Why teens take risks ... : a neurocognitive analysis of developmental changes and individual differences in decision-making under risk

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A developmental study of risky decisions on the Cake Gambling Task; Age and gender analyses of probability estimation and reward evaluation

Decision-making, or the process of choosing between competing courses of actions, is highly sensitive to age related change, showing development throughout adolescence. In this study, we tested whether the development of decision-making under risk is related to changes in risk-estimation abilities. Participants (N = 93) between ages 8-30 performed a child friendly gambling task, the Cake Gambling task, which was inspired by the Cambridge Gambling Task (Rogers et al., 1999), which has previously been shown to be sensitive to orbitofrontal cortex (OFC) damage. The task allowed comparisons of the contributions to risk perception of 1) the ability to estimate probabilities, and 2) evaluate rewards. Adult performance patterns were highly similar to those found in previous reports, showing increased risk-taking with increases in the probability of winning and the magnitude of potential reward. Behavioral patterns in children and adolescents did not differ from adult patterns, showing a similar ability for probability estimation and reward evaluation. These data suggest that participants 8 years and older perform like adults in a gambling task, previously shown to depend on the OFC in which all the information needed to make an advantageous decision is given on each trial and no information needs to be inferred from previous behavior. Interestingly, at all ages, females were more risk-averse than males. These results suggest that the increase in real-life risky behavior that is seen in adolescence is not a consequence of changes in risk perception abilities. The findings are discussed in relation to theories about the protracted development of the prefrontal cortex.

4.1 Introduction

Decision-making can be defined as the process of choosing between competing courses of actions. Often, the outcomes of decisions we make are uncertain and associated with the possibility of leading to undesirable results, therefore they involve taking risks. Successful decision-making in everyday life situations requires the ability to find a balance between possible benefits and costs that are associated with taking these risks, as well as incorporating the likelihood of achieving what we desire. Decision-making is an important and complex ability that slowly develops during childhood and into adolescence (see Boyer, 2006 for a review). Adolescence in particular has been characterized as a period of increased risk taking (Steinberg, 2004). Self-report and observation studies have shown an increase in, for example, the number of traffic accidents and in the use of illegal drugs, tobacco and alcohol during adolescence (eg. Steinberg, 2004; Furby & Beyth-Marom, 1992). These results suggest that adolescents are not capable of adult decision-making. From a cognitive perspective, many aspects of developmental changes in decision-making abilities are not well understood, even though the possible serious consequences of inadequate decision-making skills in real life make a better understanding important.

In the present study we examined the development of two important abilities that are required for successful decision-making; 1) probability estimation (deciding which choice has the largest chance of resulting in reward) and 2) evaluation of the reward associated with the least likely outcome (does the reward that can be gained make it worth taking the risk). More specifically we developed a child friendly gambling paradigm inspired by the Cambridge Gambling Task (Rogers et al., 1999), the Cake Gambling Task, which specifically taps these two processes.

Recent advances in neuropsychological and neuroimaging research have contributed to the understanding of decision-making abilities in adults. Studies on patients with damage or lesions to the orbitofrontal cortex (OFC) have given insight into the importance of this region for successful decision-making. The OFC is the region of the prefrontal cortex (PFC) which lies at the base of the brain, directly behind our forehead and comprises Brodmann area's 10, 11, 13, 14, and 47/12. Interestingly, damage to the OFC is related to impaired decision-making in real life, while other cognitive abilities remain intact (Bechara et al., 1994; Bechara, Tranel, Damasio & Damasio, 1996; Bechara, Damasio, Tranel & Damasio, 1997; Bechara, Tranel & Damasio, 2000, Rolls, Hornak, Wade, & McGrath, 1994). A distinctive characteristic of OFC patients is that they fail to perform on reversal learning tasks. In these tasks participants learn to differentiate between a stimulus that is associated with a reward and a stimulus that is not associated with a reward. During the task, the contingencies change, in such a way that the previously unrewarded stimulus becomes associated with a reward and the previously rewarded stimulus is no longer associated with a reward. The previously learned association between a stimulus and a reward has to be unlearned; OFC patients are unable to reverse stimulus-reward associations. As a consequence they fail to modify their behavior when changes in the environment require them to do so (Rolls et al., 1994).

