On the art of choosing: Developmental changes and individual differences in decision making under risk
van Duijvenvoorde, A.C.K.

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Chapter 3

Deciding in Informed and Noninformed Situations: A Developmental Study

This chapter is based on:

Abstract
Advantageous decision making progressively develops into early adulthood, most specifically in complex and motivationally salient decision situations in which direct feedback on gains and losses is provided. However, the factors that underlie this developmental improvement in decision making are still not well understood. The current study therefore investigates two potential factors, long-term memory and working memory, by assigning a large developmental sample (7–29 years of age) to a condition with either high or low demands on long-term and working memory. The first condition featured an age-adapted version of the Iowa Gambling Task (IGT; i.e., a noninformed situation), whereas the second condition provided an external store with explicit information on gains, losses, and probabilities per choice option presented (i.e., an informed situation). Consistent with previous developmental IGT studies, children up to age 12 did not learn to prefer advantageous options in the noninformed condition. In contrast, all age groups learned to prefer the advantageous options in the informed conditions, although a slight developmental increase in advantageous decision making remained. These results indicate that lowering dependence on long-term and working memory improves children’s advantageous decision making. The results additionally suggest that other factors, like inhibitory control processes, may play an additional role in the development of advantageous decision making.
3.1 Introduction

Deciding successfully between competing courses of actions is a complex process: Potential costs and benefits need to be balanced, previous decision outcomes need to be maintained in memory, and decision strategies need to be successfully updated on the basis of these outcomes. Not surprisingly, research has demonstrated large developmental changes in the realm of decision making (Cauffman et al., 2010; Crone & Van der Molen, 2004; 2007; Hooper et al., 2004; Overman et al., 2004). However, the origin of these developmental changes is not well understood. The main aim of this study is therefore to investigate potential factors that may underlie the developmental changes in risky decision making.

Developmental changes in decision making are commonly thought to be most pronounced in tasks in which a relatively strong motivational component is present when rewards and/or losses are tied to one’s choices (Carlson et al., 2009; Figner et al., 2009; Hongwanishkul et al., 2005; Kerr & Zelazo, 2004; Prencipe et al., 2011; Seguin et al., 2007). A commonly used decision task that includes motivationally salient outcomes is the Iowa Gambling task (IGT; Bechara et al., 1994), which is thought to mimic “real-life” decision making. In this task, participants need to maximize profit by selecting cards from four different decks, in which the properties of the decks, that is, gains, losses and loss probability, have to be learned from experienced feedback. Two of these decks are advantageous (low constant gains, low occasional losses), and two are disadvantageous (high constant gains, high occasional losses).

The original version of this task was designed to assess decision-making competence in a patient population with lesions to the ventromedial prefrontal cortex (VMPFC). In contrast to healthy adults, this patient population tended not to learn to select the advantageous decks but continued to opt for the disadvantageous options (Bechara et al., 1994). The IGT has subsequently been used to demonstrate impaired decision making in a wide range of neurological and psychopathological conditions (see Dunn et al., 2006, for an extensive overview). A child-friendly version of the IGT, the Hungry Donkey Task (HDT), was developed more recently (see Table 1 for detailed properties). Children (ages 6–12) were shown to perform poorly on this task, and advantageous decision making generally continued to improve into early adulthood (Crone & Van der Molen, 2004; Huizenga et al., 2007).

Since the IGT is a complex task, there are many processes that potentially affect choice behavior across development (Dunn et al., 2006). First, to solve a task like the IGT, adequate understanding of the concept of probability and outcomes (gains, losses) is needed. Moreover, choice properties need to be learned from feedback, which requires continuous updating of choice properties in working memory and storage of these properties in long-term memory. Finally, once a stable representation of choice options has been formed, participants need to be able to inhibit a lose-shift response to occasional losses with the advantageous decks. That is, they need to inhibit their reactive responding to occasional losses. Thus, similar to many decision tasks, performance on the IGT depends on understanding probability and outcome values, on the ability to update this knowledge and hold it in memory, and on the ability to inhibit responses to occasional feedback.

At first, delayed development of the understanding of probabilities was thought to be a primary cause for children’s disadvantageous decision making (Baird & Fugelsang, 2004; Piaget & Inhelder, 1975; Siegler, 1996). However, numerous studies concluded that the basic understanding of probability and outcomes, as well as the combination of this information
(expected value sensitivity) develops already in early childhood (4–5-year-olds). This seems most apparent in judgment paradigms (Acredolo et al., 1989; Reyna & Brainerd, 1994; Schlottmann, 2001; Schlottmann & Wilkening, 2010) but also in choice paradigms, in which children are shown to be able to use probability information and information on risky outcomes (Harbaugh et al., 2002; Levin & Hart, 2003; Levin et al., 2007; Reyna & Ellis, 1994; Van Leijenhorst et al., 2008). Thus, the understanding of probability seems to emerge at an early age (see also Reyna & Brainerd, 1994) and the inability to understand probability and outcomes is not considered a primary cause for children's and adolescents' immature decision abilities.

