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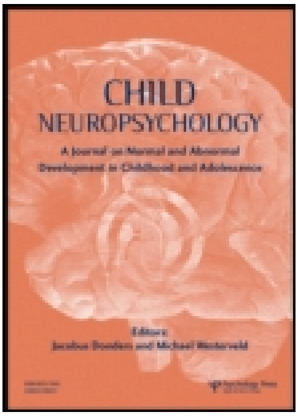

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Characterization of Children's Decision Making: Sensitivity to Punishment Frequency, Not Task Complexity

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CHARACTERIZATION OF CHILDREN'S DECISION MAKING: SENSITIVITY TO PUNISHMENT FREQUENCY, NOT TASK COMPLEXITY

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On a gambling task that models real-life decision making, children between ages 7 and 12 perform like patients with bilateral lesions of the ventromedial prefrontal cortex (VMPFC), opting for choices that yield high immediate gains in spite of higher future losses (Crone & Van der Molen, 2004). The current study set out to characterize developmental changes in decision making by varying task complexity and punishment frequency. Three age groups (7–9 years, 10–12 years, 13–15 years) performed two versions of a computerized variant of the original Iowa gambling task. Task complexity was manipulated by varying the number of choices participants could make. Punishment frequency was manipulated by varying the frequency of delayed punishment. Results showed a developmental increase in the sensitivity to future consequences, which was present only when the punishment was presented infrequently. These results could not be explained by differential sensitivity to task complexity, hypersensitivity to reward, or failure to switch response set after receiving punishment. There was a general pattern of boys outperforming girls by making more advantageous choices over the course of the task. In conclusion, 7–12-year-old children—like VMPFC patients—appear myopic about the future except when the potential for future punishment is high.

Keywords: ***development, decision making, executive function, somatic marker, gambling, perseveration, gender***

INTRODUCTION

Suppose that an 8-year-old named Sam is planning to sell his drawings at a local market. He has already made the price tags with his father, and he has decided which stand he will take when he gets there. He expects to sell much of his work, and looks forward to buying a nice toy with the money he earns. Unexpectedly, a neighbor stops by and tells Sam that his best friend Joe has broken his leg and would really like Sam to visit him in the hospital. What should Sam do in such a difficult situation? Making decisions in real life often requires consideration of multiple alternatives and reasoning about future outcomes. In situations like Sam's, it is not always possible to make a fast cost-benefit

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analysis of possible outcomes. Therefore, many decisions are made with uncertainty. Recent studies have reported developmental differences in affective decision making using modified gambling tasks (Crone & Van der Molen, 2004; Garon & Moore, 2004; Happaney, Zelazo, & Stuss, 2004; Kerr & Zelazo, 2004). In this study we examine which aspects of decision making are sensitive to development.

Development of Decision Making

Several investigators have developed behavioral paradigms to study children's understanding of probability and their capacity for decision making. In many of these studies, children were asked to compare two sets of elements of two colors in which the probability of the designated winning color was greater. These studies indicate that children as young as 5 years of age already understand the concept of 'expected value'; that is, they have a basic understanding that the value of a reward and the probability of attaining the reward are somehow related (Schlottman & Anderson, 1994; Wilkening & Anderson, 1991). However, when children have to make decisions in situations in which the choice elements are associated with different probabilities of reward, the typical finding is that young children's decisions reflect the absolute number of winning elements, regardless of how many losing elements there are. As children develop, this strategy is gradually replaced with the correct proportional strategy, which is used almost perfectly by most children of about 11 years old and older (Falk & Wilkening, 1998; Jager & Wilkening, 2001).

In these developmental decision-making tasks, the reward probabilities are given to the child, whereas in real life, probabilities have to be inferred and learned from past experience. Decision making under uncertainty does not allow for a fast cost-benefit analysis guided by simple (additive or multiplicative) rules, but requires a system that helps to constrain the decision-making space by making it manageable for logic-based, cost-benefit analyses. In prior work (Crone, Vendel, & Van der Molen, 2003; Crone & Van der Molen, 2004; see also Garon & Moore, 2004; Kerr & Zelazo, 2004), our interpretation of children's decision-making skills has been guided by the somatic marker hypothesis (Damasio, 1994), which proposes that bodily states evoked by the experience of reward and punishment signal the potential occurrence of a specific outcome. These signals guide behavior in a manner that is advantageous to the individual in the long term.

The Iowa Gambling Task as an Index of Decision Making

To measure the influence of somatic markers on decision making in children, we adopted the 'Iowa Gambling Task' (IGT), originally developed by Bechara, Damasio, Damasio and Anderson (1994). This task resembles real-life decisions in terms of reward, punishment, and uncertainty of outcomes. The task involves four decks of cards and subjects are asked to pick one card at a time. Two decks result in high reward but also unpredictable high penalty; therefore, these decks are disadvantageous in the long run. The two remaining decks result in smaller immediate gain but the unpredictable loss is also smaller; therefore, these decks are advantageous in the long run. After sampling from all decks, neurologically healthy adults gradually adopt a strategy of selecting cards from the low-reward decks (i.e., advantageous decks) and avoid decks with high immediate gain (i.e., disadvantageous decks; Bechara et al., 1994). In contrast, performance of VMPFC patients is guided by the immediate outcomes of actions, without regard for the future consequences of these decisions (mostly disadvantageous choices). In addition, Bechara, Tranel, Damasio, and Damasio (1996) found that over the course of numerous trials, neurologically intact individuals began to display anticipatory skin conductance responses that were higher preceding disadvantageous than advantageous choices, whereas VMPFC patients did not develop anticipatory skin conductance responses.

The authors considered three possibilities for this performance pattern. (1) VMPFC patients may be so sensitive to reward that they ignore the punishment that goes along with it, (2) VMPFC patients may be insensitive to punishment, and therefore the reward always prevails, or (3) VMPFC patients may be insensitive to future outcomes, and therefore they choose options that are appetitive on a short-term basis. To examine these possibilities, VMPFC and control participants completed a second version of the gambling task, but this time punishment was presented on each trial, and the reward was presented occasionally and unexpectedly. Again, neurologically intact individuals learned to choose from decks that were advantageous over the long term, whereas VMPFC patients chose from decks with immediate low loss, despite future negative outcomes (Bechara, Tranel, & Damasio, 2000). These results suggest that VMPFC patients' behavior is guided by short-term outcomes, positive or negative, whereas they are relatively insensitive to future consequences on their actions.