A neuropsychological task which was specifically designed to mimic real-life decision making, the Iowa Gambling Task (IGT), (Bechara, Damasio, Damasio & Anderson, 1994), also demonstrates OFC patients' decision-making deficit. The IGT is an experimentally controlled card game in which participants are instructed to win money by selecting cards from four decks. Two of the four decks result in frequent large gains, but selecting from these two decks is disadvantageous in the long run because of occasional large losses. Selecting cards from the two other decks is advantageous in the long run because even though this choice results in smaller gains, occasional losses are also small. Participants have to learn from the consequences of their choices during the task which decks are advantageous and which they should avoid in order to maximize their winnings. While healthy participants learn to do this over the course of the task, participants with damage to the OFC continue to select from the disadvantageous decks. Neuroimaging studies in healthy adults have confirmed the role of OFC in decision-making and risk-taking (Cohen, Heller, & Ranganath, 2005; Ernst et al., 2002; Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006; Rogers et al., 1999).

To our knowledge, most of the behavioral studies on the development of decision-making have used the IGT or child-friendly versions of this task. These studies have shown an increase in performance with age in childhood and adolescence (Crone & Van der Molen, 2004; Hooper, Luciana, Conklin & Yarger, 2004; Kerr & Zelazo, 2004; Overman, 2004). In particular, these studies demonstrate that children aged 6-12-

years select cards mainly from disadvantageous decks, whereas 13-17-year-old adolescents learn to select cards from advantageous decks over task blocks. However, comparison across studies indicates that adolescents do not yet perform at an adult level. These findings indicate that the ability to distinguish between advantageous and disadvantageous decks is still developing in late adolescence (Hooper et al., 2004; Overman, 2004). Children's inability to learn which decks are advantageous resembles that of patients with OFC damage, and has led to the hypothesis that children's behavior on the IGT is related to immaturity of the OFC. This hypothesis is consistent with recent studies on brain development that have shown that the PFC is one of the last areas of the brain to mature structurally, as indicated by age related changes in gray and white matter volumes into early adulthood (Giedd et al., 1999; Gogtay et al, 2004) and functionally, as indicated by functional neuroimaging studies that show different patterns of activation on tasks that recruit PFC in children and adults (eg.Casey et al., 2005; Ernst et al., 2005; Galvan et al., 2006). Behavioral differences between children, adolescents and adults can provide us with a window on the developing brain.

The IGT has been successful in that it closely resembles real-life decision making, and the results of developmental studies that used this task have given us many insights into age related changes in decision-making. Nevertheless, we believe our gambling paradigm can help broaden the insight into the development of different abilities that form the basic building blocks of decision-making. The IGT is a complex task, changes with development have been observed in, for example, the ability to keep, and work with information in working memory, the ability to estimate risks, and the ability to predict, and process the outcome of decisions (Hooper et al., 2004; Kirkham & Diamond, 2003). The developmental trajectories of these abilities and their respective contributions to decision-making are largely unknown. Neuroimaging studies have shown that a network of PFC regions is active when performing the IGT (Ernst et al., 2002), and IGT performance of patients with damage to PFC regions outside of the OFC has also been shown to be impaired (Clark, Manes, Antoun, Sahakian & Robbins, 2003; Bechara et al., 1998).

To address this problem in interpreting the results from developmental studies that used the IGT task or similar tasks, we chose to focus on risk perception in the absence of other processes that contribute to decision-making. The Cambridge Gambling Task that was developed by Rogers and colleagues (1999) differs from the IGT in that on each trial it gives participants all the information concerning the relative attractiveness of the risky and safe decisions. In the CGT participants are shown six boxes and are told that the computer has randomly selected one of these boxes to hide a token in. Participants are instructed to win as much money as possible by guessing in which box the token is hidden. A proportion of the boxes is red and a proportion is blue, and participants bet on one of these two possible outcome colors. Crucially, a large reward is always associated with the minority color. Importantly, because performance on the task is not dependent on the outcome of previous trials, demands on working memory are low and outcome processing is less important. Therefore this task specifically taps two abilities that comprise risk-perception; the ability to 1) estimate probabilities, and 2) evaluate rewards.

To gain more insight in the developmental pattern of these two abilities, participants ranging in age from 8 to 30, in 5 age groups: 8-9, 11-12, 14-15, 17-18, and 25-30 year olds were included in the present study. The Cake Gambling Task was developed to make the gambling paradigm understandable for young children and to stir their involvement. A simpler version of the Cake Gambling paradigm has previously been shown to be appropriate for use with children in a neuroimaging study that examined probability estimation in children and adults (Van Leijenhorst, Crone & Bunge, 2006). In the current version of the Cake Gambling Task participants are instructed to win as many credits as possible by gambling with two flavors of cake. Two specific manipulations were introduced to dissociate between separable aspects of risk perception. First, three types of cakes which differed in the probability of winning associated with gambling were presented, in order to tap the ability to estimate probabilities. Second, a number of credits that could be won or lost was associated with the choices that could be made. Similar to the Cambridge Gambling Task (Rogers et al., 1999) a large number of credits was always associated with the smallest likelihood of winning, in order to tap the sensitivity to the magnitude of the reward associated with gambling.

