DEVELOPMENTAL NEUROPSYCHOLOGY, *25*(3), 251–279

Developmental Changes in Real Life Decision Making: Performance on a Gambling Task Previously Shown to Depend on the Ventromedial Prefrontal Cortex

Eveline A. Crone and Maurits W. van der Molen
Department of Developmental Psychology
University of Amsterdam, The Netherlands

Patients with bilateral lesions of the ventromedial prefrontal cortex, when performing gambling tasks modeling real-life decision-making, opt for choices that yield high immediate gains in spite of higher future losses. Under the hypothesis that the prefrontal cortex is the last brain region to mature, it was examined whether young children would show a similar preference for immediate prospects. In Experiment 1, 4 age groups (6–9, 10–12, 13–15 and 18–25 years olds) performed 2 versions of a computerized variant of the original Iowa gambling task under 3 different feedback conditions (no feedback, global feedback, and option-specific feedback) and completed the Raven Standard Progressive Matrices as an index of inductive reasoning ability. In Experiment 2, 3 age groups (7–8, 11–12, and 15–16 year olds) performed both task versions in addition to a working memory task ('Digit Span Backwards'). Results showed a developmental increase in the sensitivity to future consequences, positive or negative, that could not be explained by developmental changes in working memory capacity or inductive reasoning. It was concluded that young children share with ventromedial prefrontal patients the failure to anticipate on future outcomes.

The primate prefrontal cortex consists of several functional systems including the dorsolateral and ventromedial regions that have been shown to make relatively independent contributions to cognition. A series of studies of Bechara, Damasio, and

Requests for reprints should be sent to Eveline A. Crone, Department of Developmental Psychology, University of Amsterdam, Roetersstraat 15, 1018 WB, Amsterdam, The Netherlands. E-mail: e.a.m.crone@uva.nl

coworkers indicate that the ventromedial prefrontal cortex plays an important role in adult decision-making (e.g., Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Tranel, Damasio, & Damasio, 1998; Bechara, Damasio, & Damasio, 2000). These studies indicate that ventromedial prefrontal patients show difficulties on real-life decision-making tasks but not on tasks taxing working memory; however, the reverse is true for dorsolateral prefrontal patients (Bechara et al., 1998). The decision-making deficit in ventromedial prefrontal patients consists of a strong preference for immediate prospects combined with a reduced sensitivity to future consequences, positive or negative.

To detect the decision-making deficit in ventromedial prefrontal patients, Bechara and co-workers designed a laboratory analogue of a real-life decision-making task—the Iowa Gambling Task (Bechara et al., 1994). The task requires participants to choose cards from four decks. For two decks (A and B), choosing a card is followed by a high reward, but the selection of the card is associated with an unpredictable high penalty (bad or disadvantageous decks). For the other two decks (C and D), the immediate gain is smaller but the unpredictable loss is also smaller (good or advantageous decks). After sampling from all decks, intact adults gradually adopt a strategy of selecting cards from the low-reward decks (i.e., good decks) and avoiding decks with high immediate gain (i.e., bad decks). By contrast, ventromedial prefrontal patients do the opposite by preferring decks with high immediate reward to those with smaller reward, although the decks with smaller reward are advantageous in the long run. This pattern of findings suggests that these patients are oblivious to the consequences of their actions and that their decision-making is guided only by immediate prospects; that is, these patients appear to have a 'myopia for the future' (cf. Bechara et al., 1994; Damasio, 1994). These reports have received support from recent neuro-imaging studies, showing involvement of the ventromedial prefrontal cortex in successful anticipation on future consequences (O'Doherty, Kringelbach, Rolls, Hornak & Andrews, 2001; Rogers et al., 1999).

The purpose of this study was to examine whether children would share with ventromedial prefrontal patients the obliviousness to future consequences. This question was inspired by the converging evidence of a protracted development of prefrontal cortex throughout childhood and adolescence, suggesting an important parallel between brain maturation and cognitive development (e.g., Nelson & Luciana, 2001; Pennington, 1998; Stuss, 1992; Stuss & Knight, 2002; Van der Molen & Ridderinkhof, 1998; Welsh, 2002). With the advent of functional MRI, it has become possible to characterize changes in brain activity during cognitive development (e.g., Casey et al., 1995). The findings emerging from brain imaging studies lend support for continued maturation of functions across widely distributed brain areas laying the groundwork for enhanced cognitive control during development (cf. Luna & Sweeney, 2001). For example, Casey and colleagues (for a review, Casey, Giedd, & Thomas, 2000) observed that working memory demands and the need to inhibit a prepotent response activate similar brain regions in adults and children (respectively, the dorsal and ventral prefrontal cortices). But the magnitude of this activity was greater and the pattern more diffuse for children compared to adults. Using a working memory task with functional magnetic resonance imaging (fMRI), Klingberg, Forssberg, and Wessterberg (2002) showed that working memory capacity increased between 9 and 18 years of age, and performance correlated with activation in the superior frontal and parietal regions. Similarly, recent developmental fMRI studies showed that children between 8 and 12 years of age are more susceptible to interference than adults, and that this developmental trend is paralleled by immature prefrontal activation, especially in the ventral fronto-stratial regions (Adleman et al., 2002; Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Durston, Thomas, Yand, Ulug, Zimmerman, & Casey, 2002). These findings led Casey, Davidson, and Rosen (2002) to conclude that the development of these executive functions is related to a refinement in the organization or efficiency in the recruitment of the prefrontal cortex. The prolonged maturation of the prefrontal cortex, including the ventromedial region, suggested to us that in performing the Iowa gambling task, young children will opt for immediate reward in spite of future, negative consequences.

The developmental literature on decision-making suggested initially that young children have little understanding of probability (Piaget & Inhelder, 1975). In many studies (but see Reyna & Brainerd, 1994), children were asked to compare two sets of elements of two colors and select the one in which the probability of the designated winning color was greater. The typical finding was that young children, about 4 or 5 years old, do not have an understanding of probability, or are dominated by the absolute number of winning elements without considering how many losing elements there are. This strategy is gradually replaced with the correct proportional strategy, which is used almost perfectly by most children of about 11 years old and beyond (cf. Falk & Wilkening, 1998). It should be noted, however, that a different picture is obtained when tasks were used that do not involve response selection; e.g., estimation tasks (Schlottman & Anderson, 1994; Wilkening & Anderson, 1991). These studies indicated that children as young as 5 years old already may have attained a concept of *expected value*; that is, a basic understanding that the value of a reward and the probability of attaining the reward are somehow related (e.g., Acredolo, O'Connor, Banks, & Horobin, 1989).

A major difference between the Iowa Gambling Task and the tasks employed to examine developmental change in the understanding of probability or expected value is the uncertainty involved in decision-making. In standard developmental tasks of decision-making, the reward probabilities are given, whereas in the Iowa Gambling Task the probabilities have to be inferred and learned from past experience (for a detailed discussion of this issue see Busemeyer & Townsend, 1993).

Decision-making under uncertainty does not allow for a fast cost-benefit analysis guided by simple (additive or multiplicative) rules. Damasio (1994) argued that decision-making under uncertainty requires guidance by *somatic markers*, helping to constrain the decision-making space by making that space manageable for logic-based, cost-benefit analyses. The somatic marker hypothesis assumes that linkages are formed between a situation and the affective states accompanied by the outcomes of the situation. These linkages lead to the development of somatic states providing value marks for similar future situations, thereby guiding the behavior in the new situation towards options that are advantageous in the long run. Accordingly, the performance deficit of ventromedial prefrontal patients on the Iowa Gambling Task is interpreted to suggest that their decision-making does not rely on somatic markers. By contrast, the decision-making of intact participants is guided by value marks that are negative for the disadvantageous choices and positive for advantageous choices, thereby leading their behavior towards long term favorable options (cf. Damasio, 1994; 1995; 1996).

In this study, participants between 6 and 25 performed on developmentally appropriate analogues of the Iowa Gambling Task. The basic format of the card gambling task was retained but card gambling was changed into a pro-social game inviting the player to assist a hungry donkey to win as many apples as possible. The change of card gambling into a pro-social game served the purpose of making the Iowa Task more meaningful for children and of stirring their involvement—'you cannot let a hungry donkey down' (e.g., Falk & Wilkening, 1998). The analogues were presented in a computerized format for reasons of between-participants standardization. The results of previous studies using computerized versions of the Iowa Gambling task are comparable to the results from the original paper-and-pencil version (e.g. Bechara, Damasio, Damasio, & Lee, 1999; Bechara, Damasio, et al., 2000; Schmitt, Brinkley, & Newman, 1999). Two versions of the task were constructed in accord with the strategy adopted by Bechara and co-workers for differentiating between sensitivity to future consequences versus sensitivity to reward or insensitivity to punishment (e.g., Bechara, Tranel, & Damasio, 2000). In one version, reward is placed up front and punishment is presented occasionally and unpredictably. In the other version, the reversed schedule is presented. Bechara, Damasio, et al. (2000) found that their ventromedial prefrontal patients were more influenced by the immediate prospects, positive or negative, than by the future consequences. This finding provides strong support for an interpretation of the patients' deficits in terms of obliviousness to future consequences. The differentiation between sensitivity to reward versus insensitivity to future consequences is important from a developmental perspective, as it has been shown that children's decision-making is guided by immediate gains while ignoring future prospects (e.g., Schlottmann, 2000).

