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

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8.

Summary and Conclusions

8.1 Introduction

The research described in this thesis aimed to gain insight in risky behavior in adolescence, by examining the development of decision-making in relation to brain development. Chapter 1 describes two existing possible explanations for adolescent risky behavior, the first explanation focuses on the development of cognitive control, and states that adolescents' immature ability to control their impulses may bias them to act risky. The second explanation focuses on emotional/motivational processes, and suggests that adolescents engage in risky behavior because they respond stronger to the possible rewards associated with risks than children and adults do. This thesis describes experiments that examine developmental changes in three cognitive processes that contribute to mature decision-making, the ability to estimate the probabilities, the ability to weigh potential positive and negative consequences associated with a risk, and cognitive control abilities. Chapters 2, 3, and 7 describe studies on developmental changes in the processes that form the building blocks of more complex decision-making under risk. Chapters 4, 5, and 6 explore the relative contributions of reward sensitivity and cognitive control to decision-making across development. The results from this thesis show that developmental models that try to explain risky behavior in adolescence can gain from knowledge about brain maturation, and from models of age related changes in brain function. In addition, based on these new insights from developmental fMRI studies, adolescent risk-taking can be explained as the consequence of a difference in the developmental time course of reward related and cognitive control related brain circuitry. An increase in reward sensitivity early in adolescence is proposed to drive teens to take risks; while the ability to control these impulses does not fully develop until late adolescence.

8.2 Development of the neural correlates of basic decision-making processes

Chapter 2 describes an fMRI study in which we examined the ability to estimate probabilities. Participants aged 9 to 12-year-olds and young adults tried to gain as many points as possible by identifying the choice option associated with the highest probability in a two-choice gambling task. On half of the trials, this was an easy task, the probability of choosing the right choice option and winning a point was high (low-risk gambles), on the other half of the trials this choice was more difficult, and the probability of winning was low (high-risk gambles). This was the first developmental fMRI study that examined the neural correlates of cognitive control as well as reward processing. We examined brain activation patterns at the moment that participants made their decision and at the moment they saw the outcome of their choice. Performance differences were minimal, and overall children and adults recruited similar brain regions when performing this task. However, there were differences in the extent of activation between children and adults. At the moment of the decision, the anterior cingulate cortex (ACC) was more active for high-risk gambles than for low-risk gambles, but this difference was larger for 9-12 year olds than for adults. The ACC is considered a key cognitive control region (Miltner et al., 2003; Ridderinkhof, Ullsperger, Crone & Nieuwenhuis, 2004), and this finding suggests that in children the more ambiguous decisions were associated with increased cognitive control. Activation in two other regions which have been linked to cognitive control and decision-making in adults, the dorsolateral PFC (DLPFC) and the orbitofrontal cortex (OFC) were also more active during high-risk relative to low-risk choices, but these regions were not differentially activated for children and adults. When the outcome of gambles was presented, in children, relative to adults, the lateral OFC was more active for losses relative to wins. This difference was taken to suggest that children experienced losses as more aversive than adults.

Further support for the continued maturation of cognitive control during adolescence is presented in Chapter 7. This chapter describes a study on the development of object and spatial working memory (WM) and related feedback processing and performance monitoring. WM and the ability to process feedback and monitor one's performance are key components of cognitive control. In addition to behavioral measures this study describes measures of heart rate (HR) changes, which provided an index of covert cognitive processes. Participants from 4 age groups (6–7, 9–10, 11–12, and 18–26 years old) performed object and spatial WM tasks, in which each trial was followed by feedback. We showed that WM for Object and Spatial information followed dissociable developmental time courses. Spatial WM task performance reached adult levels of performance by age 11, while object WM task performance showed continued change with development during adolescence. This was also seen in improved performance monitoring as reflected in HR slowing elicited by negative performance feedback. This slowing was larger in adults than in children, and did not reach adult levels at age 12, which suggests that performance monitoring continues to change during adolescence.