The proportion of pink/brown wedges, and the number of credits associated with the colors were varied systematically across trials. On each trial one of the wedges was selected randomly by the computer, according to the different proportions. This selection resulted in a 17%, 33% or 50% chance that the least likely of the two outcome possibilities was selected. For the 17% condition in which both colors were associated with 1 credit, we expected participants to choose the safe decision. This ability was expected to be present already for the youngest participants, because prior research has indicated that the ability to estimate probabilities is already present by age 5 (Schlottmann, 2001). When the number of points associated with the risky decision increased we expected participants to choose this option more often. We expected that the youngest children would be the least risk-averse, and we expected that with age participants became more risk-averse (Boyer, 2006). In addition, we expected that participants would gamble more often when the probability of winning increased, so for the 17%, 33% and 50% chance of winning conditions we expected similar patterns of results, but an increase in gambling (see Rahman et al., 2001).

An additional complication in measuring age differences in decision-making is the variance explained by individual differences. Differences in the tendency towards sensation seeking behavior are likely to contribute to differences in risk-taking (Crone, Vendel & Van der Molen, 2003). Sensation seeking can be defined as “the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience” (Zuckerman, 1979, p.10). Participants completed a sensation seeking scale to examine correlations between self-report measures of risk-taking and risk-taking as measured with the Cake Gambling task. We expected higher levels of sensation-seeking to be associated with more risk-taking (Lejeuz et al., 2002; 2003). Also, general cognitive abilities might be related to participants’ task performance. For this reason, all participants completed the Raven SPM as an index of IQ.

One further variable was taken into account. In prior decision-making studies, gender differences have also been consistently reported (Overman et al., 2004). Interestingly, on the IGT men outperform women, a pattern which is observed in children (Kerr & Zelazo, 2004; Garon & Moore, 2004), adolescents (Crone, 2005; Overman, 2004), and adults (Reavis & Overman, 2001). This finding seems to contradict self-report indices of risk-taking which show that boys and men are less risk-averse than women (for a review see: Byrnes, Miller, & Schafer, 1999). In the present study gender differences were examined to clarify these contradictory findings. By selecting an equal number of men and women in each age group, we could examine whether gender differences may be specifically present in a certain age range.

4.2 Method

4.2.1 Participants

93 volunteers, distributed among five age groups participated in the study: 19 8-9 year olds (*M* = 9.4, SD = .78, 10 female), 18 11-12 year olds (*M* = 10.9, SD = .68, 12 female), 20 14-15 year olds (*M* = 14.6, SD = .51, 10 female), 17 17-18 year olds (*M* = 17.18, SD = .70, 8 female), and 19 25-30 year olds (*M* = 27.6, SD = 1.26, 8 female). Chi-square analyses indicated that gender distributions did not differ significantly between age groups χ^2 (4) = 2.49, $p > .05$. Children and adolescents were recruited by contacting local schools. All participants were selected with the help of their teachers; informed consent was obtained from a primary caregiver. Adults were recruited through flyers. In all age groups the participant with the highest score received a small reward.

4.2.2 Cake Gambling Task

Participants completed a computerized child friendly gambling task, the Cake Gambling Task, which was inspired by the Cambridge Gambling Task (Rogers et al, 1999). In this gambling task all information that is relevant for making a decision is presented to participants on each trial and no information has to be learned or retrieved over consecutive trials. On each trial, participants gamble with a round cake presented at the center of the screen. Cakes consisted of 6 wedges that could be brown or pink, and participants were told that these wedges were chocolate-flavored (brown wedges) or strawberry-flavored (pink wedges). A brown and pink square containing a number of coins, indicating the number of credits that was associated with each flavor, were presented at the foot of each cake. The proportion of pink/brown wedges (5:1, 4:2, or 3:3), and the number of credits (1, 3, 5, 7 or 9), associated with the wedges were varied systematically across trials. Importantly, 1 credit was always associated with the most likely of the two outcome possibilities, a *safe choice,* and 1, 3, 5, 7 or 9 credits were always associated with the least likely of the two outcome possibilities, a *risky choice*. Each trial started with a 500 ms fixation cross, followed by a stimulus that was presented for 5000 ms, followed by a feedback stimulus that was presented for 1000 ms. 3000 ms after the stimulus appeared on the screen, a question mark was presented in between the squares at the bottom of the screen. At this point, participants were instructed to indicate by a left or right button press which color – pink or brown – the computer was most likely to select, given the fact that its choice was random, and to decide which of two possible gambles they wanted to accept (see Figure 4.1 for an example of a trial and trial timing)[1]. Participants had to decide between taking the risk of choosing the least likely outcome, putting a high number of credits at stake, or choosing the most likely outcome with only 1 credit at stake. To ensure that the youngest participants would understand this instruction, all participants were told to think of the computer as someone who picks a piece of cake with their eyes closed. The valence of the feedback participants received always was the consequence of the combination of the computer's random choice (according to the different proportions of the two colors) for either pink or brown and the participant's decision. If these two matched, the stake associated with the participants choice was added to the total points score, if they did not match, the stake was subtracted from the total points score. Participants were instructed to try to win as many credits as possible on every trial. To prevent participants