Children's Performance on the Gambling Task

Using an age-appropriate version of the Iowa gambling task, we recently reported that children between the ages of 6 and 12—like VMPFC patients—choose from decks that result in immediate high gain, despite future losses (Crone & Van der Molen, 2004). The ability to learn to make advantageous choices as the task progresses increased until late adolescence (Crone et al., 2003; see also Blair, Colledge & Mitchell, 2001). Using simpler gambling tasks, researchers also reported developmental changes in the ability to dissociate between advantageous and disadvantageous choices in infants (Garon & Moore, 2004; Kerr & Zelazo, 2004). When the reward and punishment schedules are reversed, children between the ages of 6 and 12 choose options that resulted in small punishments despite future losses (Crone & Van der Molen, 2004; following up on Bechara et al.'s, reversed gambling task, 2000). These findings suggest that developmental changes in decision making are not associated with hypersensitivity to reward or insensitivity to punishment; rather, with age children seem to learn to anticipate future outcomes. In this regard, children's performance on the gambling task resembles that of patients with damage to the ventromedial prefrontal cortex (VMPFC), who fail to take into account the long-term consequences of their choices (both in the gambling task and in real life; for a review, see Bechara, Damasio, & Damasio, 2000).

The slowly developing decision-making skills are in accordance with converging evidence for the protracted development of prefrontal cortex throughout childhood and adolescence, suggesting an important parallel between brain maturation and cognitive development (e.g., Dempster, 1993; Diamond, 2002; Fuster, 2002; Nelson & Luciana, 2001; Pennington, 1998; Stuss, 1992; Van der Molen & Ridderinkhof, 1998; Welsh, 2002). Prefrontal cortex is shown to be necessary for control processes of thought and action (Miller & Cohen, 2001), and the functional implications of protracted maturation of prefrontal cortex for development are only beginning to be understood. For example, research on the development of cognitive aspects of response inhibition and interference suppression—key functions of the prefrontal cortex—has shown that children's ability to flexibly switch between sorting rules (e.g., Kirkham, Cruessi, & Diamond, 2003; Zelazo, Frye, & Rapus, 1996), resist interference (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2001; Ridderinkhof & Van der Molen, 1995), and keep relevant information in mind (Crone, Ridderinkhof, Somsen, Worm, & Van der Molen, in press) improves with age.

Factors Contributing to Developmental Changes in Gambling Performance

Although the IGT is a promising tool for studying decision making, we know relatively little about the characteristics of children's decision-making process. Different task requirements could potentially contribute to children's decision-making impairments. The age at which children learn to dissociate between advantageous and disadvantageous choices seems dependent on the characteristics of the task (e.g., 4-year-old children already learned to make advantageous choices in a simple gambling task, Kerr & Zelazo, 2004). We consider several possible cognitive functions whose maturation may contribute to developmental differences in decision making.

First, working memory is important because the child must be able to remember the outcomes of different choices. There is substantial literature indicating protracted developmental change in performance on tasks that require the ability to integrate new, potentially relevant information with information that is currently being maintained in working memory (e.g., Fuster, 2000; Nelson, 1995; Pennington, 1994; Welsh, 2002). Hinson, James and Whitney (2002) showed that decision-making is compromised by high demand on working memory, in other words, the part of the cognitive system that is used to hold a limited set of information in mind (Miller & Cohen, 2001; Smith & Jonides, 1999). We addressed this issue previously by examining the relation between working memory, as indexed by Digit Span Backwards, and gambling performance, and we found no relation between working memory skills and decision making (Crone & Van der Molen, 2004; see also Bechara, Damasio, Tranel, & Anderson, 1998). These comparisons were made between tasks, however, and it could be that when the number of choices within the gambling task is reduced, young children perform as advantageously as older children. For example, Kerr and Zelazo (2004; see also Garon & Moore, 2004) studied young children's decision making in a two-choice version of the original gambling task, and they found that 4-year-old children were already able to make advantageous choices. The two-versus four-choice versions of the task may differ in the demands placed on the ability to keep information active in memory.

Second, reversal learning is important because the child must be able to abandon a habitual response set that was initiated by the high-reward decks and switch to the choices with smaller magnitude rewards. A recent review by Overman (2004) points out that the ability to reverse a previously learned association is highly sensitive to development. Overman, Bachevalier, Schuhmann, and Ryan (1996) demonstrated age-related improvements in performance on object reversal tasks in infants and young children, a function that has long been known to depend on intact orbitofrontal cortex (a region of the prefrontal cortex including VMPFC; Rolls, 2000). In the object reversal task, participants are required to learn reinforcement values of two objects, which are reversed later in the task. This function resembles requirements in the gambling task because participants have to learn that the high-reward decks have to be abandoned. Thus, it is feasible that children's decision making is compromised by the fact that they do not switch choices after receiving punishment.

Third, children must be able to deduce the strategy that, although punishments are unpredictable, decks with higher magnitude punishment should be avoided, despite the high rewards. An interesting observation in our prior experiment was that children and adults preferred options for which the delayed punishment was infrequent (10%) and large, rather than options for which the delayed punishment was frequent (50%) but smaller in magnitude (see also Mintzer & Stitzer, 2002, for similar findings). This suggests that individuals are generally guided by the prevalence of unexpected punishment and prefer options for which the chances for punishment are low (although high in magnitude). In opting for low probability of punishment, children failed to consider future consequences, as is apparent from the fact that they did not choose advantageously more often as the task progressed. Interestingly, in Kerr and Zelazo's (2004) and Garon and Moore's (2004) studies, punishment was always given with high frequency and in these studies children learned at a relatively young age (4 to 6 years) to make advantageous choices. Thus, these findings suggest that children's decision-making impairments may be associated with sensitivity to frequency of punishment and that children learn to dissociate between advantageous and disadvantageous choices faster when the probability of punishment is higher.