The second important basic process important in theories on adolescent risk-taking is developmental change in the sensitivity to rewards. In previous studies the motivational circuitry of the brain had been found to be either over-recruited (Ernst et al., 2005; May et al., 2004) or under-recruited (Bjork et al., 2004) in adolescents. These conflicting findings limited our understanding of the reasons behind adolescent risky behavior. One of the confounds of these prior studies is associated with differences in response demands and performance (i.e., leading to strategic differences and making comparisons between age groups difficult). To examine the basic processes in the brain related to anticipation of winning or losing, we performed a second developmental fMRI experiment (Chapter 3) in which we compared 10-12 year olds, 14-15 year olds, and 18-25 year olds using a slot machine task that did not require any active decisions or behavior on the part of the participant. We used this passive experimental task to control for possible confounds of behavioral requirements that could complicate the interpretation of age related differences. The results of this study reveal differences between adolescents and young adults during both the anticipation and the processing of rewards. Received rewards and the anticipation of possible rewards resulted in activation in reward related limbic regions, including the nucleus accumbens and the insula, and elicited the most pronounced activation in the adolescent brain. In contrast, in adults we found control regions in the PFC to be most active; the OFC was responsive to the omission of rewards in this age group, but not in adolescents. These findings support the hypothesis that reward related regions are more responsive in adolescence.

Taken together, the results from the experiments described in Chapters 2 and 7 support the hypothesis that cognitive control functions continue to develop during adolescence, and that these functions contribute to mature task performance. The result from the experiment described in Chapter 3 suggest that there are fundamental differences in the way that reward related brain regions, the VS in particular, respond in mid-adolescence. These results informed the interpretation of the results from the experiments described in Chapters 4, 5, and 6 in which reward sensitivity and cognitive control both contribute to decision-making, and in which rewards were dependent on performance.

8.3 Development of decision-making under risk; relative contributions of cognitive control and reward sensitivity

Chapter 4 describes a behavioral study in which an adapted version of the paradigm that was introduced in Chapter 2 was used. In this version of the paradigm both the probability of winning and the size of the reward that could be gambled with were manipulated. Participants from 5 age groups (8-9, 11-12, 14-15, 17-18, 25-30 years old) were asked to try to win as many credits as they could by choosing between high-risk/low-probability gambles associated with a higher number of credits, and low-risk/high-probability gambles associated with 1 credit. We tried to control for age related differences in WM capacity that could make the task relatively more difficult for younger participants, by presenting all the information that was needed to make a good decision on every trial. Because of this, no information had to be remembered, or inferred over the course of the task. Earlier studies that have found decision-making skills to improve until late adolescence did not control for this (Crone & Van der Molen, 2004; Hooper, Luciana, Conklin & Yarger, 2004). In contrast to these earlier studies, we found no performance differences between the age groups. This suggests that when all the information that has to be included in a decision is available, the ability to weigh probabilities and potential rewards is mature in children as young as 8 years old. These findings suggest that risky behavior in adolescence is not caused by an immature ability to understand the decisions that have to be made. However, when decisions are more complex, for example because risk information has to be inferred based on performance feedback, decision-making differences are observed until late adolescence.

As described above psychophysiological measures can gain insight into age related changes in cognitive processes in the absence of differences in behavior. This inspired the study described in Chapter 5 which aimed to test the hypotheses that adolescent decision-making is biased towards taking risks because of an increased sensitivity to possible rewards and immature cognitive control. In this experiment adolescents from three age groups (11-12-year-olds, 14-15-year-olds, and 17-18-year-olds) chose between high-risk and low-risk probabilistic gambles with varying magnitudes of reward. We modified the Cake Gambling Task to enable us to measure heart rate changes. In addition, in this experiment participants gambled with and for a monetary reward. Results showed that risk-taking decreased with age, and the HR data showed that 11-12-year-olds showed a heightened sensitivity to rewards. Age-related changes in HR responses were related to the anticipation of the outcome of risky decisions, not to the evaluation of outcomes. These findings support the hypothesis that a heightened sensitivity to rewards contributes to adolescent risk-taking, and suggest that developmental changes are related to the way adolescents weigh the potential reward when they make a decision. These results fit well with recent theories on adolescent risk-taking, described in more detail in the next section.