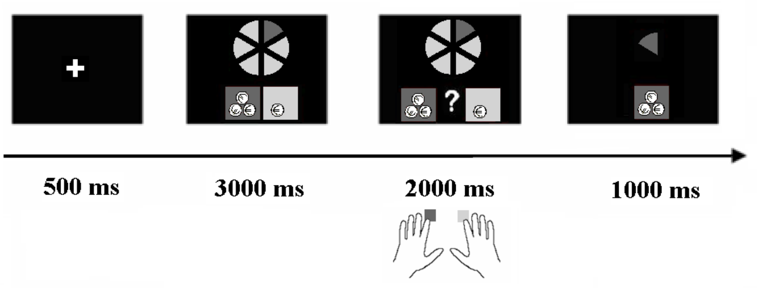

Figure 4.1 *Task example of a low-risk trial. Participants viewed the cue for 2000 ms, followed by the cue and target. Participants had 1500 milliseconds to give a response, after which gain or loss feedback was presented for 2000 ms, along with the choice of the computer. Gain was indicated by +1 and loss was indicated by -1.*

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[1] Figure 4.1 was not included in the published manuscript, but is shown here to facilitate comparisons between the different versions of the Cake Gambling paradigm described in this thesis.

from losing motivation due to disappointment following losses, we explained that the computer's choice was random, like it would be if someone who is blindfolded chooses, and winning was associated with some luck in addition to trying your best. For this reason we also didn't stress the total points score (participants were not shown their cumulative earnings on every trial), but we told participants to try and win on as many trials as possible. However, to keep participants engaged in the task we showed the cumulative score during breaks and at the end of the task and we included a small prize in each age group for the participant with the highest number of credits in total at the end of the experiment.

4.2.3 Sensation Seeking Scale

All participants over 11 years of age completed the Zuckerman's Sensation Seeking Scale (SSS) (Zuckerman, Eysenck,& Eysenck,1978). This scale has previously been adapted for Dutch adults (Feij & Van Zuilen, 1984) and adolescents (Feij & Kuiper, 1984). Participants completed the SSS appropriate for their age. Adolescents completed the adolescent version of the SSS that consists of five sub-scales measuring Extraversion, Emotionality, Impulsivity, Thrill and Adventure Seeking aspects of Sensation Seeking (TAS), and Disinhibition and Experience Seeking aspects of Sensation Seeking (Dis/Es). Some of the Dis/Es sub-scale items concerning, for example, experience with illegal drugs or sex were considered inappropriate for the youngest participants. Therefore 11-12 year olds completed a version of the SSS that did not include this sub-scale. The TAS, and Dis/Es sub-scales were examined as a measure of sensation seeking, because these sub-scales are distinguishable in both the adult and adolescent SSS version. The TAS sub-scale consists of 11 'true/false' items, such as 'I prefer to be in a place where there is a lot going on', the Dis/Es sub-scale consists of 8 'true/false' items, such as 'I would like to experience what it is like to use illegal drugs'. The Tas and Dis/Es sub-scales have an internal consistency of .79 and .69 respectively. Adults completed the adult SSS containing TAS (12 items, internal consistency .80), Disinhibition (12 items, internal consistency .78), and Experience Seeking (14 items, internal consistency .74) sub-scales. The adult SSS consists of questions such as 'I like wild, uninhibited parties' that have to be answered using a 5-point scale (1= never, 2= rarely, 3= sometimes, 4= usually and 5= always).

4.2.4 Raven Standard Progressive Matrices

Participants filled out the Raven Standard Progressive Matrices task (Raven SPM) in order to obtain an estimate of their ability to form perceptual relations and reason by analogy. The Raven Standard Progressive Matrices (SPM) is a non-verbal test designed to measure general intellectual ability (Raven, Raven & Court, 1998). The SPM consists of 60 items, five sets (A, B, C, D, & E) of 12 items each. Each item consists of a figure from which one piece is missing. Below the figure either six (sets A & B) or eight (sets C through E) pieces are displayed that can be used to complete the figure. Only one of these is correct. The different sets and items within the sets are increasingly difficult.

