On the art of choosing: Developmental changes and individual differences in decision making under risk
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Chapter 8

Summary and General Discussion
The primary goals of this thesis were to gain insight into the developmental changes and individual differences in decision-making under risk. The ‘art of choosing’ was studied in six empirical chapters that included individuals from 5 to 35 years of age and implemented a multi-disciplinary theoretical and methodological approach. That is, this thesis combined theoretical insights from economics (EU and risk-return models), psychology (decision heuristics, counterfactual emotions), and developmental psychology (studying the development of affect and control, counterfactual emotions, and decision strategies). The data-analytic techniques included traditional statistical methods, as well as latent-class analysis, and the estimation of formal decision models. Finally, the measures used in this thesis included not only observations of overt behavior, but also physiological measures such as heart rate and brain activation.

8.1 Summary of main findings

Chapters 2-4 of this thesis present studies that vary the level of affective-motivational engagement (by varying the absence or presence of immediate outcomes), and vary the load on cognitive control processes such as memory (by varying whether explicit information is given). The main goals of Chapter 2 were (1) to determine adolescents’ level of advantageous decision making in an affective and a low-affective, task, and (2) to determine whether the complexity of decision strategies used in the low-affective task was associated with complexity of decision strategies used in the affective task. The results indicated that adolescents were able to use relatively complex and advantageous (i.e., integrative and multi-attribute non-integrative) strategies in the low-affective task. However, they used a less advantageous strategy in the affective task. Thus, although most adolescents were able to understand and reason about choices in low-affective contexts, they showed poor choice behavior in high-affective contexts. A limitation of this study was, however, that the tasks differed in the presence of immediate feedback (affective-motivational component) as well as in the explicit presentation of choice attributes. These results therefore do not allow a strict distinction between the effects of affect and control on choice behavior.

The next chapters therefore specifically manipulated cognitive control demands in children’s and adolescents’ affective decision-making, by varying the reliance on (working) memory. In Chapter 3 performance was compared between an informed and a noninformed Gambling Game; with both tasks presenting immediate choice outcomes. The noninformed condition resembled the affective task in Chapter 2 in which repeated sampling was necessary to learn choice attributes. The informed condition presented a similar task, but with an explicit display of choice attributes. Results demonstrated that in the noninformed task, decision making improved monotonically with age, and continued to improve into late adolescence (see also Crone & Van der Molen, 2004; Huizenga et al., 2007). In the informed task, however, children chose advantageously, although decision making still improved across age groups. Detailed analysis of response patterns indicated that in the noninformed task, children continuously switched choices after an occasional loss, which was not observed in older adolescents and young adults. This pattern was also observed in the informed task, but to a much smaller extent. This indicates that the ability to control choice behavior was influenced by (working) memory load. Together, these results indicate that children and adolescents are
fairly capable of choosing advantageously in a risky decision-task, provided that choice options are presented explicitly.

The third empirical study in Chapter 4 further examined responses to gains and losses across development. In Chapter 3 we found that young children experienced difficulty with controlling their reactive responding towards occasional losses, specifically in situations that put a high demand on control processes (i.e., noninformed contexts). Here, we used behavioral and heart-rate measures in an informed and noninformed decision task to further study loss processing. Heart-rate slowing after a loss is thought to indicate a ‘worse than expected’ signal that would guide further behavioral adjustments. In the noninformed task, children and young adolescents showed limited heart-rate slowing after loss compared to gain, whereas heart-rate slowing was clearly present in adults. In contrast, in the informed task, all age groups showed larger heart-rate slowing after loss compared to gain. These results, in combination with task performance, indicated that outcome-monitoring was present in all age groups (in the informed task), but children and young adolescents were less able to update an expectation of outcomes, which is necessary to learn which option is best (in the noninformed task). Together with Chapter 3, these results suggest a monotonic developmental increase in control processes that steer advantageous decision making and advance learning.

In the fourth empirical study, Chapter 5, we investigated the developmental onset and trajectory of counterfactual emotions. Counterfactual emotions—or the anticipation of counterfactual emotions—may be powerful motivators for choice behavior. A latent class analysis was used to investigate individual differences in the experience of regret and relief in a large developmental sample. Results showed that the experience of regret and relief increased across age groups, but also that a subgroup of 5-year-olds already experienced these counterfactual emotions.