Developmental changes in decision making may be more crucially dependent on the development of working and long-term memory. Adult studies (Maia & McClelland, 2004) find accumulating evidence for the involvement of long-term memory and working memory in advantageous decision making in complex tasks such as the IGT. For example, dual task paradigms have shown that IGT performance in adults decreased under high working-memory load compared with low working-memory load (Dretsch & Tipples, 2008; Hinson et al., 2002; Pecchinenda et al., 2006; but see Turnbull et al., 2005). In addition, imaging and lesion studies have shown that long-term memory systems such as the hippocampus (Gupta et al., 2009), and working memory regions such as the dorsolateral prefrontal cortex (DLPFC) are critically involved in IGT performance (Bechara & Martin, 2004; Ernst et al., 2002; Manes et al., 2002).

However, there is no convincing evidence for the role of working memory in the development of advantageous decision making. Developmental results generally have not shown correlations between IGT performance and working memory as measured with the backward digit-span (Crone & Van der Molen, 2004; Hooper et al., 2004). Also, experimental manipulations of working memory load have not affected IGT performance across development (Crone et al., 2005; Crone & Van der Molen, 2004). Thus, it remains unclear to what extent maturing memory systems influence the development of advantageous decision making.

Finally, the inability to execute inhibitory control may underlie risky decision making in childhood and adolescence. Inhibitory control also shows profound maturation into late adolescence (Bunge & Wright, 2007). Correlations between IGT performance and inhibitory control tasks have been, however, largely absent in developmental studies (Crone, Vendel et al., 2003; Hooper et al., 2004), although adult studies have shown that disinhibited individuals are more likely to fail the IGT (Bechara et al., 2000). Immature inhibitory control has been linked to a heightened sensitivity to losses and gains across development (Hare et al., 2008; Somerville et al., 2010). Children and adolescents have shown high loss sensitivity in the IGT (Carlson et al., 2009; Huizenga et al., 2007; Van Duijvenvoorde et al., 2010). Specifically, adolescents also have shown heightened gain sensitivity in other decision contexts (Ernst et al., 2005; Galvan et al., 2006; Somerville et al., 2011; Van Leijenhorst et al., 2010). Immature inhibitory control may lead to a preference for the high-gain, disadvantageous choice options in the IGT (sensitivity to high gains) or lead to a reactive response pattern in which children continuously switch responses after receiving negative feedback (sensitivity to occasional losses).

Overall, these findings suggest that the development of memory and inhibitory control may be important factors in decision making and could parsimoniously account for developmental improvement in advantageous decision making. Yet convincing empirical evidence in developmental samples is lacking.
The current study therefore focuses on one of these factors, memory, by using a task manipulation in which an external store of explicit choice information is provided. In a different context (Brainerd, 1981; Brainerd & Kingma, 1985), it was suggested that the use of an external store may lead to pronounced improvements in decision situations in which immediate performance feedback is present. In the current study, we therefore compared decision making between a standard, noninformed condition (i.e., similar to the IGT) and a new, informed condition, in which explicit information on the choice properties was presented. Our manipulation minimized the necessity to store and retrieve choice information from long-term memory. Additionally, this manipulation lowered the demands on working memory since choice properties did not need to be updated, given trial-to-trial feedback.

The Current Study

We aimed to investigate whether the unburdening of working and long-term memory could improve advantageous decision making across development. We expected that providing explicit information would improve decision making, specifically for children and young adolescents, since their memory systems are still immature (Crone, Wendelken et al., 2006; Donohue et al., 2005). Confirmation of this hypothesis would indicate that memory is an important factor underlying the development of advantageous decision making. If developmental changes are still found when explicit information is provided, then processes like the ability to inhibit reactive responses to outcome feedback may play an additional role in the development of decision making.

To answer this question we administered two versions of the children’s IGT paradigm to a large developmental sample ranging from 7-year-olds to young adults. The first version was similar to the IGT, in which no information is given regarding the choice properties (non-informed condition). The other version was comparable, except that the gains, losses, and probabilities of all options were explicitly presented (informed condition). Note that before learning occurs, these two conditions resemble the differences between ambiguous and risky decision making, for example, situations in which choice properties are, respectively, largely unknown (noninformed) or known (informed; Brand et al., 2006; Brand et al., 2007; Krain et al., 2006).