Aim and Predictions

The primary aim of this study was to examine which different task requirements potentially contribute to children's decision-making impairments. We focused on three manipulations that may alter children's decision making: (i) task complexity/memory demands, (ii) response reversal, and (iii) punishment frequency. Three groups of children between the ages of 7 and 15 (7–9 years, 10–12 years, and 13–15 years) performed different versions of the modified gambling task. We expected that children aged 13–15 would be able to dissociate between advantageous and disadvantageous choices in all versions of the task, providing a baseline for the younger groups (Crone & Van der Molen, 2004).

(i) If between the ages of 7 and 15 children increasingly master to track outcomes of more options, then there should be a more pronounced developmental increase in the ability to make advantageous choices when the task includes four choices (e.g., Blair et al., 2003; Crone & Van der Molen, 2004) compared to a two-choice version of the task (e.g., Garon & Moore, 2004; Kerr & Zelazo, 2004). To test this hypothesis, children were assigned to task conditions, which could involve making selections from two- or four-choice options. Both task versions included only choices with 50% punishment probability, to avoid confounding influence of punishment frequency.

(ii) If between the ages of 7 and 15 children become better able to switch response set, then there should be a developmental increase in the ability to switch responses after receiving punishment. To test this hypothesis, we used a response reversal manipulation. Adults typically switch choices more often after receiving punishment (Crone & Van der Molen, 2004). With age, there should be an increase in the tendency to switch choices following punishment if children's decision making is compromised by a tendency to perseverate on inappropriate choices (e.g., Overman et al., 1996).

(iii) If between the ages of 7 and 15 children become less sensitive to the frequency of punishment, then there should be a steeper developmental increase in the ability to make advantageous choices on the task versions in which punishment was given with 50% probability (e.g., Kerr & Zelazo, 2004), compared to task versions with 10% probability (e.g., Crone & Van der Molen, 2004). This issue was addressed by assigning children of different age groups to task conditions in which delayed punishment was frequent (50%) or infrequent (10%). Both task versions included only two choices, to avoid confounding influence of task complexity.

One further precaution was taken. Each participant performed two versions of a developmentally appropriate analogue of the IGT, in accordance with the strategy adopted by Bechara and coworkers (e.g., Bechara, Tranel and Damasio 2000) and Crone and Van der Molen (2004) for differentiating between sensitivity to future consequences versus sensitivity to reward or insensitivity to punishment. In the standard version of the task, reward was given at each trial, and punishment was presented occasionally and unpredictably. In the reversed version, punishment was given on each trial, and reward was presented occasionally and unpredictably. In previous studies it was found that children, like VMPFC patients, were more influenced by the immediate outcomes (positive or negative) than by the future consequences (Crone & Van der Molen, 2004). In the present study, inclusion of the standard and reversed versions of the task allowed us to further test the hypothesis that children's decision-making deficits stem from insensitivity to future consequences.

Finally, we examined gender differences in decision making. Prior studies have shown that boys outperform girls on the object reversal task as young as 30 months old (Overman et al., 1996), and a similar pattern is seen for 3-year-olds (Kerr & Zelazo, 2004) and adults (Reavis & Overman, 2001) on the gambling task. Therefore, it was expected that any gender difference would favor boys.

METHOD

Participants

Three age groups participated in the study: 46 children between 7 and 9 years of age, 49 children between 10 and 12 years of age, and 45 adolescents between 13 and 15 years of age. Children and adolescents were recruited by contacting schools in the greater Amsterdam area. These participants were selected with the help of their teacher, and their primary caregiver signed a consent letter for participation. According to teacher reports, all participants had average or above average intelligence and children with learning disorders or behavioral disorders were excluded. Within age groups, subjects were randomly assigned to one of the following conditions: four-choice 50% punishment, two-choice 50% punishment, or two-choice 10% punishment.

Mean age and gender distributions are presented in Table 1 for each age group and task version. Chi-square and ANOVA analyses indicated that gender and age did not differ significantly between subjects assigned to different conditions.

Table 1 Descriptive Characteristics of the Participants, Per Age Group and Task Version, Including Mean Age, and Number of Boys and Girls.

Group	Condition	Mean (SD) Age	Boys (Girls)
7–9 years	Four-choice 50%	8.5 (.5)	10 (5)
	Two-choice 50%	8.6 (.7)	9 (8)
	Two-choice 10%	8.5 (.6)	8 (6)
10–12 years	Four-choice 50%	10.9 (.6)	8 (7)
	Two-choice 50%	11.1 (.6)	6 (9)
	Two-choice 10%	11.0 (.8)	13 (6)
13–15 years	Four-choice 50%	13.5 (.6)	5 (10)
	Two-choice 50%	13.4 (.5)	9 (6)
	Two-choice 10%	13.5 (.6)	9 (6)

Task Format

Displays. The experimental task is described in detail elsewhere (Crone & Van der Molen, 2004). Participants were seated in front of a computer monitor. Two displays were presented on each trial: a stimulus display and an outcome display. The stimulus display consisted of two or four doors (presented in a row), and a donkey sitting in front of the doors. An example of the four-choice versions is presented in Figure 1. Subjects were told to help the hungry donkey collect as many apples as possible by pressing one of two/four keys corresponding to the doors. The left and right index fingers were assigned to the C and N keys of the keyboard for the two-choice version, and the left middle, left index, right index, and right middle fingers were assigned to the C, V, B, and N keys for the four-choice version. The keys were mapped onto the doors from left to right. Upon pressing one of the keys, the stimulus display was replaced with the outcome display showing the number of apples gained or the number of apples lost (denoted by crossed-out apples). The color change of a horizontal bar at the bottom of the screen indicated the total number of apples won or lost as the task progressed.

Tasks. All participants performed the standard task and the reversed task. Each task contained 150 trials. Presentation of tasks was counterbalanced between participants. The reward/punishment schedule was similar to that used previously (Crone & Van der Molen, 2004), but the outcomes varied depending on task condition. A schematic of each task condition is presented in Table 2.