4.2.5 Procedure

All participants were tested individually in a quiet laboratory or classroom. All participants completed all tasks. Stimuli were presented in color against a black background on a 15-inch computer screen placed at a distance of approximately 70 centimeters from the participant. Preceding the task participants were given verbal instructions and were shown examples of trials and feedback displays. Following this instruction, all participants performed 15 practice trials on the laptop computer. Care was taken that all participants understood the instructions after practice. The Gambling task consisted of 270 trials and took approximately 30 minutes to complete, including instructions and 3 short breaks. The total points score was shown during the three breaks and at the end of the task. The colors pink and brown corresponded to the left and right index finger, this mapping was counterbalanced between subjects to control for key preference. Color credit associations were counterbalanced within subjects to control for a possible color preference. The Raven SPM (approx. 25 minutes to complete) and the SSS (approx. 10 minutes to complete) were administered after completion of the gambling task. All participants were given the opportunity to take a short break following the gambling task, and were offered a drink and cookie. The total duration of the experiment was approximately 80 minutes, after completion of the experiment participants were thanked for participation, the participant with the most credits within each age group received a small reward.

4.3 Results

4.3.1 Cake Gambling Task Performance

Participants' performance was examined by computing the percentage of risky choices for every combination of the probability of winning and the number of credits to gamble with. Risky choices were defined as those choices for which the participants chose to gamble with the highest number of credits, even though these were associated with a small (5:1, 4:2) or equal (3:3) probability of winning. The data were submitted to repeated measures ANOVAs with Age Group (5) and Gender (2) as between-subjects factors and Probability (5:1, 4:2, 3:3) and Credits (1, 3, 5, 7, 9) as within-subjects factors. The percentages of risky choices, for all age groups separate, are presented in Figure 4.2A.

As can be seen in Figure 4.2A, when the number of credits that could be gambled with was the same for both colors (credits = 1), participants had no preference for either pink or brown in the 3:3 condition (the number of choices for each color was at chance level). In contrast, they avoided the color associated with the lowest probability of winning in the 4:2 and 5:1 conditions (main effect Probability, F (2, 166) = 363.16, $p < .001$). This effect of probability did not differ between age groups ($p = .65$) or genders ($p = .24$), showing that all participants were able to judge probabilities.

When the number of credits to gamble with increased, the percentage of risky decisions also increased (main effect Credits, F (4, 332) = 54.78, $p < .001$). Importantly, this effect was more pronounced for the conditions with the highest probability of winning, (Probability x Credit interaction: F (8, 664) = 8.09, $p < .001$). Separate ANOVAs for each of the Probability conditions confirmed that this effect was observed for all probability conditions. That is, in the 3:3 condition the 1 Credit condition resulted in chance level performance. In contrast, the 3, 5, 7 and 9 Credit conditions were associated with more risky choices, and did not differ from each other (p's > .05). Similar post-hoc ANOVAs for the 4:2 and 5:1 conditions showed an increase in risky choices associated with each increase in credits (all p's < .05). Contrary to expectations, and demonstrated in Figure 4.2A, there were no differences in the pattern of risky decision-making between the age groups (all p's > .37).

Our analyses focused on the comparison of age groups, not age as a continuous variable to facilitate the interpretation of developmental changes in behavior. In addition we submitted participants' raw ages as a covariate factor to a mixed model ANCOVA on the Cake Gambling Task data with Gender (2) as a between-subjects factor and Probability (3) and Credits (5) as within-subjects factors. Importantly, none of the effects that resulted from our initial analyses were altered by including Age as covariate; again no changes in performance with age were found.

4.3.2 Gender differences

In contrast to the absence of an age difference in risky decision-making, there were pronounced differences in the decision-making patterns of males and females. That is, the percentage of risky choices was higher for male participants compared to female participants (main effect Gender, F (1, 83) = 9.22, $p < .01$). Moreover, this difference in the percentage of risky decisions between male and female participants increased with the number of Credits at stake (Gender x Credits interaction, F (4, 332) = 3.06, $p = .05$). This interaction is displayed for the five age groups in Figure 4.2B. Male participants made 4.56%, 7.77%, 9.18%, 12.62%, and 11.45% more risky choices than females when gambling with 1, 3, 5, 7 and 9 credits respectively (all p's < .05). This pattern was found to be consistent from late childhood through early adulthood. No significant interactions with Age Group were found.