Two further precautions were taken. First, suppose children fail on both versions of the gambling task. This finding can be interpreted to suggest that children share with ventromedial prefrontal patients the myopia for the future, arising from an immature functioning of the ventromedial prefrontal cortex. Alternatively, children's performance deficit could be due to the task demands on working memory, due perhaps to an immature functioning of the dorsolateral prefrontal cortex. That is, the task requires performance monitoring and the integration of performance feedback into a decision-making rule. In addition, the task requires tracking the balance between gains and losses for each option. There is a substantial literature indicating protracted developmental change in the performance on tasks requiring the integration of new, potentially relevant information within the existing information kept on-line (e.g., Fuster, 2000; Nelson, 1995; Pennington, 1994; Welsh, 2002).

Second, the gambling task requires participants to infer probabilities from past experience, and therefore an inductive reasoning component could be involved in the task (see also Busemeyer & Townsend, 1993). Carpenter, Just, and Shell (1990) argued that inductive reasoning, as measured by the Raven Standard Progressive Matrices (SPM) test, requires at least two general skills. First, it requires the ability to manage problem-solving skills in working memory, and second, it requires the ability to cope with novelty of a problem. Given that the gambling tasks require tracking the balance between gain and loss in a novel and uncertain situation, inductive reasoning could be an important skill that is required during gambling performance.

These two precautions (i.e., task demands on working memory and inductive reasoning in addition to risky decision-making) were addressed by design features of two separate experiments. Experiment I examined age-related change in risky decision-making and assessed whether the anticipated developmental change in risky decision-making was influenced by the task demands on working memory and inductive reasoning. The demands on working memory were varied by providing participants with a running count of their earnings and losses that could be option specific (i.e., related to a specific deck), global (i.e., averaged across decks) or absent (no feedback was given). The influence of inductive reasoning was assessed by asking participants to complete a computerized version of the Raven SPM (e.g., Vodegel Matzen, 1994), which is considered a well-accepted test of inductive reasoning capacity (Carpenter et al., 1990). The goal of Experiment II was twofold: (a) examining the robustness of the developmental change in risky decision-making that was observed in Experiment I, and (b) reassessing the influence of the task demands on working memory by having participants perform on a standard working memory task, the Digit Span Task from the Wechsler Intelligence Scale for Children–Third Edition (WISC–III; Wechsler, 1991).

EXPERIMENT 1

The primary objectives of Experiment 1 were to examine developmental patterns in risky decision-making and to assess the potential influence of working memory and inductive reasoning on gambling task performance. Children of two age groups, adolescents, and young adults performed on an analogue of the Iowa Gambling Task, using a standard version, in which reward was immediate and losses delayed, and a second version of the task in which these schedules were reversed (Bechara et al., 1994; Bechara et al, 2000).

The influence of working memory demands was examined by constructing three feedback-tracking levels of both the standard and reversed tasks. At the lowest level of working memory demand, each selection was followed by an update of the tally of wins and losses for each option, thus eliminating the need for feedback tracking. At the intermediate level of working memory demand, each selection was followed by updating a global tally of wins or losses, averaging across options. At this level, the performance feedback is comparable to the information provided by the money deck in the original Iowa Gambling Task (e.g., Bechara et al., 1994). At the highest level of working memory demand, players did not receive a tally of wins or losses—neither option-specific tallies nor a global tally averaged across options. It was anticipated that (a) with decreasing demands on feedback tracking, players would avoid disadvantageous options sooner, and that (b) children who fail at the highest level of feedback-tracking demands might succeed at a lower level.

The Raven SPM was used to provide an index of inductive reasoning (Carpenter et al., 1990; Vodegel Matzen, 1994). Co-varying performance on the Raven SPM with performance on the gambling tasks should reveal the potential influence of inductive-reasoning ability on the capacity to anticipate on future consequences.

Method

Participants

Four age groups participated in the study: 61 university students aged between 18 and 25 years, 61 young children between 6 to 9 years of age, 61 older children between 10 to 12 years of age, and 59 adolescents between 13 to 15 years of age. The students were recruited through flyers and received credit points for their participation. Children and adolescents were recruited by contacting schools. These participants were selected with the help of their teacher, and their primary caregivers signed consent letters for participation. All participants were reported to be healthy and they took a computerized version of the Raven SPM to provide an estimate of their inductive reasoning ability. Within age groups, participants were randomly assigned to one of the feedback levels: option-specific feedback, global feedback, or no feedback.

Mean age, gender distributions, and SPM-scores are presented in Table 1 for each age group and feedback level. Chi-square analyses indicated that gender, but not age, differed significantly between participants assigned to different feedback levels. Because of the unevenness in gender, an initial exploratory analysis was done to assess the possibility of systematic gender effects on task performance.

TABLE 1
Descriptive Characteristics of the Participants, Per Age Group, and Feedback-Tracking Condition; Including Mean Age, Number of Boys and Girls, and Mean SPM Scores

		Age				*SPM Score*	
Group	*FB*	*M*	*SD*	*Boys*	*Girls*	*M*	*SD*
6 to 9 years	No FB	7.8	0.85	15	5	26.75	1.7
	Global FB	8.2	0.93	9	11	26.41	1.9
	Option-specific FB	7.8	1.0	9	12	25.81	1.7
10 to 12 years	No FB	11.3	0.79	13	7	34.10	1.7
	Global FB	10.9	0.79	6	14	36.62	2.0
	Option-specific FB	11.1	0.83	8	13	36.20	1.8
13 to 15 years	No FB	13.8	0.79	13	6	44.85	1.8
	Global FB	14.1	0.72	9	11	43.75	1.8
	Option-specific FB	13.6	0.67	7	13	43.08	1.8
18 to 25 years	No FB	19.9	1.1	5	15	49.05	1.8
	Global FB	20.7	1.7	3	17	47.80	1.8
	Option-specific FB	20.3	1.7	3	18	49.74	1.8

Note. SPM = standard progressive matrices; FB = feedback-tracking.

The analysis failed to reveal gender effects. A one-way analysis of variance (ANOVA) performed on the SPM scores revealed a significant difference between age groups, $F(3, 234) = 94.81$, $p < .001$. The relation between SPM scores and task performance will be examined further.

Task Format

Displays. 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 four doors presented on a horizontal row, A, B, C, and D, and a donkey sitting in front of the doors. An example of a stimulus and outcome display is presented in Figure 1. Participants were told to assist the hungry donkey to collect as many apples as possible by pressing one of four keys corresponding to the doors. The left middle, left index, right index, and right middle fingers were assigned to the *C*, *V*, *B*, and *N* keys of the computer keyboard. The *C*, *V*, *B*, and *N* keys were mapped onto the doors from left to right. Upon pressing one of the keys, the stimulus display was replaced by the outcome display showing the number of (intact) apples gained or the number of (crossed) apples lost.

Feedback-tracking. The stimulus display presented performance feedback depending on the feedback-tracking level to which the participant was assigned. At the option-specific feedback-tracking level, a small, horizontal bar was presented

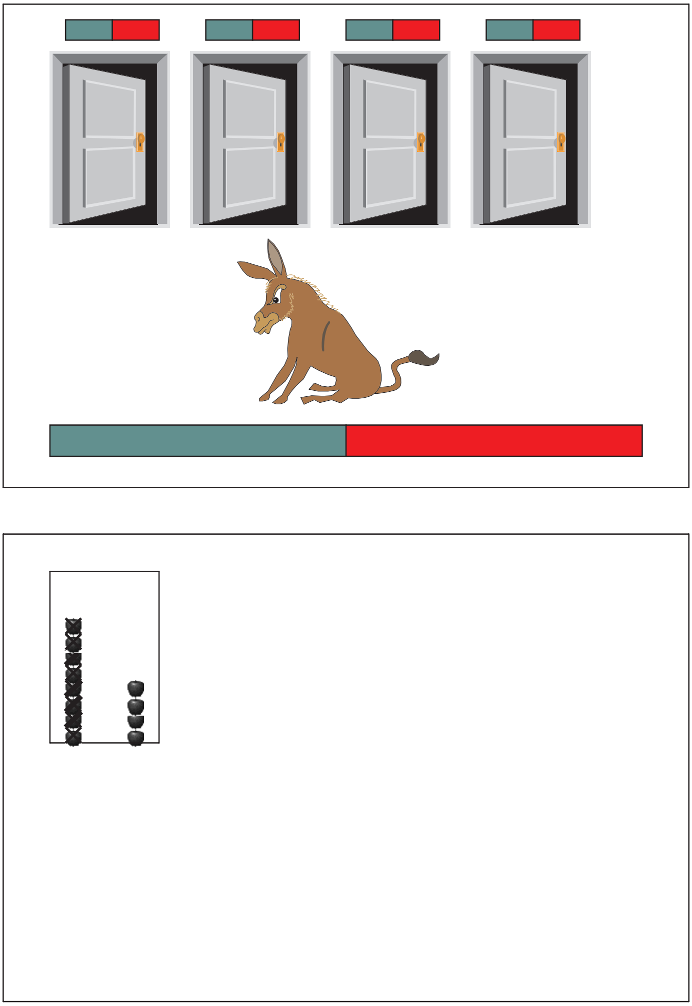

FIGURE 1 Example of stimulus display (top panel) and outcome display (bottom panel). The stimulus-screen consisted of four doors, a donkey, and bars that monitored performance (dependent on task condition). The doors were presented on the top half of the screen, approximately 2 cm from the top. They were equal in size, approximately 3 × 5 cm (length × height), and were located at a distance of approximately 2 cm from each other. The donkey (sized approximately 4 × 5 cm) was presented at the middle of the screen, approximately 1.5 cm below the doors and 2 cm above the bottom of the screen. The bars all were approximately 1 cm in height. The horizontal bar covered the whole length of the screen, until 1 cm from both sides. The bars above the doors covered the width of the doors (approximately 3 cm) and were presented approximately .5 cm above each door. Bar changes indexing the tally of wins and losses following each selection were computed using the formula: ([length/2] + [gain – loss]) / (12 × [length/2]).