Besides determining whether explicit presentation improves decision making, we aimed to characterize in which way decision making in the IGT is improved. Initially we did this by analyzing performance separately across task blocks and in the final part of the task (in which choice preferences have stabilized). In addition, we compared choices for the individual options (A, B, C, and D) and determined response switches after losses to characterize performance differences between conditions in more detail.

3.2 Method

Participants
Three hundred and four children, adolescents, and young adults participated in this study. Children were recruited from three different primary schools, adolescents from two secondary schools, and young adults from first-year psychology programs. For children and adolescents, primary caretakers were informed about the experiment and were provided with an
opportunity to exempt their child from participating. Young adults gave written informed consent for the study. All participants were informed beforehand that, dependent on performance, they could win a small prize, which eventually all participants received. Young adults were additionally given course credits for their participation. Procedures were approved by the local ethics committee.

Participants were recruited from six different grade levels. Eleven participants failed to finish the entire test set, leaving 293 participants for further analysis. At the primary school level, children were recruited from three grade levels, ages 7–9 (n = 45, 21 girls, Mean Age = 8.15 years, SD = 0.47), ages 9–11 (n = 48, 26 girls, Mean Age = 10.2 years, SD = 0.44), and ages 11–13 (n = 47, 21 girls, Mean Age = 12.3 years, SD = 0.47). At the secondary school level, adolescents were recruited from two grade levels, ages 12–14 (n = 51, 27 girls, Mean Age = 13.7 years, SD = 0.50), and 14–17 (n = 49, 29 girls, Mean Age = 15.7 years, SD = 0.75). Young adults were first-year university students, ages 18–29 (n = 53, 37 female participants, Mean Age = 20.3 years, SD = 2.53). The proportion of female participants differed slightly between age groups. Specifically the oldest age group consisted of significantly more female participants than male participants, $\chi^2(1) = 8.3, p < .005$. In order for us to account for possible confounding effects of sex, it was included as a discrete covariate in all analyses.

In order to account for possible differences in intelligence between age groups, we administered the Standard Raven’s Progressive Matrices (SPM) test (Raven et al., 1985). A speeded version of the task was used in which participants were given 20 min to answer as many problems as possible (Hamel & Schmittmann, 2006). We transformed Raven SPM scores to within-age group norm scores. The norm scores differed significantly between age groups, $F(5, 287) = 9.6, p < .001$; the 8–9-year-olds and the young adults had higher scores than the 11–13 and 12–14-year-olds. To account for possible confounding effects of intelligence, Raven norm score was included as a continuous covariate in all analyses.

Additionally, a speeded math test was administered that included automated performance of addition, subtraction, multiplication, and division operations (De Vos, 1992). Math scores were standardized per age class. In order to rule out alternative explanations in terms of math proficiency, we tested effects of math in additional control analyses (see Math Performance in Results section).

The Gambling Game
The Gambling Game was based on the computerized version of the children’s IGT, the Hungry Donkey Task (Crone & Van der Molen, 2004). The children’s IGT is an age-adapted ver-

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Figure 1. Panel A: The Gambling Game as displayed on screen for the informed condition (upper part) and noninformed condition (lower part). The score bar underneath was updated (total score) each time a machine was clicked upon. Here, the letters A, B, C, and D indicate the different machines. These letters were not presented to the participants in the task. Panel B: Sequential illustration of the workings of a machine. After a machine was started with a mouse click, the balls were shuffled. Semi randomly one ball was drawn from the machine. If a red ball was drawn, gain feedback (coins) was delivered simultaneously with loss feedback (red coins). If a green ball was drawn, only gain feedback was delivered. Feedback presentation was similar in the noninformed condition.
sion of the original IGT, and it maintains the original complexity of the task by presenting four doors to collect as many apples as possible for the Hungry Donkey. In the Gambling Game, participants repeatedly chose one of the four machines displayed on screen (A, B, C, or D) in order to collect as many points as possible (see Figure 1A). The four choice options differed systematically in amount of gain, amount of loss, and frequency of loss (see Table 1), comparable to the options in the children’s IGT.

In the Gambling Game, choice options were thus characterized by a difference in overall net gain (as in the children’s and original IGT). Two machines were advantageous (C and D: low gains, low occasional losses) and two machines were disadvantageous (A and B: high gains, high occasional losses). The (dis)advantageousness of the machines is crossed with the frequency of loss. That is, one of the (dis)advantageous machines returned frequent losses (A and C; in 50% of the cases), and one returned infrequent losses (B and D; in 10% of the cases).

