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Chapter 2

Affective and Cognitive Decision-making in Adolescents

This chapter is based on:

Abstract
Adolescents demonstrate impaired decision-making in emotionally arousing situations, yet they appear to exhibit relatively mature decision-making skills in predominately cognitive, low arousal situations. In this study we compared adolescents’ (13–15 years) performance on matched affective and cognitive decision-making tasks, in order to determine (1) their performance level on each task and (2) whether performance on the cognitive task was associated with performance on the affective task. Both tasks required a comparison of choice dimensions characterized by frequency of loss, amount of loss, and constant gain. Results indicated that in the affective task, adolescents performed suboptimally by considering only the frequency of loss, whereas in the cognitive task adolescents used relatively mature decision rules by considering two or all three choice dimensions. Performance on the affective task was not related to performance on the cognitive task. These results are discussed in light of neural developmental trajectories observed in adolescence.
2.1 Introduction

The prevalence of suboptimal decision-making appears to peak in adolescence, as demonstrated by adolescents’ heightened risk-taking behavior in daily life situations. For example, adolescents display more dangerous traffic behavior, more delinquent behavior, and more risky sexual behavior than other age groups (Arnett, 1999; Casey et al., 2008; Steinberg et al., 2008). Developmental research designed to assess adolescents’ decision-making skills has, however, reported inconsistent results. In some studies adolescent decision-making is suboptimal compared to adults (Crone & Van der Molen, 2004; Hooper et al., 2004; Overman et al., 2004). In contrast, others have concluded that adolescents’ decision-making is comparable to that of young adults, a conclusion supported by evidence for adolescents’ adult-like ability to estimate and use information on probability and reward (Reyna & Farley, 2006; Van Leijenhorst et al., 2008). This inconsistency in the literature indicates that task characteristics could play an important role in adolescents’ choice behavior (see also Crone, Bullens et al., 2008).

Decision-making is a complex skill and is thought to depend on several capacities: It not only depends on the capacity to reason about a decision problem, but also on the capacity to control emotional responses that can be elicited by a decision problem. The capacity to reason about a decision problem is thought to be relatively mature in adolescents, whereas the capacity to control emotional responses is considered to be still immature during adolescence (Steinberg, 2007). More specifically, it is generally assumed that there is a sharp increase in emotional responding during adolescence (Hare et al., 2008; Mitchell et al., 2008), which is not paralleled by a sharp increase in control processes (Steinberg, 2007; Steinberg et al., 2008). This results in an “emotional overshoot”, and is associated with a neural developmental imbalance between emotional responding and control processes (Casey et al., 2008).

Across childhood and into early adulthood, brain regions and their connections undergo large functional (Bunge et al., 2002; Crone, Zanolie et al., 2008) and structural (Giedd, 2008; Gogtay et al., 2004; Shaw et al., 2008) changes. Emotional (limbic) and control (prefrontal) brain-regions have different developmental trajectories, such that limbic structures develop earlier than prefrontal control regions. Because of this developmental imbalance during adolescence, affective (high-arousing) situations result in a heightened emotional response (Ernst et al., 2005; Galvan et al., 2006; Hare et al., 2008; Van Leijenhorst et al., 2010), combined with a relatively immature influence of prefrontal control regions (Eshel et al., 2007).

Based on this neurobiological model, adolescents’ decision-making is expected to differ in high- and low-arousing decision-making situations. Specifically, we expect that adolescents’ decision-making is suboptimal in affective (high-arousing) situations, as compared to cognitive (low-arousing) situations.

Whether a task is more or less affectively charged depends on, among other factors, whether consequences of a decision are actually experienced during the task (Loewenstein et al., 2001). For example, Figner and colleagues (2009) showed that giving feedback on gains and losses increases the level of experienced arousal. Adolescents’ decision-making in affective situations (i.e., situations with significant emotional consequences) versus cognitive situations (i.e., situations with minimal emotional consequences) has mostly been assessed in separate studies (but see Figner et al., 2009).

In the present study we therefore aim to provide a detailed account of adolescents’ decision-making skills and a direct comparison of performance in affective versus cognitive task
situations. Note that the used classification of affective and cognitive situations in this study specifically refers to the difference in affective engagement between both situations, and is not used to imply that decision-making would include either cognitive or affective processes.