just above each door and a large horizontal bar was presented just below the donkey. The left halves of the bars were colored green and the right halves were colored red. Participants were told that the green halves of the bars indicated how many apples they had won and the red halves indicated the amount of apples lost. The small bars provided this information for each door specifically whereas the large bar provided this information averaged across options. At the global-feedback tracking level, the color change of the large bar corresponded to the amounts of apples won or lost, averaged across options but the small bars were not displayed. At the no-feedback tracking level, the small and large bars were not displayed. A new trial was initiated when participants pressed the space bar of the keyboard.

Type of task. All participants performed two tasks: the standard task and the reversed task. Both tasks contained 200 trials. In the standard task, the win and loss schedule was similar to the one used by Bechara et al. (1994). That is, the relative proportions of wins and losses were identical to those used by Bechara et al. (1994) but the absolute amounts were reduced by a factor 25. The ultimate future yield of each door varied, because the wins were higher at the high paying doors (A and B), and lower at the low paying doors (C and D). Selecting door A or B resulted in a gain of four apples, whereas door C or D resulted in a gain of two apples. After selecting 10 A-doors, the participant 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 10 B-doors, the participant received 40 apples but had encountered one unpredicted loss of 50 apples, also incurring a net loss of 10 apples. After, selecting 10 C-doors, the participant received 20 apples, but had encountered five unpredicted losses of 1, 2, 2, 2, or 3 apples, bringing the cost to 10 apples, 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. Thus door D also resulted in a net gain of 10 apples. In sum, doors A and B were equivalent in terms of overall net loss over the trials. The difference was that at door A, the loss was more frequent, but of smaller magnitude, whereas at door B, the loss was less frequent but larger. Doors C and D were also equivalent in terms of overall net loss. At door C, the loss was more frequent and of smaller magnitude; at door D the loss was less frequent and of higher magnitude. Doors A and B were disadvantageous in the long run, because they resulted in a net loss; 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 a loss of four apples, whereas door C or D resulted in a loss of two apples. Again, the ultimate future yield of each door varied because the reward amounts were higher at high losing doors. After selecting 10 A-doors, the participant had lost 40 apples, but had also encountered 5 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 10 times, the participant was faced with a loss of 20 apples and 5 unpredictable gains of 1, 2, 2, 2, or 3 apples, resulting in a net loss of 10 apples. After selecting the D-door 10 times, the participant lost 20 apples, and had encountered one unpredictable gain of 10 apples, also resulting in a net loss of 10 apples. Thus, in the reversed task, doors A and B were equivalent in terms of overall net gain over the trials. The difference was that for door A the gain was more frequent and smaller in magnitude, whereas at door B the gain was less frequent but higher in magnitude. Doors C and D were also equivalent in terms of overall net gain over the trials. At door C, the gain was more frequent but of smaller magnitude, and at door D the gain was less frequent but of higher magnitude. In this 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.

Stimuli and Apparatus

The experimental tasks were presented using personal computers with 17-inch monitors, or laptop computers with 15-inch monitors. The computers registered response speed (i.e., the time interval between pressing the space bar and pressing one of the response keys) to the nearest ms. Participants were seated at a distance of approximately 75 cm from the monitor.

Instructions, Design, and Procedure

Participants were instructed to assist the hungry donkey sitting in front of the doors to win as many apples as possible. They were told that donkey families were living behind the doors. In each family, there were nice donkeys that were willing to give some apples and mean donkeys that were taking apples away. Selecting a door could therefore result in winning a certain amount of apples or winning and losing apples. Following each selection, the number of intact apples (gain) and the number of crossed apples (loss) indicated the specific earnings. The participants were told which key corresponded to each door and that they could initiate a new trial by pressing the space bar. They were told that they had to play many times but that they could switch between doors as often as they wanted. Their goal was to win as many apples as possible for the hungry donkey.

All participants were tested individually in a quiet laboratory or classroom. They performed the standard and reversed tasks in counterbalanced order. The assignment of gain/loss schedules was counterbalanced across response keys to control for finger/hand preferences. However, the disadvantageous and advantageous choices were always assigned to the same hand. Thus, the disadvantageous options were always *C* and *V* (left keys) or *B* and *N* (right keys), and vice versa for the advantageous choices. The gain and loss frequencies were counterbalanced within hands, e.g., assigned to keys *C* or *V*, and to keys *B* or *N*.

Both the standard and the reversed task took participants approximately 15 min to complete. After the completion of the standard task, participants were asked which door they preferred, and to provide a rationale for their preference. The procedure described in Bechara et al. (1997) was used for scoring. This scoring provides an estimate of the conceptual knowledge stage. These stages are (a) wrong preference (preference for disadvantageous doors; Bechara et al., 1994, referred to this stage as 'pre-punishment phase'), (b) pre-hunch phase (no idea what the task is about), (c) hunch phase (hunch that disadvantageous doors are riskier), and (d) conceptual knowledge phase (knowledge why the disadvantageous doors are disadvantageous in the long run).

The Raven SPM was administered following the completion of both tasks. Participants were then thanked for participation and students were given credit points. Including instructions and breaks, participants spent approximately 1 hr in the laboratory or classroom.

Results

The results are described in four sections. The choices made were considered first to establish adults' overall approach and to examine how children deviate from the adult strategy. The second section considered whether decision-making speed provides additional information with regard to the anticipated differences between the strategies adopted by adults versus children. The third section examined the conceptual knowledge stage and assessed whether stages can be related to developmental change in decision-making strategy. The fourth section examined the association between skills assessed by the experimental task and inductive reasoning ability as assessed by the Raven SPM.

Decision-Making Strategy

Two analyses were conducted to evaluate developmental change in decision-making strategy. The first analysis was adopted from the Iowa Gambling Task literature and consisted of calculating net score differences between advantageous and disadvantageous scores (e.g., Bechara et al., 2000; Grant, Contoreggi, & London, 2000; Schmitt et al., 1999). For the standard task, the difference was taken between the total number of choices for doors C and D (advantageous choices) minus the total number of choices for doors A and B (disadvantageous choices). For the reversed task, the net difference was between door A or B choices versus door C or D choices. A positive score indicates an overall net gain over trials whereas a negative score indicates an overall loss. Net scores were calculated across 20 trials for 10 blocks (each task comprised a total of 200 trials) to allow for an examination of strategy change during the course of task performance.

The net scores were subjected to ANOVA with Age Group (4) and Feedback Tracking (no tracking, global tracking, option-specific tracking) as between-participants factors and Type of Task (standard vs. reversed) and Trial Block (10) as within-participants factors. All main effects were significant with the exception of Feedback Tracking, F (2, 229) = 2.53; $p > .10$; Age Group, F (3,220) = 8.70, $p < .001$; Type of Task, F (1, 229) = 12.31, $p <. 005$; and Trial Block, F (9, 2061) = 6.56, $p < .001$. The only interaction that reached significance was between the effects of Age Group and Trial Block, F (27,1980) = 4.92, $p < .001$. This interaction is plotted in Figure 2. It can be seen that overall gain (indexed by the net difference score) increased for adult participants during the course of task performance. By contrast, there seems to be little if any gain for the two youngest groups, and this did not change during task performance. These visual impressions were statistically verified by post-hoc comparisons yielding a significant difference between adults and adolescent children, F (3, 990) = 3.30, $p < .001$, and a significant difference between the adolescents versus the two youngest age groups, F (9, 990) = 3.61, $p < .01$, that did not differ amongst each other, F (9, 981)= 1.53, $p > .10$.