In the standard task, after selecting ten A-doors, the participant had received 40 apples, but had also encountered five unpredicted losses of either 8, 10, 10, 10, or 12 apples, bringing the total cost to 50 apples, thus incurring a net loss of 10 apples. After selecting ten B-doors, the participant had received 40 apples but had encountered one unpredicted loss of 50 apples, also incurring a net loss of 10 apples. After selecting ten C-doors, the participant had received 20 apples, but had encountered five unpredicted losses of 1, 2, 2, 2, or 3 apples, for a total cost of 10 apples, thus incurring a net gain of 10 apples. The same happened at door D, except that instead of encountering five losses, there was one larger unpredicted loss of 10 apples, resulting in a net gain of 10 apples. Thus, doors A and B were disadvantageous in the long run because they resulted in a net loss, whereas doors C and D were advantageous in the long run because they resulted in an overall gain.

In the reversed task, selecting door A or B resulted in an immediate loss of 4 apples, whereas selecting door C or D resulted in a loss of 2 apples. However, the ultimate future yield of each door varied because the reward amounts were higher at high-loss doors. After selecting ten A-doors, the participant had lost 40 apples, but had also encountered five unpredictable gains of 8, 10, 10, 10, or 12 apples, resulting in a net gain of 10 apples. The same happened for door B, except that there was one large unpredicted gain of 50 apples. After selecting door C ten times, the participant was faced with a loss of 20 apples and five unpredictable losses of 1, 2, 2, 2, or 3 apples, resulting in a net loss of 10 apples. After selecting the D-door ten times, the participant had lost 20 apples, and had encountered one unpredictable gain of 10 apples, also resulting in a net loss of 10 apples. In this task, unlike the standard task, doors A and B were advantageous in the long run. Doors C and D on the other hand were disadvantageous in the long run.

Conditions. In the four-choice 50% condition, four doors were presented and the amounts of gain and loss followed an AACC scheme (resembling two A decks and two C decks of the original GT), resulting in unpredictable loss (standard task) and reward (reversed task) on 50% of the trials. In the two-choice 50% condition, two doors were presented and the amounts of gain and loss followed an AC scheme (resembling the A and C decks of the original

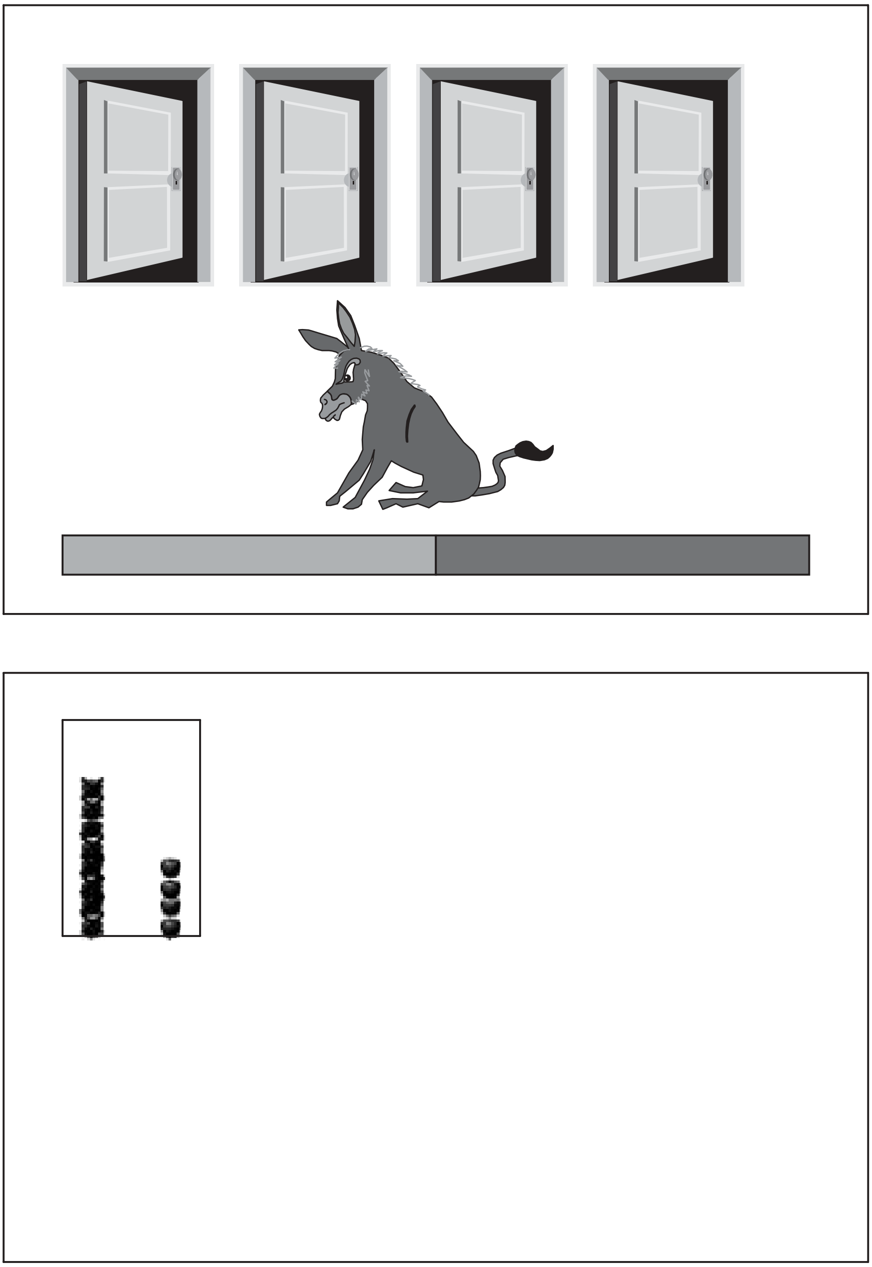

Figure 1 An example of a stimulus display for the four-choice version of the Hungry Donkey Task. The two-choice versions were similar except that the middle two doors were not displayed. The lower panel shows an example of the outcome display.

GT), again presenting unpredictable loss (standard task) and reward (reversed task) on 50% of the trials. In the two-choice 10% condition, two doors were presented and the amounts of gain and loss followed a BD scheme (resembling the B and D decks of the original GT), presenting unpredictable loss (standard task) and reward (reversed task) on 10% of the trials.