Each machine was characterized by a gain that was won every time this machine was chose, and each machine contained 10 balls that were either green or red. Red balls were provided with a number signifying the amount of loss. The number of red balls in the machine coded the frequency of loss. Upon the participant’s choosing one of the machines, the balls were shuffled, and one ball was drawn (semi randomly) from the machine, with frequency of loss was controlled for within 20 trial blocks. If the machine drew a red ball, the gain was obtained, and the amount displayed on the red ball was lost. If the machine, however, drew a green ball, the gain was obtained, and no points were lost. The outcomes (gains and losses) of each choice were displayed in both visual and numerical formats, below the chosen machine (see Figure 1B). The total number of points won or lost was represented by a horizontal bar, which was updated every time a machine was chosen, as indicated by a number and color change. Participants started with zero points.

Participants were randomly assigned to one of two conditions: the informed or the noninformed condition. In the informed condition, machines in the game were “open”, and the amount of gain was displayed numerically on the machine (see Figure 1A, upper panel). Therefore, the amount of gain, loss, and frequency of loss per choice option were presented directly to the participants. In the noninformed condition, the machines in the game were “closed” (see Figure 1A, lower panel). The amount of gain was not displayed on the machines, and participants could not see the amount of red or green balls in the machines. In both conditions immediate feedback (gain/loss) after each choice was provided. However, participants in the noninformed condition had to use this feedback to learn the contingencies of the different options, whereas this was not the case for participants in the informed condition.

The Gambling Game was administered individually on 15-inch laptops. The task consisted of 200 trials, although duration of the game was not known beforehand. The sequence of machine presentation (A, B, C, D) on screen was fully randomized. Participants were first explained the workings of the machines and were instructed to collect as many points as possible by opting for the best machine(s). It was explicitly stated that they could switch as often as they wanted. Generally, participants needed approximately 20 min to complete the game. The speeded Raven and the math test were administered in class on a different date than the Gambling Game.
3.3 Results

Analyses on the informed and noninformed Gambling Game were fourfold. First, we investigated differences in performance by a net score, subtracting the amount of choices for the disadvantageous options (A + B) from the amount of choices for the advantageous options (C + D). Higher net scores thus indicate better task performance, in which participants favored advantageous over disadvantageous options. This was done first across task blocks and, second, for the final 60 trials in which performance stabilized. Third, we determined choice frequency per option (A, B, C, D), to determine whether preference was toward high gain options (A and B) or infrequent loss options (B and D). Fourth, we analyzed the percentage of switches after loss and gain to determine reactive responses after performance feedback.

Net Score Across Task Blocks
Net score (C + D) - (A + B) was determined across task blocks (grouped into ten 20-trial blocks). The results are depicted in Figure 2.

A Task Block (10) × Age Group (6) × Condition (2) repeated measures analysis of variance (ANOVA) was performed in which Raven score and sex were included as continuous and discrete covariates. Since sphericity was violated, multivariate test results (Wilks’ Lambda) are reported. Results indicated an increase in advantageous choice behavior across task blocks, main effect of Task Block: $F(9, 271) = 11.4, p < .001, \eta^2_p = .27$. Performance also increased with age, main effect of Age Group: $F(5, 279) = 11.9, p < .001, \eta^2_p = .18$, and was higher in the informed compared with the noninformed condition, main effect of Condition: $F(1, 279) = 34.9, p < .001, \eta^2_p = .11$. Moreover, results showed an interaction between Task Block and Age Group, $F(45, 1215.4) = 1.4, p < .05, \eta^2_p = .05$, indicating that older age groups, compared with younger age groups, chose significantly earlier in the task for the advantageous machines.

1. There was no significant main effect of sex. There was a significant main effect of Raven score, $F(1, 279) = 6, p < .02$, in which higher Raven scores were associated with more advantageous choice performance. There was no significant interaction effect between Task Block and Raven score.
2. The main effect of age was present in all task blocks except for the first task block for both conditions (see Figure 2).
Deciding in Informed and Noninformed Situations

There was no Age × Condition interaction \((p = .8)\), nor a Condition × Task Block interaction \((p = .1)\). Finally, results revealed a three-way interaction between Task Block × Age Group × Condition, \(F(45, 1215.4) = 1.42, p < .05, \eta^2_p = .05\).