The second ANOVA focused on the actual choices, and thus included two additional within-participants factors: Gain (advantageous vs. disadvantageous choices) and Frequency (i.e., doors associated with frequent vs. occasional punishment/reward). The most important result that emerged from this ANOVA was an interaction

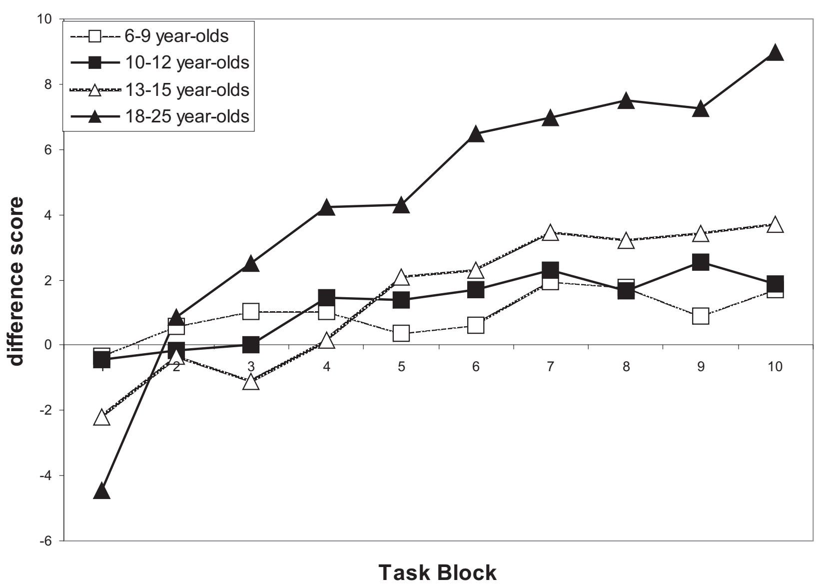

FIGURE 2 Net scores as a function of trial block for each age group averaged across the standard and reversed tasks.

between Age Group, Gain and Trial Block, $F(27, 1980) = 4.92, p < .001$. The interaction is depicted in Figure 3, showing that adults started to select advantageous doors early during task performance, whereas children developed this preference only later, if at all. Post-hoc analyses revealed that adults made significantly more advantageous than disadvantageous choices from the third trial block onwards. For the adolescent group, the shift in preference occurred at the fifth trial block. The difference between advantageous versus disadvantageous choices remained unreliable for the two youngest groups of children, $F(9, 981) = 1.53, p > .10$.

The interaction between Gain and Type of Task was also significant, $F(1, 229) = 12.31, p < .001$. In the reversed task, the mean number of advantageous choices relative to the mean number of disadvantageous choices was higher than in the standard task (11.38 vs. 8.62 and 10.62 vs. 9.38, respectively). The effect of Type of Task was also included in an interaction with the effects of Trial Block and Frequency, $F(9, 2061) = 9.04, p < .001$. This interaction, plotted in Figure 4, shows that during the performance on the standard task, participants increasingly preferred choices associated with low frequency (but large) punishment relative to high frequency (but smaller) punishment. Their performance on the reversed task showed an increasing preference for choices associated with a high frequency (but low) reward relative to a low frequency (but high) reward. All other interactions and the main effect of Feedback Tracking failed to reach significance (ps > .10).

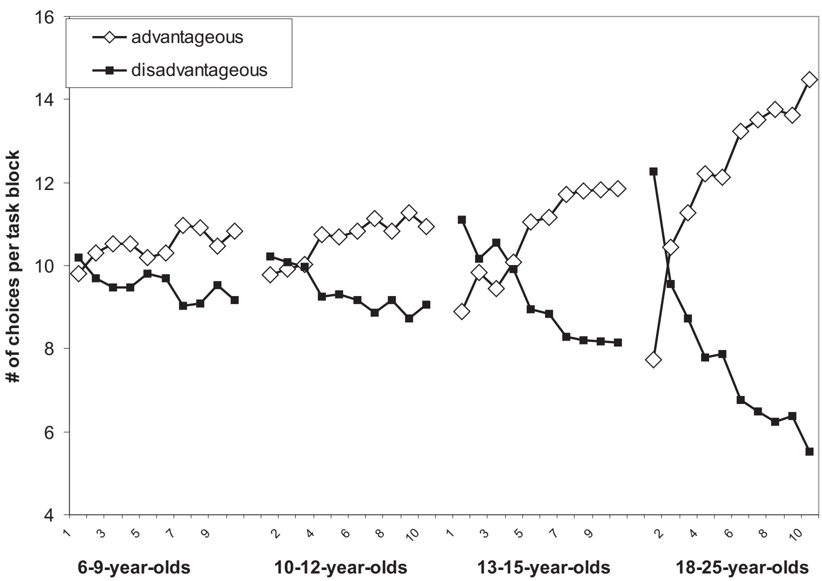

FIGURE 3 Number of advantageous and disadvantageous choices as a function of trial block, for each age group separately.

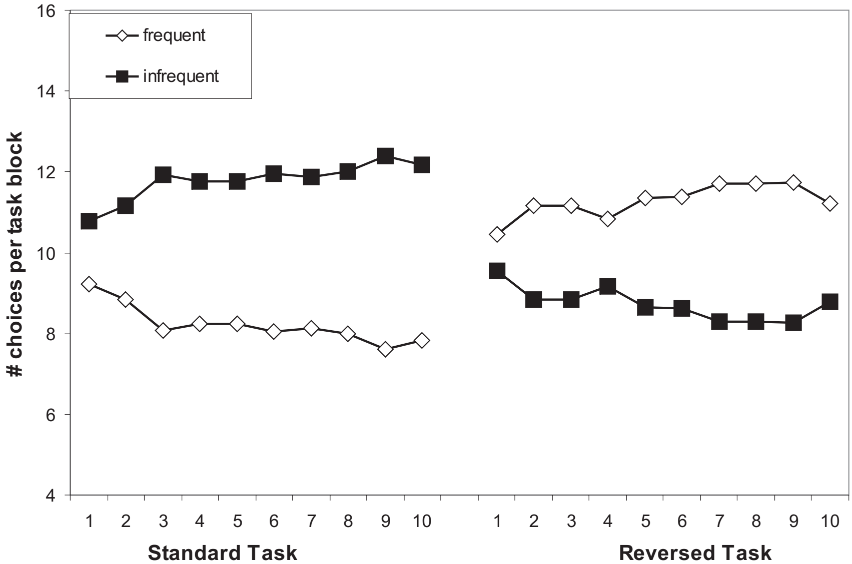

FIGURE 4 Number of choices associated with high frequency punishment or low frequency punishment as a function of trial block in the standard task (left panel). Number of choices associated with low frequency reward or high frequency reward as a function of trial block in the reversed task (right panel).

A third ANOVA performed on actual choices focused on local effects of loss in the standard task. For this analysis, we compared the frequency (%) with which participants switched response options following gain and loss. The 4 (Age Group) × 3 (Feedback Tracking) × 2 (Gain/Loss) ANOVA resulted in main effects of Age Group, F (3, 229) = 15.46, $p < .001$, and Gain/Loss, F (1, 229) = 249.00, $p < .001$. The Age effect showed that, in general, young children switched choices more (76%) than older children (73%), adolescents (66%) and adults (49%) and the Gain/Loss effect showed that, as expected, participants switched choices more often following loss (78%) than following gain (55%). An interaction between Age/Group and Gain/Loss showed that the difference in choice switches following gain versus loss was larger for adults than for the three younger age groups, F (3, 229) = 4.92, $p < .01$. However, separate post hoc analyses showed that differences were highly significant for each age group. That is, the percentage choice switches following loss was higher than the percentage choice switches following reward for young children (84% vs. 69%), F (1, 57) = 30.09, $p < .001$, older children (85% vs. 61%), F (1, 56) = 62.52, $p < .001$, adolescents (77% vs. 54%), F (1, 58)= 61.75, $p < .001$, and adults (65% vs. 35%), F (1, 58) = 101.84, $p < .001$. Feedback tracking did not have a significant effect.