The fifth empirical study, Chapter 6, investigated the neurodevelopmental trajectory of risky choice in children, adolescents, and adults. With a risk-return model we studied the developmental changes in risk- and return-sensitivity, and responses to experienced gain and loss outcomes. Risk (i.e., outcome variability) sensitivity tended to increase across age groups, being absent in children, but present in adolescents and adults. Neural activation in response to risk peaked in adolescents, in which higher risk led to heightened anterior insula and medial prefrontal cortex activation. Moreover, in adolescents these neural risk-responses were related to behavioral risk-sensitivity, with greater negative risk-attitude related to larger neural activation. Return (i.e., expected value) sensitivity increased linearly across age groups. Accordingly, we observed a linear age-related increase in activation in the ventral striatum, posterior cingulate cortex, and the ventral medial PFC. These neural return-related responses were positively related to behavioral return-sensitivity. Furthermore, little evidence was found for a specific adolescent increase in neural activation to obtained gains. Similar to previous studies, however, we did observe a primarily monotonic age-related increase in loss-related activity in the parietal cortex and subcortical structures as the thalamus. We also observed an adolescent peak in loss-related activity in parietal and frontal cortex. Taken together, this study highlights the advantage of decomposing observed behavior into components of risky choice, which is not yet common in developmental (imaging) studies.

The sixth empirical chapter, Chapter 7, focused on the neural mechanisms underlying integrative, EV maximizing, and non-integrative, loss-minimizing decision-strategies in adults. In the integrative group we expected neural activation in relation to the EV-difference be-
between choice options, whereas in the non-integrative group we expected greater uncertainty and conflict during choice. That is, during the evaluation of options, a non-integrative decision maker may notice that attributes provide conflicting information on which choice option is best. Accordingly, we observed that integrative decision makers showed neural activation proportional to the EV-difference in parietal cortex, occipital cortex, and ventral medial, whereas the non-integrative group showed no neural activation related to this parametric EV-signal. The non-integrative group showed larger dorsal medial prefrontal cortex activation, which has been linked to decision conflict and uncertainty. These results highlight the prominent role of individual differences in risky decision-strategies in an adult population and foster knowledge of their underlying neural mechanisms.

The implications of these results for developmental theories will be further discussed in the following section.

8.2 Conclusions and future directions

Neurobiological Model – Affect and Control

The relative impact of affect and control in decision making is subject to large developmental changes. That is, adolescence has been associated with an intensification of affective processes, combined with yet immature—or selectively recruited—cognitive control processes, which is thought to explain an adolescent increase in risk-taking and reward-seeking behavior (Casey et al., 2008; Crone & Dahl, 2012). It has been suggested, however, that large individual differences exist and that an imbalance between affective and control processes may also lead to increased sensitivity to negative stimuli (Somerville et al., 2010). The studies in this thesis have several implications for theory on the developmental role of affect and control.

First, research on decision-strategies indicated that most adolescents are fairly capable of using an advantageous decision strategy in a complex, but ‘low-affective’ risky choice task (GMT; Chapter 2). In general, adolescents are thus not insensitive to risk or incapable of understanding risk. They may, however, not always apply this knowledge. For instance, in affective choice-contexts most adolescents resorted to simpler, disadvantageous strategies (Chapter 2). This result provides further support for the dual role of affect and control in decision making.

Studies including multiple age groups showed that advantageous affective decision-making improved monotonically across childhood and into adolescence (Chapter 3; Chapter 4). Detailed analyses of behavioral response patterns indicated an age-related decline in reactive responses (impulsive response-switches) toward occasional losses. Such impulsive response switches lead to overall poorer choice, since options with the highest expected value (but with occasional losses) are not continuously chosen. Heart-rate analysis indicated an age-related increase in the ability to update an expectation of outcomes on the basis of losses and adjust behavior accordingly. Together, these findings are consistent with a monotonic increase in control processes that guide behavior in risky decision-making and in learning, but find little support for a heightened imbalance in adolescence. In addition, whereas the neurobiological model primarily focuses on the role of positive outcomes, the current results further stress that developmental changes are also prominent in the processing of negative outcomes (Chapter 6; see also Huizenga et al., 2007; Somerville et al., 2010; Spear, 2011).
Moreover, these developmental differences in affective decision-making are smaller when demands on memory are reduced (Chapter 3, 4). That is, children already preferred advantageous choice options in informed contexts and reactive responses toward occasional losses were diminished. This further highlights the importance of maturing control processes in decisions under risk and the potential to improve decision making by lowering memory demands.