Table 2 Task Design: The top panels show the gain and loss schedules for the original IOWA Gambling Task GT) and for the original Hungry Donkey Gambling Task. Each cell shows a typical gain and a typical loss as well as the percentage of times these were delivered. The bottom panels show the gain and loss schedules in the current experiment. AACC, AC, and BD refer to the gain and loss schedules of the original task and how these were distributed over the four doors in the current experiment. Net scores are based on ten choices of each deck/door. Doors A and B are disadvantageous; doors C and D are advantageous.

	Deck/Door A	Deck/Door B	Deck/Door C	Deck/Door D
Original IOWA GT	Gain: 100 (100%) Loss: 200/250/300 (50%) Net Score: 1000-1250=-250	Gain: 100 (100%) Loss: 1250 (10%) Net Score: 1000-1250=-250	Gain: 50 (100%) Loss: 25/50/75 (50%) Net Score: 500-250= 250	Gain: 50 (100%) Loss: 10 (10%) Net Score: 500-250= 250
Original Donkey GT	Gain 4: (100%) Loss: 8/10/12 (50%) Net Score: 40-50=-10	Gain: 4 (100%) Loss: 50 (10%) Net Score: 40-50=-10	Gain: 2 (100%) Loss: 1/2/3 (50%) Net Score: 20-10= 10	Gain: 2 (100%) Loss: 10 (10%) Net Score: 20-10= 10
AACC (four choices, 50% punishment)	Gain: 4 (100%) Loss: 8/10/12 (50%) Net Score: 40-50=-10	Gain: 4 (100%) Loss: 8/10/12 (50%) Net Score: 40-50=-10	Gain: 2 (100%) Loss: 1/2/3 (50%) Net Score: 20-10= 10	Gain: 2 (100%) Loss 1/2/3 (50%) Net Score: 20-10= 10
AC (two choices, 50% punishment)	Gain: 4 (100%) Loss: 8/10/12 (50%) Net Score: 40-50=-10	X	X	Gain: 2 (100%) Loss 1/2/3 (50%) Net Score: 20-10= 10
BD (two choices, 10% punishment)	Gain: 4 (100%) Loss: 50 (10%) Net Score: 40-50=-10	X	X	Gain: 2 (100%) Loss: 10 (10%) Net Score: 20-10= 10

Apparatus

The experimental tasks were presented using laptop computers with 15-inch monitors. Subjects were seated at a distance of approximately 75 cm from the monitor.

Instructions, Design and Procedure

Participants were tested individually in a quiet classroom. The order of presentation of the standard and reversed tasks was counterbalanced across subjects. The assignment of gain/loss schedules was counterbalanced across response keys to control for finger/hand preferences. The experiment took approximately 30 minutes to complete.

RESULTS

The first section of the results considers whether the previously reported age differences in decision-making strategy depend on task complexity and/or frequency of reward or punishment. The second section of the results examines the local effects of reward and punishment on sequential choices.

Decision-Making strategy

The scoring method, adopted from the Iowa Gambling Task literature, consisted of calculating net score differences between advantageous and disadvantageous scores (e.g., Bechara, Tranel and Damasio, 2000; Crone & Van der Molen, 2004). The score was calculated in the following manner for each of the tasks: standard four-choice 50%: [(C1 + C2) - (A1 + A2)]; standard two-choice 50%: (C - A); standard two-choice 10%: (D - B). For the reversed task, the method for calculating net-score difference was the same except that the sign was reversed because A and B were advantageous, and C and D were disadvantageous. A positive score indicates an overall gain across trials, whereas a negative score indicates an overall loss. Net scores were calculated across 15 trials for 10 blocks (each task comprised a total of 150 trials) to allow for an examination of choice change over the course of task performance.

The net scores were subjected to repeated-measures ANOVAs with age group (7–9 year, 10–12 years, 13–15 years), gender, and condition (four-choice 50%, two-choice 50% and two-choice 10%) as between-subjects factors, and task (standard vs. reversed) and trial block (10 blocks, each of 15 trials) as within-subjects factors. There were significant effects of task, $F(1, 122) = 4.79$, $p < .05$, and trial block, $F(9, 1098) = 43.41$, $p < .001$, and a significant interaction between task and trial block, $F(9, 1098) = 3.51$, $p < .001$. As can be seen in Figure 2, participants learned to differentiate between advantageous and disadvantageous choices more quickly in the reversed task than in the standard task.

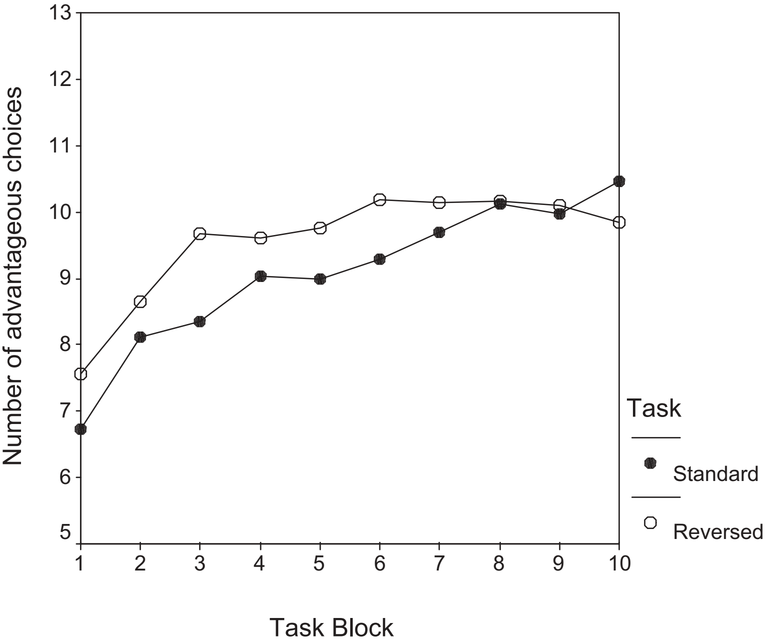

Figure 2 The number of advantageous choices as a function of trial block for the standard and reversed tasks. Each task block consists of 15 choices. Scores higher than 7.5 reflect more advantageous choices than disadvantageous choices. Scores lower than 7.5 reflect more disadvantageous choices than advantageous choices. Number of advantageous choices increased as the task progressed, but earlier for the reversed task than for the standard task.