Decision-Making Speed

Median reaction times (RTs) were computed across the first and second 100 trials for each task separately. The median RTs for each task were subjected to an ANOVA with Age Group (4) and Feedback Tracking (3) as between-participants factors and Task Half (first vs. second 100 trials), Gain (2), and Punishment Frequency (2) as within-participants factors. The standard-task ANOVA yielded a significant effect of Age Group, F (3, 221) = 12.50, $p < .001$, and this effect was included in an interaction with Gain, F (3, 221) = 3.28, $p < .025$. The interaction is plotted in Figure 5, showing that the two oldest groups (adults and 13–15 year olds, F (1,109) = 9.52, $p < .001$) selected advantageous doors faster than disadvantageous doors. This difference was not significant for the two youngest groups, F (1,112) = 1.81, $p > .10$. The standard-task ANOVA yielded also a significant main effect of Punishment Frequency, F (1, 221) = 48.64, $p < .001$. This effect was also included in an interaction with Gain, F (1, 221) = 7.622, $p < .01$. This interaction showed that disadvantageous responses to doors associated with infrequent punishment were faster (776 ms) compared to doors associated frequent punishment (888 ms), F (1, 222) = 34.93, $p < .001$. The opposite pattern was obtained for advantageous responses; that is, faster responses associated with frequent punishment (778 ms) relative to responses associated with infrequent punishment (838

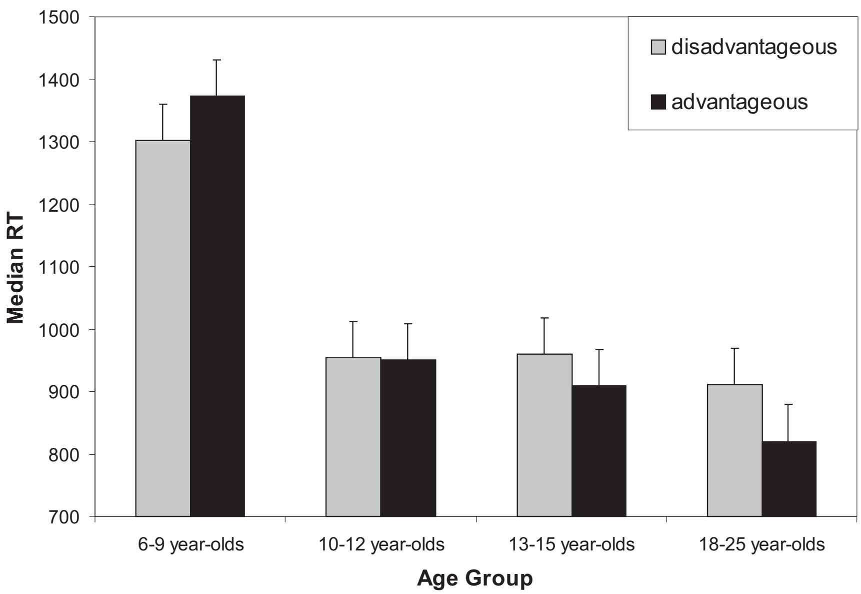

FIGURE 5 Median Reaction Times associated with advantageous and disadvantageous choices in the standard task, for each age group.

ms), F (1, 225) = 8.52, $p < .001$. Finally, the standard-task ANOVA revealed significant main effects of Task Half, F (1, 221) = 51.09, $p < .001$, and Feedback tracking, F (2, 221) = 7.28, $p < .001$. The effect of Task Half consisted of faster responses during the second half of the task compared to the first half, 757 and 879 ms, respectively. The Feedback-Tracking effect consisted of slower responses when option-specific feedback was provided (927 ms) relative to global feedback (806 ms) and no feedback (720 ms). The effect of Feedback Tracking did not interact with any of the other factors included in the standard-task ANOVA.

A similar ANOVA was done for the median RTs obtained from the reversed task. The reversed-task ANOVA showed a significant main effect of Age Group, F (3, 210) = 11.55, $p < .001$. There was an age-related increase in the speed of responding from 927 ms for the 6–9 year olds, to 765 ms, 672 ms, and 712 ms for the 10–12 year olds, 13–15 year olds, and adults, respectively. The other significant effects were for Feedback Tracking, F (2, 210) = 7.71, $p < .001$; Reward Frequency, F (1, 210) = 12.66, $p < .01$; and Task Half, F (1, 210) = 52.36, $p < .001$. The Feedback-Tracking effect consisted of slower responses when option-specific feedback was provided (877 ms), compared to global feedback (780 ms), and no feedback (684 ms). Responses were faster to doors associated with frequent rewards (760 ms) compared to door associated with infrequent rewards (880 ms). Finally, responses were faster during the second half of the reversed task (724 ms) relative to the first half (836 ms). Other main effects or interactions were not significant, (p's > .10).

Conceptual Knowledge Stage

The responses obtained from the strategy interview were categorized into one of four knowledge stages, as defined in Bechara et al. (1997). These responses were obtained only for the standard task and the response frequencies are presented in Table 2. Chi-square analysis indicated that age groups differed significantly in their conceptual knowledge stage, $\chi^2(9) = 52.45, p < .001$. Very few participants reported they didn't use a strategy ("don't know"), suggesting that most participants had at least a basic preference for a specific choice. Most adults reached the "hunch" or "conceptualization" stage, 88%. This percentage decreased to 68% for the adolescents and to 50% and 31% for the two youngest age groups. After task completion, about 54% of the two youngest age groups reported to prefer risky choices, "wrong preference" strategy. This percentage was reduced to 28% and 10% for the adolescent and adult groups, respectively.

To examine the relation between reported strategy and actual responses, a Knowledge Stage (4) × Trial Block (10) ANOVA was performed on the net scores obtained from the standard task. The ANOVA yielded significant main effects of Knowledge Stage and Trial Block that were included in a significant interaction, F (27, 2061) = 2.45, $p < .001$, that is depicted in Figure 6. It can be seen that the "con-

TABLE 2
Conceptual Knowledge Stage for Each Age Group

Stage	*Age Group*	*Number*	*%*
Wrong preference	6 to 9 years	34	59.6
	10 to 12 years	27	45.8
	13 to 15 years	17	28.3
	18 to 25 years	6	10.3
Don't know	6 to 9 years	5	8.8
	10 to 12 years	2	3.4
	13 to 15 years	2	3.3
	18 to 25 years	1	1.7
Hunch	6 to 9 years	11	19.3
	10 to 12 years	10	16.9
	13 to 15 years	7	11.7
	18 to 25 years	11	19.0
Conceptual knowledge	6 to 9 years	7	12.3
	10 to 12 years	20	33.9
	13 to 15 years	34	56.7
	18 to 25 years	40	69.0

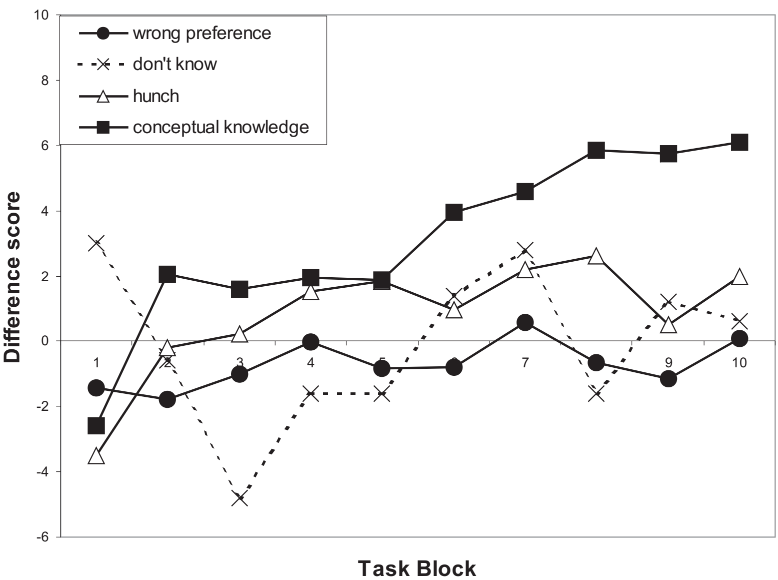

FIGURE 6 Net scores as a function of trial block in the standard task for each Knowledge Stage.

ceptual-knowledge" stage is associated with an increase in advantageous responding during the course of task performance. A similar trend, albeit less pronounced, can be observed for the "hunch" stage. The "wrong preference" stage is associated with little difference between advantageous versus disadvantageous choices and this does not change during the course of task performance. The "don't know" stage reveals a jagged pattern. The fact that this pattern is based on only few observations may contribute to its unevenness.

Inductive Reasoning Ability

The association between decision-making strategy and inductive reasoning was explored to assess whether the Age Group × Trial Block interaction remained significant after the age effects on inductive reasoning were partialled out. Net scores were subjected to an analysis of covariance (ANCOVA) with Age Group (4) and Feedback Tracking (no tracking, global tracking, option-specific tracking) as between participant factors and Type of Task (standard vs. reversed) and Trial Block (10) as within-participants factors. A significant effect of Age group, $F(3, 220) = 5.76$, $p < .001$, was obtained, and most importantly, an interaction between Age Group and Trial Block, $F(27,1980) = 2.75$, $p < .001$. Correlation analyses done within each separate age group examining the relation between SPM scores and the number of advantageous choices failed to reveal significant findings (all r's < .18). These results indicate that inductive-reasoning ability, as measured in this study, does not contribute to the observed developmental trend in risky-decision making.

Discussion

The adult findings of this experiment yielded a perfect replication of the results reported previously by Bechara et al. (1994; Bechara et al., 2000). That is, adults made increasingly more advantageous choices during the course of task performance. In addition, type of task (standard vs. reversed) did not influence this pattern. Most importantly, however, these findings showed a strong developmental trend in the ability to anticipate on future consequences. This trend cannot be explained by a reward-oriented response style, as it was observed also for the decisions made in the reversed task, in which punishment was placed up front and reward was presented occasionally and unpredictably. Moreover, inductive-reasoning ability did not influence the age-related change in gambling task performance.