4.3.3 Performance during the task

Even though the Cake Gambling paradigm was designed to minimize the importance of learning for task performance, it is possible that participants tried to optimize their behavior by learning from the outcomes of their choices over the course of the task. To examine task performance over time, we divided the task in three blocks of 90 trials. The results from this repeated measures ANOVA with Task block (3), Probability (3), and Credits (5) as within subjects factors and Age group (5) as between subjects factor mimicked the results from the previous analyses, showing an increase in the percentage of risky decisions with an increase in the probability of winning, and the number of credits that could be gambled with for all age groups (Probability x Credits F (8, 536) = 5.79, $p < .001$). This pattern did not differ between task blocks

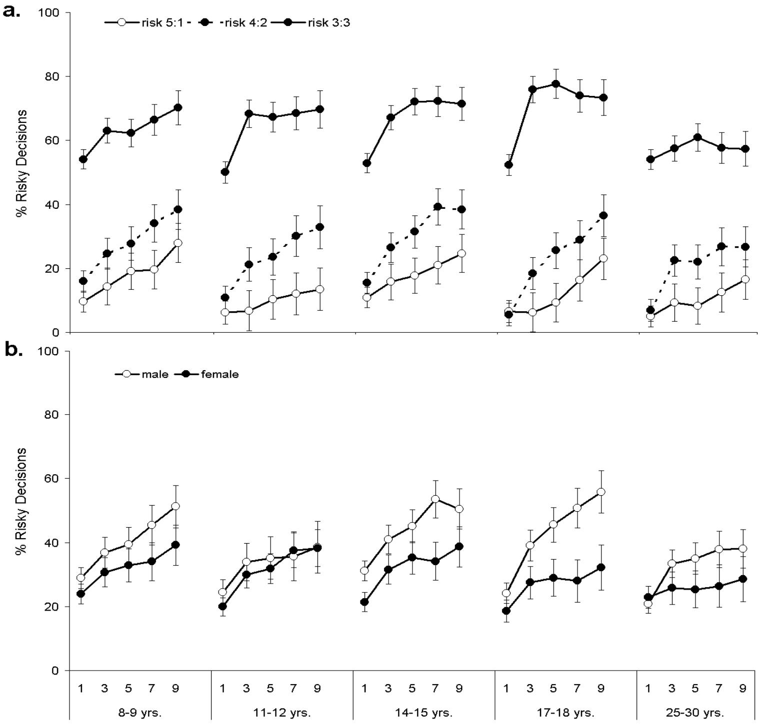

Figure 4.2 *Average percentage of risky choices plotted for all age groups as a function of the number of credits gambled with (1, 3, 5, 7 or 9) for a.) the different probabilities of winning (3:3, 4:2, 5:1), and b.) male and female participants. In all age groups gambling increases with the probability of winning and with the number of credits, and male participants made more risky decisions than female participants.*

(Probability x Credits x Task block, *p* >.05). A main effect of Task Block (*F* (2, 146) = 11.70, *p* <.001), indicated that participants took more risks during the first trial block than during the last two trial blocks. This main effect was qualified by a Probability x Task Block interaction (*F* (4, 292) = 4.61, *p* = .001). Separate ANOVAs for each of the probability conditions showed that the decrease in the percentage of risky decisions from the first to the later blocks of the task was most pronounced in the 4:2 condition, that is, the percentage of risky choices decreased from the first (M = 32.76, SD = 21.99) to the second block (M = 24,62, SD = 22.63) as well as from the second to the third block (M = 20.78, SD = 23,36) (*p* <.001). No differences in risk taking behavior over time were observed in the 3:3 condition (*p* > .05) (M =

66.31, SD = 18.95, M = 63.13, SD = 22.61, and M = 62.48, SD = 23.84 respectively), in the 5:1 condition the percentage of risky choices decreased from the first block (M = 18.40, SD = 17.88) to the second block (M = 15.00, SD = 21.70) (p < .05), but did not differ between the second block and the third block (M = 13.46, SD = 21.78) (*p* > .05) Again, there were no interactions with age group.

4.3.4 Sensation Seeking

Participants' raw scores were z-transformed and a median split, creating groups of high sensation seekers and low sensation seekers was performed for each age group, gender and Sensation Seeking sub scale separately. This technique has been shown to be unlikely to change the conclusions drawn from the results while it facilitates the interpretation of the results (Farrington & Loeber, 2000). The 11-12 year olds, 14- 15 year olds, 17-18 year olds and 25-30 year olds raw scores on the Thrill and Adventure Seeking sub scale of the Sensation Seeking questionnaire were M = 5.89, SD = 2.45; M = 6.85, SD = 2.48; M = 8.06, SD = 2.59; and M = 6.11, SD = 3.02 respectively, and 14- 15 year olds, 17-18 year olds and 25-30 year olds respective raw scores on the Disinhibition/Experience Seeking sub-scale of the sensation seeking questionnaire were; M = 2.05, SD = 1.36; M = 2.88, SD = 1.90; and M = 10.63, SD = 4.39. Interactions with the task manipulations were only significant for the Disinhibition/Experience Seeking Scale (DIS/ES). Participants labeled as high sensation seekers on the Dis/Es scale showed more risky decision-making with an increase in the probability of winning compared to participants labeled as low sensation seekers on this scale (Probability x Dis/Es interaction, *F* (2, 88) = 4.12, *p* < .05). This interaction was qualified by a Probability x Credits x Dis/Es interaction, *F* (8, 35) = 2.24, *p*< .05) showing that participants labeled as high sensation seeking took more risks when the amount of credits that could be gambled with increased compared to participants labeled as low sensation seeking.