The main effect of condition, $F(2, 122) = 16.96$, $p < .001$, was qualified by interactions between condition and age group, $F(4, 122) = 2.95$, $p < .05$, and condition, age group, and trial block, $F(36, 1098) = 1.65$, $p < .005$. The latter interaction is presented in Figure 3, and was followed up by a post hoc ANOVA of the three conditions. The only condition

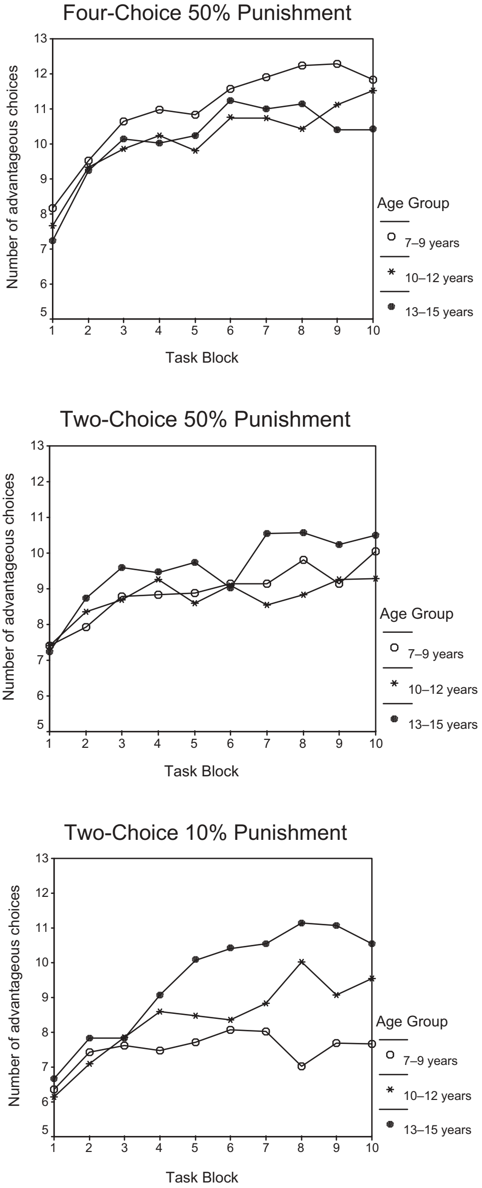

Figure 3 Number of advantageous choices as a function of trial block, for each age group and task condition separately, collapsed over standard and reversed tasks. Task conditions were four-choice 50% punishment, two-choice 50% punishment, and two-choice 10% punishment. Each task block consisted of 15 choices. Scores higher than 7.5 reflect more advantageous choices than disadvantageous choices. Scores lower than 7.5 reflect more disadvantageous choices than advantageous choices.

that resulted in interactions with age was the two choice 10% condition. The repeated measures ANOVA resulted in a significant Age Group × Trial Block interaction, $F(18, 369) = 2.31$, $p < .001$. When age groups were compared with separate ANOVAs, Age Group × Trial Block interactions showed that 7–9-year-olds learned to make advantageous choices more slowly than 10–12-year-olds, $F(9, 252) = 2.63$, $p < .01$, and 13–15-year-olds, $F(9, 243) = 3.79$, $p < .001$, whereas 10–12-year-olds and 13–15-year-olds did not differ from each other, $F(9, 243) = .92$, $p = .51$. None of the above interactions with Age Group was qualified by an interaction with Task. Age Group and Age Group × Trial Block interactions were not significant for the 50% conditions (Age Group × Trial Block interaction for four choice 50% condition: $F(18, 333) < 1$, Age Group × Trial Block interaction for two choice 50% condition: $F(18, 396) = 1.16$, $p > .25$).

Finally, the main analysis resulted in a significant Gender × Task Block interaction, $F(9, 1098) = 2.07$, $p < .05$. This interaction is plotted in Figure 4 and shows that as the task progressed, boys made more advantageous choices than girls. There were no significant interactions between gender and age group, gender and condition, or other interactions with gender.

In sum, developmental changes in decision making were apparent only when the delayed punishment was infrequent. There was no developmental difference in performance between the four-and two-choice versions of the task. Additionally, there was a general pattern of boys performing better than girls independent of task condition or age group.

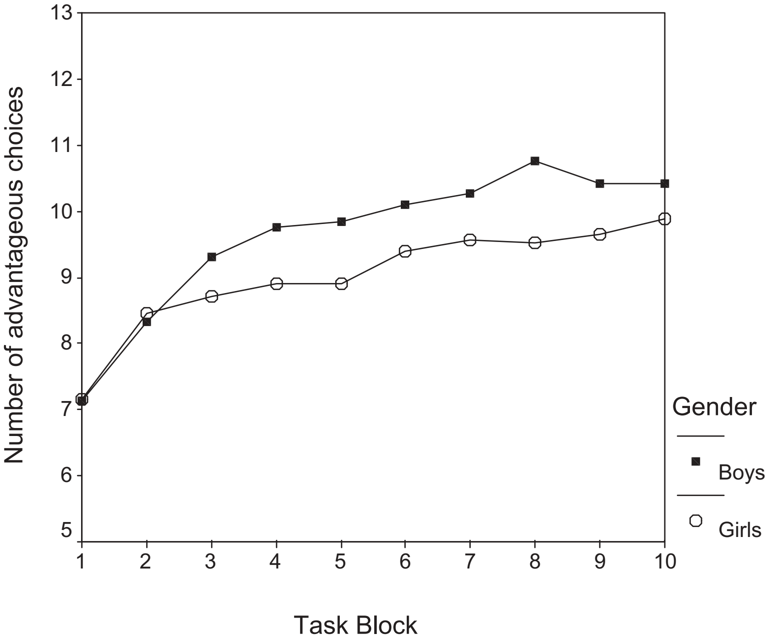

Figure 4 Number of advantageous choices as a function of trial block for boys and girls separately, collapsed over task conditions and standard/reversed task. Each task block consisted of 15 choices. Scores higher than 7.5 reflect more advantageous choices than disadvantageous choices. Scores lower than 7.5 reflect more disadvantageous choices than advantageous choices. Number of advantageous choices increased faster for boys than for girls.