Follow-up analyses in the noninformed condition indicated that learning rates across blocks differed between age groups, Task Block × Age Group interaction: \(F(45, 580.2) = 1.8, p < .005, \eta^2_p = .11\). That is, performance of the youngest age groups (7–9, 9–11, and 11–13-year-olds) did not change significantly across task blocks (all \(p\)'s > .05), whereas the older age groups showed a linear increase in performance across task blocks: 13–15 years, \(F(1, 21) = 14.2, p < .005, \eta^2_p = .4\); 15–17 years, \(F(1, 22) = 10.7, p < .005, \eta^2_p = .33\); young adults, \(F(1, 23) = 29, p < .001, \eta^2_p = .56\). In contrast, a similar analysis in the informed condition showed no interaction between Task Block and Age Group \((p = .6)\), indicating that in the informed condition, learning rates did not differ significantly between age groups. That is, all age groups showed a linear increase in performance across task blocks (all \(p\)'s < .05; see Figure 2).

To summarize, the effect of age on performance across task blocks differed between the noninformed and informed conditions. In the noninformed condition, older participants learned to exploit the advantageous options, whereas this was not the case for the youngest age groups (until age 12). In the informed condition, however, all age groups learned to choose advantageously to a certain extent.

Net Score in Last 60 Trials

Next, our focus was on the final task blocks, in which choice behavior stabilized. On the basis of previous research, the last 60 trials of the task were selected and the summed net score was calculated (Crone & Van der Molen, 2004; Huizenga et al., 2007). In order to ascertain stabilization of choice performance, we performed a Block (3) × Age Group (6) × Condition (2) ANOVA on these final three task blocks. Results showed no significant main effect of task block \((p = .1)\) or any interactions with task block (all \(p\)'s > .08).

![Figure 3](image-url)
Deciding in Informed and Noninformed Situations

An Age Group × Condition (2) ANOVA was performed with Raven score and sex included as continuous and discrete covariates. Results showed that performance improved with age, main effect of Age Group: \( F(1, 287) = 52.6, p < .001, \eta^2_p = .16 \), and was more advantageous in the noninformed than in the noninformed condition, main effect of Condition: \( F(1, 287) = 20.6, p < .001, \eta^2_p = .07 \). The condition effect tended to be most pronounced for the youngest age groups, \( F(1, 287) = 3.3, p = .069, \eta^2_p = .01 \), linear contrast for Age, see Figure 3. Since our hypotheses were specifically aimed toward the youngest age groups, we performed follow-up analyses per age group. Results showed that performance improved significantly between informed and noninformed conditions for the 7–8-year-olds, \( F(1, 41) = 7.5, p < .01, \eta^2_p = .15 \), and for the 9–11-year-olds, \( F(1, 44) = 4.9, p < .05, \eta^2_p = .09 \), but not for other age groups (all \( p \)'s > .1). These findings indicate that especially performance of the youngest age groups (7–11-year-olds) improved in the informed compared with the noninformed condition.

Additionally, an ANOVA per condition showed a significant age effect, both in the noninformed, \( F(5, 137) = 8, p < .001 \), and in the informed condition, \( F(5, 140) = 3.5, p < .01 \). This result indicates that even in the informed condition, performance increases with age.

Finally, one-sample t tests were used to test whether net scores differed from zero, that is, whether participants sampled more from advantageous than from disadvantageous options. In the noninformed condition, only participants from 12–14 years of age onward sampled more from advantageous than from disadvantageous options, 12–14-year-olds: \( t(23) = 4.3, p < .001, SE = 6.14 \); 14–17-year-olds, \( t(24) = 3.4, p < .005, SE = 7 \); young adults, \( t(25) = 9, p < .001, SE = 5.12 \). In the informed condition, all age groups sampled more from the advantageous than from the disadvantageous options (all \( p \)'s < .05).

Summary

Together, the results on performance in the Gambling Game show two main findings. First, the results from the noninformed condition are similar to those of previous studies. That is, children until age 12 do not exploit advantageous options and continue to sample from advantageous and disadvantageous options. Second, we extended previous findings by showing that in the informed condition, decision making improved significantly, specifically for the youngest age groups. That is, even children under the age of 12 learned to choose more from the advantageous options, and this improvement seemed to continue into adolescence. Note, however, that there still remained an effect of age in the informed condition, although much smaller than in the noninformed condition.

Choice Frequency Per Option

Analyses per choice option provide a more detailed insight into differences between the noninformed and informed condition. Therefore, we also compared the number of choices for the individual machines A, B, C, and D in the final 60 trials of the task (see Figure 4). We applied a deviation contrast to test whether choice preference for each machine deviated from chance level responding per age class (60/4 = 15) and Raven score and sex were included as continuous and discrete covariates. These results are displayed in Figure 4.