4.3.5 *Raven SPM*

As expected, the number of correct solutions on the Raven SPM task increased with age (*F* (4, 76) 20.84, *p* < .001). Post hoc Tukey tests revealed that the 8-9 year olds were the least accurate (*M* = 37.67, *SD* =

8.94), followed by 11-12 year olds (*M* = 43.89, *SD* = 5.06) and 14-15 year olds (*M* = 44.87, *SD* = 4.00), who did not differ from each other. Finally, the highest scores were achieved by the 17-18 year olds (*M* = 51.73, *SD* = 3.04), and 25-30 year olds (*M* = 53.37., *SD* = 4.66), who also did not differ from each other. Raven scores were z-transformed in order to enable comparisons between the different age groups. Correlations were run to determine whether or not inductive reasoning ability may influence the findings. However, there was no correlation between z- transformed Raven SPM scores and the average percentage of risky decisions (r = -.06, *p* = .572). The SPM scores were then entered as a covariate in a repeated measures ANOVA with Gender (2) and Group (5) as between-subjects factor and Probability (5:1, 4:2, 3:3) and Credits (1, 3, 5, 7, 9) as within-subjects factors. This analysis showed that Raven SPM scores were no significant covariate (*F* (1, 70) = .112, *p* = .74), and including Raven SPM scores as a covariate did not change the pattern of results.

4.4 Discussion

This study examined the development of risk perception, an important aspect of decision-making, in participants aged 8-30 using the Cake Gambling Task, a child friendly gambling paradigm inspired by the Cambridge Gambling Task (Rogers et al., 1999). In particular, the focus of the study was on two aspects of risk perception: probability estimation and evaluation of reward. In concurrence with previous findings by Rogers and colleagues with a similar paradigm in adults (1999), we found that in participants from all age groups an increase in the probability of winning, and an increase in the number of credits associated with gambling, resulted in an increase in the number of risky decisions. Contrary to our expectations, we did not find differences in task performance between the age groups. Therefore, both the likelihood of winning and the magnitude of the reward associated with winning contribute to decision-making from middle childhood on, suggesting that increases in risky behavior that are observed in adolescence are not likely to be the consequence of immature risk perception abilities.

The results are in sharp contrast with the results of previous developmental studies that have used the IGT or similar tasks which have shown age related changes in risky decision making throughout adolescence (Overman, 2004; Crone & Van der Molen, 2004). These age related changes are therefore likely to be related to task demands that are specific to the IGT. As mention in the introduction, The IGT (Bechara et al., 1994) and reversal learning tasks (Rolls et al., 1994) differ from the Cambridge Gambling Task (Rogers, 1999) and the Cake Gambling Task in that they place great demands on working memory and outcome processing in addition to risk perception abilities. In these tasks participants have to infer the task contingencies based on feedback they receive about their decisions over trials, whereas in the Cambridge Gambling Task (Rogers et al., 1999) and Cake Gambling Task all the information is presented to participants on any given trial. The current results suggest that developmental differences in decision making as measured with the IGT are associated with the demands that this task places on the ability to infer task contingencies over trials.

More support for the hypothesis that the IGT and the Cake Gambling Task tap into different processes and underlying brain circuitry comes from the comparison of gender differences. Interestingly, on the Cake Gambling Task, male participants in all age groups take *more* risks than female participants, mirroring the results of self-report studies that report males to be more risk taking in real life (Byrnes, Miller & Schafer, 1999), but contradicting prior findings using the IGT that show male participants to outperform female participants (e.g., Overman, 2004). Advantageous performance on the IGT requires participants to learn which decks are profitable, and in order to do this, outcome processing as well as updating information kept in working memory are important. The higher number of advantageous choices for men relative to woman on the IGT could be associated with aspects of contingency learning, rather than risk perception. Support for the idea that the neural correlates of IGT performance differ between men and women comes from a study by Bolla, Eldreth, Matochik & Cadet (2004). The authors report that the brain mechanisms engaged by men and women when performing the IGT differ. In men activation is lateralized to the right hemisphere, and men showed more activation in right lateral OFC than women did. In contrast, in women activation was found in both hemispheres, and women showed more activation in left DLPFC than men. These findings suggest that women differ from men in the cognitive strategies they use when performing the IGT (Bolla et al., 2004). These findings suggest that male strategies result in better learning abilities in this specific task, together with increased risk taking compared to women.