Finally, although these results show little evidence for a heightened response to reward in adolescents, imaging results indicated a heightened sensitivity to risk in adolescents or even a heightened sensitivity to loss in adolescence. For example, adolescents showed increased activation in emotional regulation areas such as the medial prefrontal cortex and anterior insula in response to increasing risk (Chapter 6). Results from formal risk-return models also indicated that risk-taking tendency, and sensitivity to risk were subject to large individual differences in adolescents (and children) compared to adults. These results indicate that adolescence is still a period of large reorganization that leads to high variability between individuals.

In sum, these results are in accordance with a maturing increase in control that guides choice behavior. However they extend current models by illustrating that the role of affect and control in decision making is largely dependent on choice contexts and individuals’ sensitivities. More specifically, they highlight a sensitivity to risk in adolescence and claim an important role for reactivity to negative outcomes across childhood and adolescence.

Counterfactual emotions
This thesis presented one empirical study on the development of counterfactual emotions (Chapter 5). These emotions may be expected to mature relatively late in childhood, given that the experience of counterfactual emotions depends on the ability to compare a reality ‘that is’ to an alternative reality that ‘could have been’. The results in this thesis, however, show that these emotions are present from a young age, although individual differences are pronounced.

What is not studied here, is how these counterfactual emotions actually shape risky choice (see also Burnett et al., 2010). That is, experienced counterfactual emotions may influence future choice behavior, and anticipated counterfactual emotions may drive choice toward avoiding regret. These emotions have the potential to increase ‘bad’ decision-making, (think about the anticipated regret of not joining a party), but also the potential to increase ‘good’ decision-making (think about the anticipated regret of a bad grade). Studying how these emotions guide children’s and adolescents’ decision making may be a promising target for future research.

Decision Strategies
Finally, developmental psychologists formulated influential theories on the development of problem solving strategies (Siegler 1976; 1981). These problem solving strategies have a strong correspondence to the non-integrative, lexicographic heuristics in decision theory. That is, decision theories state that choices can be made on the basis of an integrative strategy (value × probability), but also on the basis of non-integrative, attribute-based, comparisons of choice options. In accordance with Piagetian theory the complexity of decision strategies may increase with age (Jansen et al., 2012; Huizenga et al., 2007, but see Reyna & Farley 2006; Rivers et al., 2008), which may be an important factor driving developmental differences in
risky choice. The research in this thesis primarily highlighted the large individual differences that exist in the tendency to prefer one or the other strategy (Chapter 2, Chapter 7).

Accordingly, it was observed that in an adult (and adolescent, Chapter 2) population, both integrative and non-integrative strategies were used in a risky-decision task (Chapter 7). Moreover, fMRI results indicated that these strategies were linked to different underlying neural mechanisms. Importantly, overt choice behavior did not always differ between strategies (i.e., sometimes different strategies resort in the same choice), but patterns of neural activation (and response times) consistently indicated the different processes underlying these strategies. These findings indicate that a sole focus on group averages is not optimal, and highlight the added value of studying components of choice (and not only overt choice behavior).

What is yet unknown, and not studied in this thesis, is how these decision strategies relate across contexts. We observed that strategies did not correspond between low-affective and a more affective choice task (Chapter 2). Future studies may further focus on how individuals’ decision strategies vary between such contexts.

Conclusion
To conclude, in this thesis children’s, adolescents’, and adults’ risky choice was studied by using a multidisciplinary theoretical and methodological approach. Across these studies, some general conclusions emerge. First, individual differences are key. Although adolescence may generally be a phase of heightened emotionality, not all adolescents are risk takers and the methods in this thesis (latent class analysis and formal modeling) are useful tools to characterize individual differences. Second, context matters. That is, in this thesis contexts were studied that varied in the immediacy of outcomes and the explicitness of choice information. Understanding in which contexts risk-taking occurs, and how that is predictive for other contexts, is a promising target for future research. Finally, decomposition is essential. That is, decomposition may indicate which components of the decision process drive observed behavior. A challenge for future studies will be to further construct tasks that allow decomposition of the decision process, trigger affective engagement, and predict daily-life risky choice (Schönberg et al., 2011).

Advancing the understanding of developmental changes in risky decision-making is important before starting ambitious next steps such as finding tools to optimize children’s and adolescents’ decisions. As is apparent from the mixture of theories and methods in this thesis, this is both an exciting and a challenging field. But who said decision making (or decision making research) was ever easy?