8.4 The adolescent brain: Control and emotion out of balance

In Chapter 6 we directly tested the hypothesis that reward related and control related brain regions follow different developmental trajectories in an fMRI experiment. Participants chose between Low-Risk gambles associated with a high probability of obtaining a small reward (1 Euro) and High-Risk gambles associated with a smaller probability of obtaining a higher reward (2, 4, 6, or 8 Euro). We examined brain activation patterns during choice selection and outcome processing in participants from four age groups (pre-pubertal children, early adolescents, older adolescents and young adults). Behavioral findings showed similar behavior across age groups; participants in all age groups were more willing to take a risk when the potential reward was higher. But, with age risk-taking decreased for low rewards. The fMRI results confirmed that High-Risk choices were associated with activation in VMPFC, whereas Low-Risk choices were associated with activation in lateral PFC. Activation in dorsal ACC showed a linear decrease with age, whereas activation in VMPFC showed an inverted-U shaped developmental pattern, with a peak in adolescence. Gain following High-Risk choices was associated with activation in the VMPFC and VS, and this VS activation peaked in adolescence. These results support the hypothesis that risky behavior in adolescence follows from an imbalance caused by different developmental trajectories of reward related and regulatory brain circuitry. We argue that in future studies adolescent development should be examined in terms of the interplay between subsystems, rather than the development of single mechanisms.

8.5 Conclusions and future directions

The two theoretical accounts presented in Chapter 1 provide different predictions with respect to the development of risk-taking behavior. Behavioral changes in risk taking across development, are sometimes described in terms of a linear decrease as a consequence of increasing cognitive control from childhood to adulthood (Crone & Van der Molen, 2004; Reyna & Ellis, 1994), and sometimes in terms of a peak in adolescence as a consequence of heightened arousal in this developmental phase (Arnett, 1992; Steinberg, 2004). The research presented in this thesis supports the hypothesis that risky behavior in adolescence follows from an imbalance caused by different developmental trajectories of motivational and regulatory brain circuitry (Casey, Getz & Galvan, 2008; Galvan et al. 2006; Steinberg 2008). We argue that recent theories based on these insights from developmental neuroimaging studies provide a framework for understanding risky behavior in adolescence that enables these perspectives to be integrated and can account for the inconsistent findings in the literature. Because risky behavior has been difficult to measure in a laboratory context, psychophysiological and neuroImaging approaches have been particularly valuable. These techniques have helped gain insight into cognitive processes that could not be observed on a behavioral level.

Taken together, the studies in this thesis suggest that adolescents risky behavior is the consequence of increased sensitivity to rewards, paired with immature cognitive control abilities. This conclusion is consistent with recent theories which suggest that reward related and cognitive control related brain systems are complimentary, and together produce decision-making. The first, evolutionary older, system builds on subcortical structures that have been linked to the processing of emotionally salient information, such as the amygdala and the nucleus accumbens (Ernst *et al.*, 2005; Galvan et al., 2006) and VMPFC, whereas the second, evolutionary younger, system that is important for the control of impulses builds on cortical brain regions, including the lateral PFC/OFC and the ACC (Adolphs, 2003). Age related differences in risk-taking are proposed to be associated with the different patterns of functional development followed by these two brain systems (Casey *et al.*, 2008; Rivers, Reyna & Mills, 2008; Steinberg, 2008). These differential developmental patterns produce a fragile balance between impulses and control in adolescence. We argue that during development both systems contribute to decision-making, but that behavior is dependent on the relative strength of each system in a given situation.