Finally, it was anticipated that feedback would assist participants in making advantageous choices by reducing uncertainty and working memory demands. This prediction was not supported by the data. Feedback tracking failed to facilitate decision-making. This failure may raise the question of whether participants actually used the feedback provided to them. Although performance feedback did not affect the choices being made, it did have an effect on response speed. The analysis of median RTs indicated that responses were delayed when more detailed feedback was provided. This pattern could be interpreted to suggest that the information provided by the feedback was evaluated, and thus delayed the response. But the outcome of the feedback evaluation was not used for guiding decision-making. The question then remains whether the lack of an effect of feedback indicates that participants, especially children, did not understand the feedback manipulation or that working memory load is not relevant to this task. A second experiment was therefore performed to further assess the potential interaction between working memory load and risky decision making on the Iowa Gambling Task.

EXPERIMENT 2

In this experiment, participants performed on the standard and reversed versions of the gambling task used in the previous experiment but received only global feedback. In addition, participants took the Backward Digit Span task from the WISC-III (Wechsler, 1991), which provide an index of working memory capacity. The Backward Digit Span task is often used as a measure of working memory, as it requires not only holding information on-line but also manipulating it (Baddeley, 2002; Diamond, 2002; Mesulam, 2002). In addition, marked improvements in the number of digits held in mind have been reported between ages 7 and 13 (Dempster, 1981; Diamond, 2002). We predicted that if gambling performance reflects the ability to anticipate future outcomes, independent of the capacity to store information in working memory, then developmental changes in gambling performance should remain significant once variance that can be attributed to working memory was partialled out.

Method

Participants. Three age groups participated in the study: 30 young children between 7 to 8 years of age, 30 older children between 11 to 12 years of age, and 29 adolescents between 15 to 16 years of age. Children and adolescents were recruited by contacting schools. These participants were selected with the help of their teacher, and their primary caregiver signed a consent letter for participation. All participants were reported to be healthy and to perform at school at average level or above.

All participants were given a standardized administration of the Digit Span task (forwards and backwards) from the WISC-III (Wechsler, 1991), to obtain an estimate of their working-memory capacity. Mean age, gender distributions and working-memory scores are presented in Table 3 for each age group, separately. Preliminary analysis revealed no significant difference in gender distribution between age groups.

TABLE 3
Descriptive Characteristics of the Participants Per Age Group; Including Mean Age, Number of Boys and Girls, and Standardized Digit Span Scores (Experiment 2)

	Age				*Standardized Digit Span Score*		*Digit Span Backward Score*	
Group	*M*	*SD*	*Boys*	*Girls*	*M*	*SD*	*M*	*SD*
7 to 8 years	7.8	.85	17	13	9.67	3.25	3.03	.30
11 to 12 years	11.3	.79	11	19	10.26	2.27	5.07	.30
15 to 16 years	15.8	.79	19	10	10.52	2.69	6.14	.31

Task format. Stimulus displays, stimuli, and apparatus were the same as in Experiment 1. All participants completed the standard and reversed tasks with only global feedback. The order of tasks was counterbalanced across participants. The gain and loss schedules were similar to those in Experiment 1.

Instructions, design and procedure. Design and procedure were the same as in Experiment 1. Participants took the Digit Span task after they were done with the two versions of the gambling task.

Results and Discussion

Age differences in working memory. A one-way ANOVA performed on the Digit Span Backward scores revealed a significant difference between age groups, F (2, 86) = 26.57, $p < .001$. Post hoc comparisons showed that adolescents reported more numbers than older children, F (1, 57) = 54.59, $p < .001$, and older children reported more numbers than younger children, F (1, 58) = 27.92, $p < .001$. A similar ANOVA performed on standardized Digit Span scores (based on both forward and backward performance) revealed no differences between age groups, F (2, 86) = .74, $p = .48$. As can be seen in Table 3, the scores observed for the three age groups were close to average standard scores.

Decision-making strategies. As in Experiment 1, two analyses were conducted to evaluate developmental change in decision-making strategy. First, the net scores were subjected to ANCOVA with Age Group (3) as between-participants factor and Type of Task (standard vs. reversed) and Trial Block (10) as within-participants factors. The Digit Span Backwards scores were added as covariate factor. A main effect of Type of Task, F (1, 81) = 5.42, $p <. 05$, revealed higher net scores in the reversed than in the standard task. There were no main effects of Age Group, F (2, 81)= .29, $p = .75$, and Trial Block, F (9, 729)= .93, $p =$

.50, but their interaction reached significance, F (18, 729) = 2.33, $p < .001$. This interaction is plotted in Figure 7. It can be seen that, as in Experiment 1, overall gain (indexed by the net difference score) increased for adolescent participants during the course of task performance. By contrast, there seems to be little if any gain for the two youngest groups, and this did not change during task performance. These visual impressions were statistically verified by post-hoc comparisons yielding a significant difference between adolescents versus the two youngest age groups, F (9,738)= 2.09, $p < .05$, who did not differ amongst each other, F (9, 432)= .80, $p >$ .05. Digit Span Backwards did not alter the Age × Task Block interaction (correlation with number of advantageous choices, $r = .13$, *ns*).

The second ANCOVA focused on the actual choices, and thus included two additional within-participants factors; Gain (advantageous vs. disadvantageous choices) and Frequency (i.e., doors associated with frequent vs. occasional punishment/reward). The effect of Frequency was included in an interaction with Type of Task, F (9, 2061) = 9.04, $p < .001$. As in Experiment 1, participants increasingly preferred choices associated with low frequency (but large) punishment (M = 11.58, SD = .10) relative to high frequency (but smaller) punishment (M = 8.42, SD = .10). Their performance on the reversed task showed an increasing preference for choices associated with a high frequency (but low) reward (M = 11.28, SD = .12)

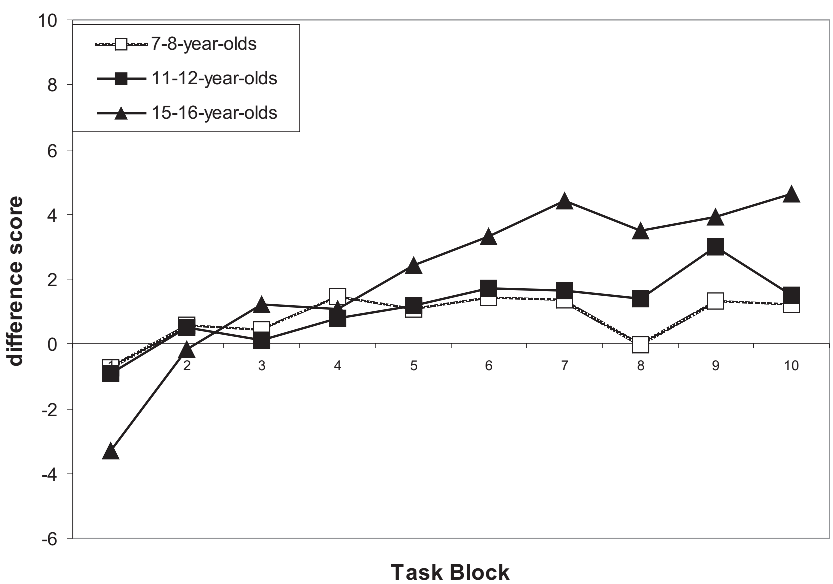

FIGURE 7 Net scores as a function of trial block for each age group averaged across the standard and reversed tasks (Experiment 2).

relative to a low frequency (but high) reward (M = 8.72, SD = .12). There were no further interactions including the factor frequency.

The results that emerged from this analysis are consistent with the notion that younger children are less capable than adolescents to anticipate on future outcomes. Younger children more often chose for disadvantageous options that resulted in immediate profit, whereas adolescents learned to opt for long-term advantageous choices during the course of task performance. Most importantly, the results ruled out an interpretation of this developmental trend in terms of age-related changes in working-memory capacity, as measured by Digit Span Backwards. That is, the Digit Span Backward scores discriminated significantly between age groups but were not related to the gambling performance. This pattern of findings suggest that the ability to anticipate future outcome and working-memory capacity draw upon independent mechanisms.

GENERAL DISCUSSION

The results that emerged from this study are discussed in two sections. The first section examines whether the results obtained from adult participants performing this analogue of the Iowa Gambling Task are consistent with the findings reported by previous studies employing the original version of the task. It also examines whether the detailed focus on the actual made choices and the speed with which these decisions were made contribute to a deeper understanding of the decision-making processes engaged by the task. Developmental trends will be examined in the second section.

Adult Decision Making

The net-scores analysis of adult decision-making in Experiment 1 yielded a pattern of findings that is highly comparable to the results reported previously by Bechara and coworkers for intact participants (Bechara et al., 1994; Bechara et al., 1997; Bechara, Damasio, Tranel, & Anderson, 1998; Bechara et al., 1999). Adults sampled first from all doors and then selected advantageous doors and avoided disadvantageous ones. Moreover, the preference for advantageous doors occurred at the same instant; that is, after 2 trial blocks or approximately 40 trials (e.g., Bechara et al., 2000). The preference for advantageous doors persisted for the remainder of the task and was similar for the standard task and the reversed task, as in the Bechara, Damasio, et al. (2000) studies. It is important that these preferences appeared independent of the involvement of inductive reasoning and working memory capacity. 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 dorsolateral prefrontal patients showed the opposite pattern. This dissociation suggests that decision-making functions relatively independent of working memory capacity (see also Bechara et al., 2000).

