (in this instance number of steps), typically used as the sole measure of risk-taking behavior (Lejuez et al., 2002, 2007), but shyness was not related to the computational modeling parameters. This finding implies that shy children engaged in less exploratory behavior on the task but not that they necessarily had a lower propensity for risk taking. Shyness in children is associated with a broad array of characteristics and behaviors, including reticent behaviors (Coplan, Arbeau, & Armer, 2008), social fear and self-consciousness (Crozier, 2010), lower self-esteem (Crozier, 1995), and reduced creativity (Kemple, David, & Wang, 1996). Our findings dovetail with these accounts, showing that shy children engage in less exploration or experimentation on an experience-based decision task. Higher impulsivity was associated with a lower learning rate on the experience-based task, but perhaps unexpectedly it was not associated with measures of risk-taking

propensity on either task. Thus, our findings provide only partial support for intuitively plausible hypotheses regarding associations between child temperament and risk taking. We acknowledge, however, that we relied solely on teacher ratings of temperament, and there is at least some evidence that such ratings might not always align with parent ratings (Allan, Lonigan, & Wilson, 2013); future studies further examining the relations between temperament and risk taking in experience-based and description-based tasks may benefit from also taking parent/caregiver ratings.

We compared children's risk-taking behavior on prototypical description-based and experience-based decision tasks. Our choice of experience-based task was motivated in part by the extensive computational modeling that has been employed to decompose behavior on the BART (e.g., Rolison et al., 2012; van Ravenzwaaij et al., 2011; Wallsten et al., 2005), which is structurally similar to the Hungry Squirrel task we created for use with very young children. Computational modeling techniques afforded a decomposition of behavior into separate learning and risk-taking propensity components, enabling us to make a direct comparison with an analogous component of children's description-based risk taking. The Iowa Gambling Task (IGT) offers another tool for measuring experience-based risk taking, intended to mimic real-life learning from experienced gains and losses (Bechara, Damasio, Damasio, & Anderson, 1994). In the IGT, participants choose repeatedly among four decks of cards, two of which are advantageous (yielding small gains and occasional small losses) and two of which are disadvantageous (yielding large gains and occasional large losses), and receive feedback in response to each decision.

Although we are not aware of studies that have used the IGT to investigate experience-based risk taking among children as young as those we studied in the current research, studies using child-friendly versions of the IGT have found that children learn to prefer advantageous choice options from around 12 years of age (Crone & van der Molen, 2004; Van Duijvenvoorde et al., 2012). In a novel variant of the IGT, Van Duijvenvoorde et al. (2012) furnished children with explicit information about the gain and loss amounts and respective probabilities for each choice option to relieve the burden of learning on their developing working memory and long-term memory processes. Doing so improved children's decision making, indicating that working memory and long-term memory play an important role in advantageous decision making. With respect to our current findings, we observed an underlying age-related difference in sensitivity to outcomes common to both experience-based and description-based risk taking. Thus, even though the burden of learning on working memory and long-term memory would have been relieved by the provision of explicit information in our description-based task, we observed a common age-related difference underlying behavior on the two types of tasks. This finding adds to the growing body of literature on the child development of risk-taking behavior.

In conclusion, the current research reveals new insight into age-related differences in childhood risk taking. Comparing behavior on an experience-based task and a description-based task within the same sample of children revealed, on the face of it, seemingly disparate age-related differences in risk-taking behavior. However, our computational modeling alongside inspection of the behavioral data implied a general age-related difference in sensitivity to experienced and anticipated gains and losses underlying behavior on the two types of decision tasks. Individual differences analyses based on the modeling also suggested that there was an underlying tendency to engage in risk taking that was manifest across both tasks. In addition to these new insights into children's risk taking and its development, our findings also highlight the importance of assessing commonalities and differences in developmental behavior across qualitatively different tasks.

Appendix. Instructions

Experienced-based decision task (Hungry Squirrel)

Hungry Squirrel is collecting acorns for winter and wants your help in collecting acorns on the Wobbly Bridge.

Help Hungry Squirrel to collect the acorns by pressing the red button to move forward. When you have collected all the acorns, press the green button to send Hungry Squirrel home with his acorns.

[The child guided the squirrel across the bridge to collect 10]

There is a problem. One of the steps on the bridge might be broken, and we don't know which one. If Hungry Squirrel steps on a broken step, he will lose all the acorns that he has collected on the bridge. Watch what happens when Hungry Squirrel steps on a broken step and loses his acorns.

[The child watches an animation in which Hungry Squirrel steps on a broken step on the 10th step and loses his acorns]

Oh no, poor Hungry Squirrel stepped on a broken step!!! He lost all the acorns he collected that time on the bridge. He is going to try again now, but one of the steps might be broken again, and if so it might not be the same one this time.

[The child watches an animation in which Hungry Squirrel collects acorns on the bridge until the 20th step and returns without stepping on a broken step]

Hungry Squirrel did not step on a broken step that time. He decided to go home before he got to a broken step!!! So that time he got to keep his acorns. His acorns went into his sack to keep for later. Now he is going to try again to collect more acorns. Remember that one of the steps might be broken, and Hungry Squirrel does not know which one it could be.

[The child watches an animation in which Hungry Squirrel steps on a broken step on the 30th step and loses his acorns]

Oh no, Hungry Squirrel stepped on a broken step and lost his acorns that time!!! He still has some acorns in his sack, but he did not get any more that time. Now it is your turn to help Hungry Squirrel collect acorns on the bridge. You are going to get lots of chances to do this. If you have enough acorns collected in the sack at the end of the game, you will get a prize. Remember that one of the steps might be broken, and you won't know which one it could be, so you need to be careful. You don't need to go to the end of the bridge every time. You can stop and go home with the acorns you have collected.

Description-based decision task (Pirate)

Gain domain

Open treasure chests to collect as many gold coins as you can. If you collect enough gold coins, you will win a present.

Peter and Ben will help you to collect gold coins.

Peter always puts one gold coin in each of his treasure chests. If you open one of Peter's chests, you are sure to win a coin.

Ben always puts all of his gold coins in one of his treasure chests. If you open one of Ben's chests, you could win all of his coins or no coins at all.

Open Peter's and Ben's treasure chests to see what gold coins are hidden inside. Each time you play, you can open only one of Peter's or Ben's treasure chests.

[As an illustration, the child is guided to open each of two of Peter's boxes and two of Ben's boxes. Peter has one coin in his hand when each of his boxes is opened. Ben has two coins in his hand when the winning box is opened and no coins in his hand when the losing box is opened (i.e., lottery option)]

Loss domain

Captain Hook and Captain Red Beard will try to steal your gold coins by hiding skulls in their treasure chests.

For each skull you collect, you will lose a gold coin.

Hook puts one skull in each of his treasure chests. If you open one of Hook's chests, you are sure to find a skull and lose one of your gold coins.

Red Beard always puts all of his skulls in one of his treasure chests. If you open one of Red Beard's chests, you could find all of his skulls and lose as many of your gold coins.

Open Hook's and Red Beard's treasure chests to see what skulls are hidden inside. Each time you play, you must open one of Hook's or Red Beard's treasure chests.

[As an illustration, the child is guided to open each of two of Captain Hook's boxes and two of Captain Red Beard's boxes. Captain Hook has one coin in his hand when each of his boxes is opened. Captain Red Beard has two coins in his hand when the losing box is opened and no coins in his hand when the empty box is opened (i.e., lottery option)]

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