3 Sex did not have a significant main effect. Raven score did show a significant main effect, \( F(1, 287) = 7.1, p < .01 \), with higher Raven scores were associated with more advantageous choice behavior.

4 Within each age group, sex and Raven score were not significant covariates.
Machine A was generally avoided, that is, selected at below chance level, in all age groups and in both conditions. In the noninformed condition, Machine B was chosen at above chance level by the 7–9-year-olds and avoided only by the young adults. In the informed condition, however, this machine was not preferred by the youngest age group and avoided already by those of ages 12–14. Machine C was preferred only in the older age groups (from ages 12–14) in both conditions, although for the older age groups this preference was more pronounced in the noninformed condition. Finally, Machine D was preferred specifically in the informed condition, although a significant preference was found only in some age groups.

Thus, providing explicit information decreased preference for the disadvantageous Option B in the youngest age groups and increased preference for the advantageous Option D and to a lesser extent Option C. This latter option was preferred in both conditions from ages 12–14. Finally, note that the disadvantageous Option A was generally avoided in both conditions. In sum, in the informed condition, children’s focus shifted away from high gains with infrequent high losses (Option B), toward low gains with infrequent low losses (Option D), and to a lesser extent toward low gains with frequent losses (Option C).

Switches After Losses
A reactive response pattern was defined as the proportion of switches after losses in the final part of the task. This proportion of switches after losses thus represented to what extent par-
Participants are able to inhibit a lose-shift response when responses should be stabilized. In order to correct for an overall tendency to switch, we compared switches after losses to switches after gains. That is, we compared the percentage of response switches after receiving a loss (switch after loss/total amount of losses) to switches after a gain (switch after gain/total amount of gains) in the last 60 trials. Thus, a larger percentage of switching after loss than after gain could be interpreted as a more reactive response tendency.

A Loss–Gain (2) × Age Group (6) × Condition (2) ANOVA was performed with Raven score and sex as continuous and discrete covariates (see Figure 5). First, results showed that the amount of switches, irrespective of whether this switch occurred after a loss or a gain, decreased into early adulthood, main effect of Age: $F(5, 279) = 10.7, p < .001, \eta^2_p = .16$, and that participants switched less in the informed compared with the noninformed condition, main effect of Condition: $F(1, 279) = 12, p < .005, \eta^2_p = .04$.

Furthermore, results revealed that participants switched more after loss than after gain, main effect of Loss–Gain: $F(1, 279) = 37, p < .001, \eta^2_p = .12$. This effect was more pronounced in the younger age groups compared with the older ones, Interaction Loss–Gain × Age Group: $F(5, 279) = 4.6, p < .01, \eta^2_p = .08$, and was more pronounced in the noninformed compared with the informed condition, Interaction Loss–Gain × Condition: $F(1, 279) = 8.6, p < .005, \eta^2_p = .03$. Finally, results showed a three-way interaction between Loss–Gain × Age Group × Condition, $F(5, 279) = 2.3, p < .05, \eta^2_p = .04$, indicating that the age-related decrease in reactive responding to losses was most pronounced in the noninformed condition (see Figure 5). These findings illustrate that children and adolescents in the noninformed condition seemed

Figure 5. Mean percentage of switches after loss and switches after gain in the final 60 trials of the Gambling Game, as a function of Age Group, displayed separately for the noninformed and informed condition. Asterisks indicate a significant difference between switches after loss and gain at $p < .05$. Error bars indicate +/- 1 standard error around the mean.

Female participants generally switched more often than did male participants, main effect Sex: $F(1, 279) = 7.3, p < .01$, and additionally female participants switched more often after loss than after gain compared with male participants, interaction Loss–Gain × Sex: $F(1, 279) = 12.1, p < .01$. Raven score was not a significant covariate.
to employ a reactive response pattern, in which they continued to switch after they experienced losses.

Sex Differences
Sex was factored out in all above-mentioned analyses. For Gambling Game performance, no significant effects of sex were found. These findings indicate that males and females did not perform differently in the present tasks. However, sex differences were found on the amount of switches; female participants switched more after losses than gains compared with male participants, which was generally apparent in all age groups (see Footnote 5). This indicates that in female participants there was a heightened sensitivity to negative feedback (e.g., losses).

Math Performance
The transparency of the informed compared with the noninformed condition may have led to an unburdening of calculation operations. To investigate possible influences of math skill, we repeated all analyses with standardized math score as an additional independent variable and determined main and interaction effects with task condition. Math score did not yield a main effect or an interaction effect with condition in any analysis. In addition, the effects of all other independent variables did not change when math score was included.