In this study, behavior did not differ between children, adolescents and young adults, suggesting that the basic mechanisms of probability estimation and reward evaluation are already in place at age 8. What then causes adolescents to engage in more risk-taking behavior than children and adults in real life? Adolescents may be highly sensitive to environmental influences. For example, Choudhury, Blakemore & Charman (2006) recently suggested that adolescence is a period which is characterized by increased social awareness. Thus, it is possible that age related differences in risk-taking are present under the influence of social pressure. Initial evidence for this hypothesis comes from a study by Gardner & Steinberg (2005), in which risk-taking on a laboratory task greatly increased in adolescents, not children and adults, when peers were physically present. Another explanation comes from epidemiological studies which have suggested that adolescents engage in risky behaviors, despite the increase in cognitive awareness of the risks involved, because they believe the risks to be acceptable (Fromme, Katz, & Rivet, 1997; Furby & Beyth-Marom, 1992; Gerrard, Gibbons, Benthin, & Hessling, 1996; Moore & Gullone, 1996). Also, adolescent risk participation correlates positively with the number of benefits the adolescent perceives associated with making a risky decision and correlates negatively with the number of potential negative consequences that are perceived (Cohn, Macfarlane, Yanez, & Imai, 1995; Goldberg, Halpern-Felsher, & Millstein, 2002; Lavery, Siegel, Cousins, & Rubovits, 1993). Therefore, adolescents may accept some probability of negative consequences because they desire the potential positive outcomes the risks might bring about (cf. Boyer, 2006, p. 302). Along this line, recently it has been suggested that adolescents might experience risks different compared to children and adults as a consequence of the rates at which motivational and cognitive control systems in the brain mature. Relatively mature motivational circuitry biases adolescents towards risky “exciting” behavior, while relatively immature cognitive control circuitry makes it difficult for adolescents to control these impulses, which makes adolescence a period of increased vulnerability to risky behavior. For example, a recent study by Galvan et al. (2006) indicates that reward anticipation in adolescence is characterized by a hypersensitive emotion-inducing system and an under active emotion-regulation system, even when differences in performance are absent.

Decision-making is a multi-faceted concept, the perception of risk is just one of many abilities that contribute to it. The relationship between activation in the PFC and decision making behavior is complex in a similar way. Different regions of the PFC are likely to contribute to decision making behavior, and in addition to gaining insight into the development of these different regions and the component processes of decision-making the interaction between different regions will have to be taken into account in future studies.

Future research might also address some limitations in the current study. We did not include direct measures of brain activity; functional Magnetic Resonance Imaging (fMRI) studies could provide more insight into changes with development in the relative contribution of different PFC regions, such as the OFC. In a previous fMRI study using a simplified Cake Gambling task (Van Leijenhorst, Crone, & Bunge, 2006) we found that children used different brain circuitry to reach adult decisions, in the absence of differences in behavior. The present study looked at the perception of risks in a gambling task under experimentally controlled circumstances. We assume that behavior in this situation is similar to behavior in real-life, but we have to acknowledge that there could be differences between the processes involved in performing the experimental task and real-life decision making. It should also be taken into account that limited task engagement could account in part for the lack in performance differences between the age group. The overall higher level of risky decisions in male participants could reflect differences in the way they experienced the task, possibly they were more engaged because of gender related differences in the way participants interpreted the competition element. The relation between Cake Gambling Task behavior and individual differences in sensation seeking tendency, suggests that risk perception as assessed with the Cake Gambling task does relate to real-life risky behavior, and the consistent performance in all age groups over the duration of the task suggest that participants involvement in the game did not differ throughout the experiment. Also, in the Cake Gambling Task the differences between the conditions were relatively clear. More subtle differences might be required to measure age related differences in risk estimation abilities. For example, a study by Budhani & Blair (2005) found evidence for a relation between task performance in a response reversal task and the salience of changes in task contingencies. Children with mild OFC impairments performed worse as the changes in task contingencies were more subtle.

In conclusion, the present results indicate that risk perception is already in place at the age of 8 and does not change between ages 8-30. These results suggest that increases in real-life risky behavior in adolescence are not likely to result from a protracted development of risk perception abilities which results in immature decision-making. Gender differences are consistent across this age period, with male participants taking more risks than female participants. This study adds to current knowledge about the development of decision-making abilities in that it offers insight into the relative contribution of risk perception to decision-making from childhood until young adulthood. Insight into the development of abilities that contribute to adult decision-making is important in order to better understand potential problems adolescents face.