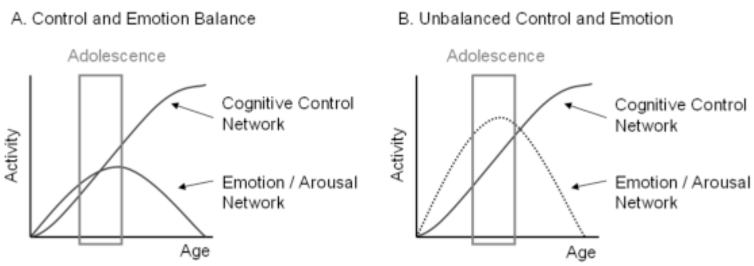

Figure 8.1 *Schematic representation of the relative contributions of cognitive control and emotion/arousal brain systems to decision-making across development. The grey border depicts the difference between both systems in adolescence. Figure A. shows the pattern of brain activation of control relative to emotion arousal regions in neutral conditions,where cognitive control is sufficient to prevent risk-taking; Figure B.shows the same pattern in conditions of increased emotion/arousal, when immature cognitive control abilities cannot prevent risk-taking.*

Figure 8.1A shows a schematic representation of the contribution of both systems as a function of age in an emotionally neutral situation (such as often seen in laboratory tasks). In this situation emotion and cognitive control are balanced, and the model would predict a linear decrease in risk-taking behavior with age, as a consequence of a linear increase in cognitive control abilities. Figure 8.1B shows the situations in which the balance is disturbed, because either the emotion-arousal network is overactive relative to the control network (as in everyday arousing situations for example in the presence of peers), or because the immature cognitive control abilities are insufficient to cope with task requirements (as for example when complex decisions have to be made). In these situations we predict a peak in risk-taking in adolescence.

Previous studies examining the development of risk-taking in adolescence have used different tasks and methods, and the integration of these methods (including laboratory and real-life assessments, and cognitive, emotional and social task manipulations) is necessary for a full understanding of this phase in development. Adolescence is a unique developmental period that can be characterised by different types of developmental stages. For example, teens can be pre-pubertal, pubertal or post-pubertal, and from a cognitive and social perspective, teens can be referred to as in early, middle, or late adolescence. These distinct stages should be recognized, and studied in order to further disentangle the effects of puberty related hormonal changes and brain maturation.

A recent study illustrates the importance of taking these changes into account, and shows the benefits of using a theoretical approach based on the assessment of cognitive processes that are important in the development of decision-making in terms of their developmental time course and psychophysiological manifestation. During adolescence, friendships change and peers become more and more important. For example, more and more time is spent in the presence of peers than in the presence of parents. It has been suggested that the opinions of peers become more important as well (Harris, 1995). In an experimental study on the influence of peers on adolescent risk-taking, adolescents (13-16-years-old), young adults (18-22-years-old), and adults (24-years-old) played a risk-taking game in the presence of peers and alone (Gardner & Steinberg, 2005). This study showed a disproportionate increase in the number of risky decisions in the presence of peers in adolescents, not adults. It could be that in this task the presence of peers, or the need to fit in, influenced the emotion and arousal brain network in adolescents to such an extent that it led to risk-taking. This illustrates that because of differences in brain function, a situation that would seem risky to adults could be perceived differently by adolescents. For example, because of the presence of friends, the same situation might be perceived as fun by adolescents and scary by adults.

Even though neuroimaging has provided strong evidence for developmental change in brain structure and function and has vastly increased our understanding of child development, many questions still remain to be answered. One of the major limitations of current fMRI research is the limited ability to explain individual differences in behavior. For example, the results described in Chapter 6 show that differences in risk-taking propensity in the task modulated brain activation in all age groups. Unfortunately, traditional fMRI analyses do not have enough power to draw conclusions about individuals (Logothetis, 2008; Poldrack, 2006). Even though many cognitive functions have been mapped onto specific brain regions, this does not mean that these regions are uniquely responsible for these functions. Conventional fMRI analyses do not allow us to infer from brain activation in a specific region, what cognitive process takes place. Using the traditional analysis methods available today we cannot predict if an adolescent is at a heightened risk based on their brain activation, because activation in a particular region for an individual could be different from the average of the group. Future studies should take these individual differences into account, in particular in the context of studies on development. Individual differences in performance as well as patterns of brain activation are especially large in children and adolescents. The studies described in this thesis, and the potential consequences of adolescent risky behavior underline the importance of further research. We argue that it will be important for future studies to take individual differences into account, and strive for a more detailed understanding of the relation between patterns of brain activation and cognition. The first studies aimed at resolving this issue are currently under way.