Sequential Analyses

The second set of ANOVAs focused on local responses to loss in the standard task. For this analysis, we compared the frequency with which subjects switched response options following gain and loss. The factor 'gain switches' was computed by calculating the proportion of choice switches following gain as a function of the total number of gain trials. Likewise, the factor 'loss switches' was computed by calculating the proportion of choice switches following punishment as a function of the total number of loss trials. The Age Group (3) × Gender (2) × Condition (3) × Gain/Loss (2) ANOVA resulted in a main effect of gain/loss, $F(1, 130) = 103.10$, $p < .001$, showing that participants switched responses more often following loss (66% of the time) than following gain (34% of the time). Further, there was a three-way interaction between age group, condition, and gain/loss, $F(4, 130) = 5.09$, $p < .001$, which is presented in Figure 5. This interaction was followed up by ANOVAs for each condition separately. In the two-choice 10% task, young children switched responses more often following punishment than older children and adolescents, as seen by the interaction between age group and gain/loss, $F(2, 44) = 4.05$, $p < .01$. In contrast, in the 50% tasks, older children and adolescents switched responses more often than younger children, as indexed by Age Group × Gain/Loss interaction for the four-choice 50% condition: $F(2, 40)= 3.74$, $p < .05$, and for the two-choice 50% condition: $F(2, 46) = 3.53$, $p < .05$. There were no effects of gender (all p's > .20).

Thus, children of all age groups switched responses more often following punishment than following reward, and there were no differences between boys and girls.

DISCUSSION

This study is consistent with previous reports in showing an age-related increase in preference for choices associated with small rewards than larger ones, because these choices resulted in smaller punishment and therefore were more advantageous in the long run (Blair et al., 2001; Crone & Van der Molen, 2004; Garon & Moore, 2004; Kerr & Zelazo, 2004). The current study provided a detailed focus on task complexity and the frequency of delayed punishment and rewards, and shows that the context of delayed punishment/reward puts important constraints on the decision-making impairments seen in young children. Below, we will discuss the developmental consequences of different task characteristics that may contribute to the development of decision making.

Sensitivity to Punishment Frequency

When performing a condition of the gambling task with low punishment frequency (10%), there was a pronounced developmental change in the ability to choose advantageously, whereas this pattern was absent when punishment was frequent (50%). Thus, when punishment was frequent, children learned at a younger age to choose advantageously. This result is consistent with our prior findings (Crone & Van der Molen, 2004). In the prior study, we found that developmental changes in task performance were characterized by 6–12-year-old children making mainly disadvantageous choices that could result in infrequent punishment, whereas age differences were much smaller for disadvantageous choices that could result in frequent punishment. This pattern is interesting because the choices in the 50% and 10% conditions do not differ in terms of overall net loss. These choices differ only in terms of punishment frequency; in other words, one

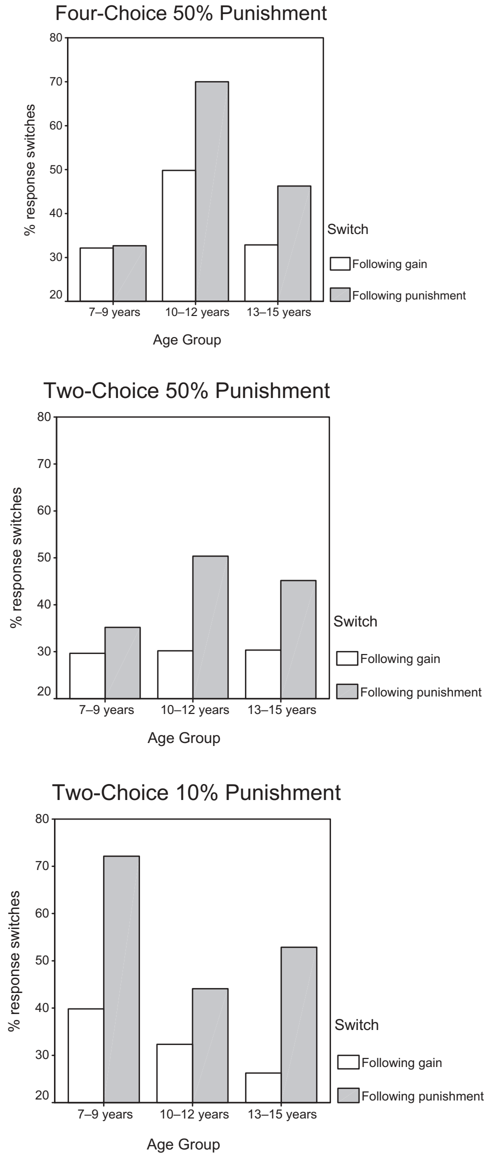

Figure 5 Number of response switches following gain and loss for each task condition and age group. Task conditions were four-choice 50% punishment, two-choice 50% punishment, and two-choice 10% punishment. See text for details on switch percentages.

choice is associated with frequent but small losses, whereas the other choice is associated with infrequent but large losses.

The results are consistent with findings by Garon and Moore (2004) and Kerr and Zelazo (2004), who observed a developmental increase in the ability to make advantageous choices in young children. Using only frequent delayed punishment, these researchers showed that by the age of 4 or 6 (depending on task complexity), children learn to adopt an advantageous strategy. Thus, it is compelling that the ability to learn to make advantageous choices develops later in childhood. However, the frequency of unexpected punishment may influence the time at which children learn to make advantageous choices.

A possible explanation for age difference in preference for disadvantageous choices with infrequent punishment could be that younger children discount the value of punishment more quickly. Thus, despite the fact that even young children might experience the punishment as aversive, they appear to 'forget' the negative consequences more quickly when punishment is infrequent and switch back to disadvantageous choices. This interpretation is consistent with the somatic marker hypothesis, which argues that recent experience of choice outcomes influences future decision making (Damasio, 1994). Therefore, across childhood the development of somatic markers may be sensitive to the frequency with which punishment is experienced.