3.4 Discussion
The current study aimed to investigate whether immature long-term and working memory may account for pronounced developmental differences in decision making. Therefore, we compared performance on a noninformed and an informed Gambling Game. The noninformed condition resembled the children’s IGT. The informed condition, however, provided a transparent display of choice properties, thereby lowering dependence on long-term memory (storage of choice information) and on working memory load (updating of choice information). We expected that if maturation of memory systems was related to development of decision making, this manipulation would improve decision making, and most profoundly in the youngest age groups. If other processes, as the ability to inhibit reactive responding, play an additional role, decision making would still improve in the informed decision situation.

Results from the noninformed choice condition were consistent with previous research in demonstrating that children did not exploit the advantageous choice options until age 12 and that performance on the task continued to improve into late adolescence (Crone & Van der Molen, 2004; Huizenga et al., 2007). More important, our results demonstrated that in the informed compared with the noninformed condition, children’s decision making improved significantly. That is, even children under the age of 12 learned to choose more from the advantageous than from the disadvantageous options. This finding indicates that long-term memory and working memory processes are important factors underlying the development of advantageous decision making. This is consistent with recent adult and lesion studies showing involvement of both long-term memory regions as the hippocampus and working-memory structures as the DLPFC in IGT performance (Bechara & Martin, 2004; Gupta et al., 2009; Pecchinenda et al., 2006). In the informed condition, there was, however, still a developmen-
tal increase in advantageous decision making, even though the demands on long-term and working memory were relatively low. This suggests that other processes, such as inhibitory control, play an additional role in advantageous decision making.

Detailed analyses on response switches supported this general conclusion. Response switches after losses were most frequent in the younger age groups, especially in the noninformed condition. This developmental pattern was also present, although to a lesser extent, in the informed condition. This suggests that children and adolescents in the noninformed condition displayed a continued reactive response pattern (lose-switch), which can be largely, although not fully, remedied by providing explicit information on choice options.

The analyses per choice option additionally indicated that young children already avoided the disadvantageous Option A in both conditions, thereby showing a different response pattern than that seen in adult VMPFC patients (Bechara et al., 1994). Moreover, these analyses indicated that in the informed condition, children's decision making improved due to a decreased preference for the disadvantageous, infrequent loss, Option B in favor of a preference for the advantageous, infrequent loss, Option D (and to a lesser extent the advantageous, frequent loss Option C). Thus, these results tentatively indicated a shift within the infrequent loss options, in which explicit choice information changed a focus on high gains toward a focus on low losses. Previous findings also indicated that children preferred options with infrequent losses in the children's IGT (Carlson et al., 2009; Crone et al., 2005; Huizenga et al., 2007). This may relate to a tendency to underweight the occurrence of low-probability events in decisions involving feedback (Harbaugh et al., 2002), which would make infrequent loss options more attractive.

Together, the current findings implicate that lowering demands on long-term and working memory highly influences children's, and to a certain extent adolescents', ability to decide advantageously. The difference in task performance between these two conditions suggests that either immature long-term memory or immature working memory largely explains poor decision making in children and adolescents. Additionally, results suggest that immature decision making is also dependent on the ability to execute ample inhibitory control. This can be linked to the reactive route to risk taking, in which risky decisions are thought to stem from a maturational lack of inhibition (Reyna & Farley, 2006) and to children's and adolescents' heightened sensitivity to losses (Carlson et al., 2009; Crone et al., 2005; Huizenga et al., 2007; Mitchell et. al., 2008; Van Duijvenvoorde et al., 2010).

Our results further suggest sex differences in sensitivity to negative feedback: Female participants compared with male participants switched more after losses. Typically, women are reported to be more risk averse than men (Weber et al., 2002) and more focused on avoiding losses (Figner & Weber, 2011; Weller et al., 2010). Heightened sensitivity for negative emotional information is also supported by imaging studies showing that women, compared to men, have higher emotional responses and recruit emotional regulation networks to a lesser extent (Domes et al., 2010). Together, these findings highlight that women may be specifically prone to react to negative emotional information. Note in addition that the current study indicated that this sex difference in loss sensitivity did not change across development.