Our detailed focus on actual choices made revealed an interesting pattern of findings. During the performance of the standard task, participants developed a preference for advantageous choices associated with a low punishment frequency. When performing the reversed task, they developed a preference for advantageous choices associated with a high reward frequency. This pattern is interesting in that it suggests that, although participants ’ decision-making is guided by a long-term goal (i.e., maximize yield) rather than immediate prospects, their local choices are still reward-driven. Recall that in the standard task, the advantageous choices do not differ in terms of overall net loss. They differ in terms of punishment frequency; i.e., one choice is associated with frequent but small magnitude of punishment, whereas the other choice is associated with infrequent punishment that is higher in magnitude. The preference for the latter choice seems to suggest that participants opt for reward and try to avoid punishment. In the reversed task, one advantageous choice is associated with a frequent but small reward, whereas the other advantageous choice is associated with an infrequent but large reward. The preference for the former choice, again, suggests that participants are reward-oriented. Nonetheless, their sensitivity to reward does not seem to interfere with their long-term strategy of maximizing ultimate yield.

The information provided by the RT analysis indicated that, at least in the standard task, advantageous choices were made faster than disadvantageous choices and that disadvantageous choices associated with infrequent punishment were made faster than disadvantageous choices associated with frequent punishment. A trivial interpretation of this pattern of findings is that the latency differences in selection speed are simply due to “time-on-task.” Recall that choices were made faster during the second half of the task compared to the first half. Furthermore, more advantageous choices were made later compared to the initial stages of the task. Finally, most advantageous choices were choices associated with infrequent punishment.

Alternatively, and not necessarily inconsistent with the trivial interpretation, this pattern could be interpreted in terms of the decisional-field theory proposed by Busemeyer and Townsend (1993). These authors suggest that decision-making is biased by preference states derived from previous choices. This bias causes the more favorable choice to be selected more quickly. Possibly, preference states may act as a somatic marker, by reducing the decision-making space (cf. Damasio, 1995), and bias the selection process towards favorable options. When preference states are not available or somatic markers are absent, decision-making is less efficient; that is, it is more time consuming and its outcomes are less favorable than possible.

Finally, participants were quizzed to provide a rationale for the strategy they had adopted while performing the task. Their responses were categorized by using the conceptual-knowledge stages proposed by Bechara et al. (1997). Most adult responses were indicative of the 'hunch' or 'conceptualization' stage; few adults provided responses suggestive of the 'wrong preference' stage, that is, a stage associated with a preference for risky choices that are disadvantageous in the long run. The validity of this categorization was supported by the observation that the 'conceptual-knowledge' stage was associated with an increase in advantageous choices during the course of task performance. These findings indicate that adult participants are well aware of the strategy they adopted to maximize ultimate yield.

All in all, it seems fair to conclude that this version of the Iowa Gambling Task yielded a pattern of findings that is virtually identical to the results reported by previous studies using the original version. The pattern of adult findings provides the context for a discussion of developmental changes in the performance on the Hungry Donkey Task.

Developmental Changes in Decision-Making

Under the hypothesis that prefrontal brain cortex does not mature until late in adolescence (e.g., Nelson & Luciana, 2001; Pennington, 1998; Van der Molen & Ridderinkhof, 1998; Welsh, 2002), it was predicted that the ability to make long-term advantageous choices, an ability purportedly relying on ventromedial prefrontal function (Bechara et al., 1994; Bechara et al., 2000; O'Doherty et al., 2001; Rogers et al., 1999), would increase with age. Our findings are consistent with this prediction and suggest that children share with ventromedial prefrontal patients the obliviousness for future outcomes.

The analysis of net scores indicated that with advancing age, participants made increasingly more advantageous choices during the course of task performance. Most interestingly, type of task did not influence this pattern. This finding is important in that it rules out an interpretation of children's failure to consider future consequences in terms of reward sensitivity (Bechara et al., 1994; Bechara et al., 2000). Alternatively, it could be argued that children's failure to consider future consequences must be attributed to their lack of an understanding of probability (e.g., Piaget & Inhelder, 1975), but recent studies suggest that even 5-year-olds may have a basic understanding of the concept of probability (Anderson & Schlottmann, 1991). It should be noted, however, that probability has many faces, and that different trends in the development of probability understanding have been observed, depending upon the type of judgment and reasoning required (cf. Falk & Wilkening, 1998). Moreover, this task requires the ability to understand that when probabilities are different, outcomes will be different, but only in the long run. Most likely, this understanding is attained much later than the concept of probability equitably that is assessed in most developmental studies of probability understanding. Indeed, these results suggest that children's decision-making is influenced primarily by immediate prospects. The ability to consider future consequences does not seem to emerge until adolescence, which would agree with Piaget and Inhelder's conclusion that a full understanding of probability (including the notion that the actual situation may differ from long-term outcome) is not present until formal operations (Tryphon & Voneche, 2000).

A second important finding was that working memory did not seem to influence developmental trends in advancing capacity to anticipate on future outcomes. Both experiments failed to reveal an effect of working memory capacity. This finding is important, given that recent theoretical accounts on frontal lobe/executive functions have proposed that developmental changes in frontal lobe functioning may be characterized by separate cognitive processes; working memory and inhibition (e.g., Diamond, 2002; Pennington, 1994; 1998; Welsh, 2002). These theoretical accounts have received support from developmental fMRI studies, showing that ventral and dorsal prefrontal areas are separately involved in respectively increased inhibition and working memory capacity during childhood (Adleman et al., 2002; Bunge, et al., 2002; Casey et al., 1995; Casey et al., 2000; Durston et al., 2002). Beveridge, Jarrold, & Pettit (2002), for example, reported significant age-related improvement in 6- to 8-year-old children in both working memory and inhibition but, interestingly, no evidence for an interaction between these functions (but see also Roberts & Pennington, 1996).

The role of inhibitory control in gambling performance was examined in a separate study (Crone, Vendel, & Van der Molen, 2003), in which we made a distinction between behavioral inhibition and cognitive inhibition, the former referring to an important aspect of executive control, and the latter referring to inhibition as a trait dimension. In this study, we observed that trait disinhibited individuals (as assessed with the disinhibition subscale of Zuckerman's, 1979, Sensation Seeking Scale) performed less advantageous on the standard, but not the reversed gambling task, suggesting a reward oriented response style. Behavioral disinhibition (as assessed with the Matching Familiar Figures Test), however, was not related to gambling performance. The implication of these and our results is that individual differences in working memory capacity and behavioral inhibition seeming do not affect the ability to anticipate on future outcomes. Future research, involving different indexes of working memory and other concepts' inhibitory ability, is needed to assess the robustness of these results.

Finally, inductive reasoning, as indexed by performance on the Raven SPM, was not related to advantageous decision making. Inductive reasoning requires participants to create and store subgoals in working memory, preserve previous progress, and then derive a rule linking responses to the correct stimulus (cf. Carpenter et al., 1990). The finding that the ability to anticipate future outcomes was not related to the participants' SPM scores suggest that the observed developmental trend in gambling performance is due to obliviousness to future outcomes, rather than age-related changes in the ability to keep important information on-line and to use this information for rule-guided performance.

It should be noted that the analysis of the net scores revealed that for the two youngest age groups, the number of advantageous versus disadvantageous choices was about equal, and did not change during the course of task performance. This finding may suggest that the two youngest age groups continued sampling all options equally (i.e., a random-choice strategy). If true, this suggestion might imply that the children were either not engaged by the task or failed to understand its meaning. The latter suggestion can be ruled out on the basis of the results that emerged from the analysis of the actual choices made. First, all age groups switched strategy following loss, showing that for all age groups feedback directly influenced the decision on the next stimulus encounter. Second, all age groups preferred advantageous options associated with low frequency punishment when performing the standard task and advantageous options associated with high frequency reward when performing the reversed task. This pattern suggests that, like adults, children's choices are oriented toward reward, not random. But unlike adults, in opting for reward children failed to consider future consequences, as is apparent from the non-diverging number of advantageous versus disadvantageous choices as the task was progressing.

A final important finding, indicative of the children's understanding of the task, is provided by the responses they gave when quizzed to provide a rationale for their strategy. Only few children responded that they did not know. Most children's responses were categorized at the "wrong preference" level. That is, they preferred risky choices oriented toward immediate gain while ignoring the possibility of future punishment. Interestingly, there were a considerable number of children who reached the "hunch" or "conceptual" level, suggesting that they had a vague, if not full, understanding of the need to consider immediate prospects in view of future consequences. The nature of these individual differences should be investigated in a special study.

In closing, it should be noted that adults selected advantageous options faster than disadvantageous options. This finding was interpreted to suggest that preference states (Busemeyer & Townsend, 1993) or somatic markers bias selection processes by reducing the decision-making space, and thus facilitate the selection of advantageous options. Children did not select advantageous options faster than disadvantageous options. This finding may suggest that they did not take advantage of somatic markers or that somatic markers were not available to them. These possibilities should be investigated in the future by recording autonomic nervous system measures during task performance.