Reversal of Reward Representations

Another possibility we considered was that children have more difficulty reversing representations of advantageous and disadvantageous choices after first encountering only rewards for disadvantageous decks (following up on Overman et al.'s 1996 reports on developmental changes in response reversal). Importantly, all age groups tended to switch their choices following loss, showing that for all age groups, the outcome on one trial directly influenced the decision on the next stimulus encounter. This finding rules out the possibility that children's decision-making deficits are due to an inability to switch response set in general. Even in the two-choice 10% punishment task children did not sample randomly. The sequences of choices following loss showed that 7–9-year-old children switched choices following loss as often as 13–15-year-olds; in fact, they changed responses *more* often than older children. The latter finding may be related to the fact that young children chose more disadvantageously; therefore, they encountered losses of higher magnitude, which may have led them to change strategy more often. However, instead of continuing to choose advantageously following a choice switch, children switched back to making disadvantageous choices. Thus, the hypothesis that developmental changes in decision making are associated with perseveration of initially rewarded choices could be disconfirmed.

It should be noted that the concept of perseveration has many faces. The tendency to perseverate on sequential trials is greatly reduced over the course of development, as seen for example by children's performance on the Wisconsin Card Sorting Task and its analogues (e.g., Chelune & Baer, 1986; Crone et al., in press; Overman et al., 1996; Zelazo et al., 1996). The current data suggest that this type of sequential perseveration and disadvantageous decision making are functionally separable (see also Bechara, Damasio and Damasio, 2000; Blair et al., 2001). However, it could be that children are able to locally switch choices but still fail to change their representation of disadvantageous and advantageous decks. It has been argued that the ability to consider and integrate two dimensions (in this case, gain and loss) is sensitive to age-related change, at least in infants (Zelazo & Frye, 1998). This hypothesis is based on reports showing systematic age-related changes in children's ability to formulate complex, higher-order rules for operating on lower-order rules (Zelazo et al., 1996). Along a similar vein, Rolls (2000) suggested that orbitofrontal cortex is required for flexible representation of the reinforcement value of stimuli. Possibly, young children fail to integrate these representations when rewards and gains are uncertain.

Sensitivity to Task Complexity

Finally, the hypothesis that decision-making impairments in children are related to task complexity/greater working memory demands was not supported by the data because there were no age changes in the number of advantageous choices on the four-choice 50% punishment or the two-choice 50% punishment task. This result suggests that the observed developmental trend in gambling performance is not due to age-related changes in the ability to keep track of previous outcomes. This finding corresponds well with studies performed by Bechara et al. (1998), in which ventromedial prefrontal patients showed impaired decision-making capacity but intact working memory capacity, whereas a subgroup of dorsolateral prefrontal patients showed relatively greater impairment on the working memory task and a smaller impairment on the decision-making task. This dissociation suggests that decision making may function relatively independently from working memory capacity (see also Bechara et al., 2000; but see Manes et al., 2002) or the ability to update performance outcomes (Crone & Van der Molen, 2004). Taken together, these findings suggest that at least one factor contributing to decision-making impairments in children or VMPFC patients is unrelated to working memory.

Reward Sensitivity, Punishment Insensitivity, or Insensitivity to the Future?

The possibility that children are hypersensitive to reward when punishment probability is low could be ruled out on the basis of the findings of the reversed task. In general, performance on the reversed task was better than performance on the standard gambling task. This pattern is also reported by others (e.g., Bechara, Damasio and Damasio, 2000) and may reflect people’s tendency to focus more on reward when anticipating long-term goals (i.e., maximum yield). These and prior findings with the reversed task (Crone & Van der Molen, 2004) indicate that when the response contingencies are reversed, children between ages 6 and 12 choose options for which chances of immediate loss are low, despite reduced future reward. These findings suggest that when the frequency of punishment is low, children are insensitive to the future outcomes of their decisions.

Gender Differences in Gambling Performance: Boys Outperform Girls

An interesting finding in the current study was that boys learned to dissociate between advantageous and disadvantageous choices more quickly than girls on all versions of the task. Examining gender issues was not an initial goal of this study, which resulted in somewhat unequal gender distribution; in other words, overall more boys participated in the study than girls. There was no reliable difference, however, in distribution of boys and girls over all conditions, so it is unlikely that the frequency effects reported in this study resulted from unequal gender distribution. The gender difference parallels findings by Reavis and Overman (2001) in adults and Kerr and Zelazo (2004) in 3-year-olds, showing that men performed better than woman and boys performed better than girls on different versions of the gambling task. Likewise, on an object reversal task presumed to rely on orbitofrontal cortex, Overman et al. (1996) found that boys outperformed girls when they were younger than 30 months. It is interesting to note that Overman (2004) reported that on a gambling task, females chose more from infrequent punishment trials than males. This suggests that females may perform more disadvantageously than males for the same reason that young children perform more disadvantageous than older children when punishment is infrequent (for example, because they forget consequences in the past quicker). The current study did not have enough power to dissociate between gender differences within different conditions. Still, the overall difference in performance between boys and girls is intriguing and should be looked into further in future research.

CONCLUSIONS

Taken together, the results of this study reinforce the idea that children are insensitive to the future when outcomes are uncertain, and this 'myopia for the future' mimics the performance of VMPFC patients. The age-related improvement in performance between 7 and 15 years of age might reflect continuing growth during childhood of neural systems involving VMPFC. The complexity of the cognitive processes that the task requires is likely to be an important contributor to age-related changes in decision making. For example, using simple versions of the task, Kerr and Zelazo (2004) and Garon and Moore (2004) found evidence of improvement in performance between 3 and 6 years of age. More complex versions of the task, such as the current task and the original Iowa Gambling Task, show protracted development into adolescence (Blair et al., 2001; Crone et al., 2003; Overman, 2004). The slowly developing decision-making skills are in accordance with converging evidence for the protracted development of prefrontal cortex throughout childhood and adolescence (e.g., Dempster, 1993; Diamond, 2002; Fuster, 2002; Welsh, 2002). Children's insensitivity to future outcomes may be related to the absence of emotional markers ('somatic states') that help to bias the selection of an advantageous response from an array of possible outcomes (Bechara et al., 1996; Damasio, 1996).

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