A possible limitation of the current experimental study is that demands on long-term memory cannot be reduced without lowering demands on working memory. Therefore, the effects of working memory and long-term memory cannot be dissociated. Since previous experimental and correlational studies indicated that the development of decision making is
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not related with working memory (Crone & Van der Molen, 2004; Hooper et al., 2004), it is tempting to conclude that the present results should merely be attributed to lowering dependence on long-term memory. However, several studies do show an influence of working-memory load on IGT performance (Dretsch & Tipples, 2008; Hinson et al., 2002; Pecchinenda et al., 2006), and noninformed decision making has been related to DLPFC activation (Krall et al., 2006), which is strongly implicated in working-memory processes (Bunge & Wright, 2007; Crone, Wendelken et al., 2006). Future imaging studies will be important to verify the underlying (neural) mechanisms involved in different decision situations (informed and noninformed) across development and may add to disentangling the involvement of long-term and working memory in advantageous decision making.

One alternative explanation to consider may be that, besides memory load, conditions may also differ in level of arousal. Arousal is thought to lead to more risky and less favorable decisions (Figner et al., 2009; Steinberg, 2005; Van Duijvenvoorde et al., 2010) Note, however, that in the current study performance feedback, which is a prime factor influencing arousal (Loewenstein et al., 2001), was given in both noninformed and informed conditions. Nonetheless, there are indications from imaging studies that noninformed (so-called ambiguous) and informed (so-called risky) decision making rely on different neural networks. That is, noninformed decision making relies on lateral prefrontal activation, whereas informed decision making relies on parietal and striatal regions (Hsu et al., 2005; Huettel et al., 2006). These results may indicate an increased necessity to execute inhibitory control over arousing noninformed decision situations. Future studies into the differences between informed and noninformed decision making may include arousal, for example measured by skin conductance, as a moderating factor.

Additionally, it might be argued that the current noninformed condition was not functionally equivalent to the IGT or the children’s version of the IGT. This concern is not supported by results of the current noninformed condition, which match those of previous developmental IGT studies (Crone & Van der Molen, 2004; 2007). However, there were some slight differences between the IGT and the noninformed version of the current Gambling Game. First, visualization of the different choice options in gambling machines differs from a presentation such as doors or decks. Second, our high frequent-loss options (A and C) did not include a variation in amount of loss, as is common in the IGT. Therefore, a net loss never occurred in Option C. This may have led to a higher preference of the advantageous Option C than in previous studies. Note, for example, that in the noninformed condition adults highly preferred the advantageous, frequent-loss Option C over the infrequent-loss Option D, which was reversed in the informed condition. This may implicate that specifically in noninformed situations adults prefer to never receive a net loss. Thus, although developmental effects on the current noninformed task are equivalent to effects on the IGT, there might be some subtle differences in specific choice behavior.

The present results suggest a linear developmental increase in advantageous decision making. Current neurobiological theories, however, suggest that risk taking shows a curvilinear pattern in which risk-taking peaks during adolescence (Casey, et al., 2008). This would be due to protracted development of cognitive control systems compared with systems that process rewards. Although the peak in risky decision making in adolescence has been observed in some decision tasks (Figner et al., 2009; Steinberg, 2008), it was not observed in others, including the IGT (Crone & Van der Molen, 2004; Levin et al., 2007; Weller et al., 2010; but
see Cauffman et al., 2010). In the current study we also did not observe increased risk taking and reward sensitivity in adolescents, as high-gain options were not specifically favored by adolescents. Future research is therefore required to determine the circumstances in which the adolescent peak in risk taking can be observed.

Furthermore, the informed and noninformed conditions seem to resemble the distinction between descriptive and experiential decision making, which are known to lead to differences in risky decision making, such as the underweighting of rare events and recency effects (Hertwig & Erev, 2009). However, descriptive choice paradigms, in contrast to experiential paradigms, generally don’t include performance feedback, which is a key factor influencing risky decision making and decision strategy (Jessup et al., 2008; Reyna & Brainerd, 1994). The current research included feedback in both the informed and the noninformed condition. Therefore, the so-called descriptive experience gap in decision making cannot account for the observed differences in decision performance.

To conclude, the current study shows that lowering the dependency on long-term and working memory positively influences children’s and adolescents’ risky decision making. This developmental improvement is shown in a decision situation having a relatively strong motivational component (i.e., feedback), in which decision making is normally subject to long-lasting developmental changes. Specifically, when we lowered long-term and working memory load in the informed condition, children performed more advantageously and demonstrated diminished reactive responses toward occasional losses. These results are, to our knowledge, the first to describe not only an improvement of decision making on the IGT (Carlson et al., 2009) but actual advantageous decision making in children as young as 7 years of age. These findings importantly highlight that providing explicit information on pros and cons of choice options can lead to advantageous decision making in children and adolescents, even in complex and relatively high-motivational decision situations.

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