ACKNOWLEDGMENTS

This research was supported by Nederlands Wetenschappelijk Onderzoek–SGW Grant 222–0590 from the Netherlands Science Organization.

We thank Charlotte de Liagre Bohl, Sandra Eriksson, Clara Hammer, Hanneke van Kempen, Michel Koerts, and Volker Krenz for their help in collecting the data. The technical assistance by Bert van Beek was greatly appreciated.

REFERENCES

Acredolo, C., O'Connor, J, Banks, L, & Horobin, K. (1989). Children's ability to make probability estimates: Skills revealed through application of Anderson's functional measurement methodology. *Child Development, 60*(4), 933–945.

Adleman, N. E., Menon, V., Blasey, C. M., White, C. D., Warsofsky, I. S., Glover, G. H., & Reiss, A. L. (2002). A developmental fMRI study of the stroop color-word test. *Neuroimage, 16*(1), 61–75.

Anderson, N. H., & Schlottmann, A. (1991). A developmental study of personal probability. In Anderson, N. H. (Ed.), *Contributions to information integration theory: Vol. III Developmental* (pp. 111–134). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Baddeley, A. (2002). Fractionating the central executive. In D. T. Stuss & R. T. Knight (Eds.). *Principles of frontal lobe function* (pp 246–260). Oxford, New York: University Press.

Bechara, A., Damasio, A. R., Damasio, H & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7–15.

Bechara, A., Damasio, H., & Damasio, A. R. (2000) Emotion, decision-making and the orbitofrontal cortex. *Cerebral Cortex, 10*(3), 295–307.

Bechara, A., Damasio, H., Damasio, A. R. & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *The Journal of Neuroscience*, *19*(13), 5473- 5481.

Bechara, A., Damasio, H., Tranel, D., & Anderson, S. W. (1998). Dissociation of working memory from decision-making within the human prefrontal cortex. *The Journal of Neuroscience*, *18*(1), 428–437.

Bechara, A., Damasio, H., Tanel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, *275*, 1293–1295.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain, 123*(11), 2189–2202.

Beveridge, M., Jarrold, C., & Pettit, E. An experimental approach to executive fingerprinting in young children. *Infant and Child Development, 11*(2), 107–123.

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, J. D. E. (2002). Immature frontal lobe contributions to cognitive control in children: Evidence from fMRI. *Neuron, 33*(2), 301–311.

Busemeyer, J.R., & Townsend, J. T. (1993). Decision field theory – A dynamic cognitive approach to decision-making in an uncertain environment. *Psychological Review, 100* (3), 432–459.

Carpenter, P. A., Just, M. A., & Shell, P. (1990) What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological Review, 97*(3), 404–431.

Casey, B. J., Cohen, J. D., Jezzard, P., Turner, R., Noll, D. C., Trainor, R. J., Giedd, J., et al. (1995). Activation of prefrontal cortex in children during a nonspatial working memory task with functional MRI. *Neuroimage, 2*, 221–229.

Casey, B. J., Davidson, M., & Rosen, B. (2002). Functional magnetic resonance imaging: Basic principles of and application to developmental science. *Developmental Science, 5*(3), 301–309.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000) Structural and functional brain development and its relation to cognitive development. *Biological Psychology, 54*, 241–257.

Crone, E. A., Vendel, I., & Van der Molen, M. W. (2003). Decision-making in disinhibited adolescents and adults: Insensitivity to future consequences or driven by immediate reward? *Personality and Individual Differences, 35,* 1625–1641.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason and the human brain.* New York: Grosset/Putnam.

Damasio, A. R. (1995). On some functions of the human prefrontal cortex. In J. Graftman, K. J. Holyoak, & F. Boller (Ed.), *Structure and functions of the human prefrontal cortex* (pp. 241–251). New York Academy of Sciences.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical transactions of the royal society of London, B-biological sciences*, *351*, 1413–1420.

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin, 89*, 63–100.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In J. Editor & K. Rotide (Eds.), *The Frontal Lobes* (pp. 433–472). London: Oxford University Press.

Durston, S., Thomas, K. M., Yang, Y., Ulug, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science, 5*(4), 9–16.

Falk, R., & Wilkening, F. (1998). Children's construction of fair chances: Adjusting probabilities. *Developmental Psychology, 34* (6), 1340–1357.

Fuster, J. M. (2000). The prefrontal cortex of the primate: A synopsis. *Psychobiology, 28*(2), 125–131.

Grant, S., Contoreggi, C., & London, E. D. (2000). Drug abusers show impaired performance in a laboratory test of decision-making. *Neuropsychologia*, *38*(8), 1180–1187.

Klingberg, T., Forssberg, H., & Wessterberg (2002). Increased brain activity in frontal and parietal cortex underlies the development of visuo-spatial working memory capacity during childhood. *Journal of Cognitive Neuroscience, 14* (1), 1–10.

Luna, B., & Sweeney, J. A. (2001). Studies of brain and cognitive maturation trough childhood and adolescence: A strategy for testing neurodevelopmental hypotheses. *Schizophrenia Bulletin, 27*(3), 443–455.

Mesualam, M. M. (2002). The human frontal lobes: Transcending the default mode through contingent encoding. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp 8–30). Oxford, New York: University Press.

Nelson, C. A. (1995). The ontogeny of human memory: A cognitive neuroscience perspective. *Developmental Psychology, 31*(5), 723–738.

Nelson, C. A., & Luciana, M. (Eds.) (2001). *Handbook of developmental cognitive neuroscience*. Cambridge, MA: MIT Press.

O'Doherty, J, Kringelbach, M. L., Rolls, E. T., Hornak, J., & Andrews, C. (2001). Reward and punishment representations in the human orbitofrontal cortex. *Nature Neuroscience, 4*(1), 95–102.

Pennington, B. F. (1994). The working memory function of the prefrontal cortices: Implications for developmental and individual differences in cognition. In M. M. Haith, & J. B. Benson (Eds.), *The development of future-oriented processes. The John D. and Catherine T. MacArthur Foundation series on mental health and development* (pp. 243–289). Chicago: University of Chicago Press.

Pennington, B. F. (1998). Dimensions of executive functions in normal and abnormal development. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.). *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp. 256–281). Baltimore, MD: Brookes Publishing Co.

Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chances in children*. New York: Norton.

Reyna, V. P., & Brainerd, C. J. (1994). The origins of probability judgment: A review of data and theories. In G. Wright, & P. Ayton (Eds), *Subjective probability* (pp. 239–272). New York: John Wiley & Sons.

Roberts, R. J., & Pennington, B. F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology, 12*, 105–126.

Rogers, D. R., Owen, A. M., Middleton, H. C., Williams, E. J., Pickard, J. D., Sahakian, B. J., & Robbins, T. W. (1999). Choosing between small, likely rewards and large, unlikely reward activates inferior and orbital prefrontal cortex. *The Journal of Neuroscience, 19*(20), 9029–9038.

Schlottmann, A. (2000). Children's judgment of gambles: A disordinal violation of utility. *Journal of Behavioral Decision-making, 13*(1), 77–89.

Schlottmann, A., & Anderson, N. H. (1994). Children's judgments of expected value. *Developmental Psychology, 30*(1), 56–66.

Schmitt, W. A., Brinkley, C. A., & Newman, J. P. (1999). Testing Damasio's somatic marker hypothesis with psychopathic individuals: Risk takers or risk averse? *Journal of Abnormal Psychology*, *108*(3), 538–543.

Stuss, D. T. (1992). Biological and psychological development of executive functions. *Brain and Cognition, 20*, 8–23.

Stuss, D. T. & Knight, R. T. (2002). *Principles of frontal lobe function*. Oxford, New York: University Press.

Tryphon, A., & Voneche, J. (2000). *Working with Piaget: Essays in honor of Barbel Inhelder.* Hove, Philadelphia, PA: Psychology Press.

Van der Molen, M. W., & Ridderinkhof, K. R. (1998). The growing and aging brain: Life-span changes in brain and cognitive functioning. In A. Demetriou, W. Doise, & C. Van Lieshout (Eds.)*, Life span developmental psychology* (pp. 35–99) New York: Wiley.

Vodegel Matzen, L. (1994). *Performance on Raven's Progressive Matrices: What makes a difference?* Unpublished thesis, University of Amsterdam, The Netherlands.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children—Third Edition*. San Antonio, TX: Psychological Corporation.

Welsh, M. C. (2002). Developmental and clinical variations in executive functions. In D. L. Molfese & V. J. Molfese (Eds.), *Developmental variations in learning: Applications to social, executive function, language, and reading skills* (pp. 139–185). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Wilkening, F., & Anderson, N. H. (1991). Representations and diagnosis of knowledge structures in developmental psychology. In N. H. Anderson (Ed.), *Contributions to information integration theory: Vol. III Developmental* (pp. 45–80), Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Zuckerman, M. (1979). *Sensation seeking: Beyond the optimal level of arousal.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.