*Decision-Making in Affective Situations*

In affective situations, participants’ decisions result in emotionally significant consequences (gains and/or losses). A widely used affective decision-making task is the Iowa Gambling Task (IGT; Bechara et al., 1994). In this task, a participant is repeatedly asked to play from one of four decks of cards. Two of the decks are advantageous and the other two are disadvantageous in the long run. The advantageous decks result in constant moderate-gains, but also in probabilistic moderate- or low-losses. The disadvantageous decks, conversely, result in constant high-gains, but also in probabilistic high-losses. Each deck is thus characterized by its amount of constant gain, its frequency of loss, and its amount of loss. However, the choice properties of the different decks are not described to the participants, but rather have to be inferred by using the feedback (gains/losses) provided after each choice. As a multidimensional choice task, the IGT thus requires the capacity to reason about a complex decision problem. Moreover, participants are directly confronted with the outcomes of their decisions, and therefore the IGT also addresses the capacity to control emotional responses.

Adolescents demonstrate impaired decision-making in this task when compared to adults (Crone & Van der Molen, 2004; Hooper et al., 2004; Overman et al., 2004). That is, children and adolescents, in contrast to adults, seemed to opt mostly for the disadvantageous options, in which both gains and losses are high. Therefore, it has been proposed that children and adolescents opt for short-term high-gain options. However, a recent reanalysis of developmental IGT data suggests that adolescents are not necessarily focused on short-term gain, but rather are focused on avoiding frequent loss. Therefore, they eventually opt for decks with the lowest frequency of loss, whether they be advantageous or disadvantageous (Crone et al., 2005; Huizenga et al., 2007).

In sum, adolescents’ performance on the affective IGT is shown to be suboptimal compared to adults. However, debate remains as to whether the primary focus of adolescents’ decisions is based on an attraction towards high-gain options, or whether it is an avoidance of options characterized by a high-frequency loss. Furthermore, previous research indicated that some age groups, particularly adolescents, showed considerable variation in IGT performance (Crone & Van der Molen, 2004; Hooper et al., 2004). The present study aims to further investigate both issues.

*Decision-Making in Cognitive Situations*

In cognitive situations, participants’ decisions do not result in emotionally significant consequences (gains and/or losses), since participants are not directly confronted with the outcomes of their decisions. Therefore, these situations primarily address reasoning capacities, and not the capacity to control emotional responses. Studies on cognitive decision-making, focusing on logical reasoning abilities, have, for example, used proportional reasoning paradigms. In proportional reasoning, choice options differ on one or multiple choice dimensions (e.g., probability, amount of loss/reward), which must be integrated in order to obtain a correct solution. Results from this line of work suggest that there is a developmental increase in proportional reasoning skills.
Children progress through a series of suboptimal stages before they use the correct multiplication/proportional rule. Young children first consider only one (dominant) dimension in their answer (one-dimensional decision rule). In the next stage, children also first focus on the dominant dimension, but if the dominant dimension for the two presented choices is equal, they subsequently consider the subordinate dimension as well (two-dimensional decision rule). Eventually the correct strategy will be adopted, in which the choice dimensions are multiplied (integration rule) (Siegler, 1981).

Recent research suggests that young children (from age 5) are already capable of processing probability information (Schlottmann, 2001), including the use of one- or two-dimensional decision rules (e.g., focusing on the probability alone or on the probability and the amount of loss). Furthermore, young adolescents (age 13) have been shown to be able to use correct proportional integration between two task dimensions (i.e., number of winning and number of losing beads; Falk & Wilkening, 1998).

These results indicate that adolescents perform fairly well in proportional reasoning tasks, being able to understand probability and use multidimensional strategies in decision problems. These reasoning capacities can be considered important for advantageous choice behavior. Moreover, adolescents have been shown to not differ from adults in their risk perception (Van Leijenhorst et al., 2008) or their ability to evaluate consequences (Beyth-Marom et al., 1993). Immature cognitive-reasoning skills thus do not seem to account for adolescents’ diminished performance in affective tasks. However, most research on reasoning capacities focuses on choices determined by a maximum of two dimensions, whereas choices in affective decision-making tasks commonly depend on more dimensions. For example, in the affective Iowa Gambling Task, options are characterized by three choice-dimensions: frequency of loss, amount of loss, and amount of constant gain. As a consequence, no firm conclusions can be drawn about adolescents’ reasoning capacities in these more complex tasks. Therefore, another aim of this study is to investigate adolescents’ level of cognitive decision-making in more complex decision-making situations.

The Current Study
In this study, we first aim to describe adolescents’ performance on an affective decision-making task. Specifically, we will investigate performance variation between adolescents and determine whether adolescents’ choices are characterized primarily by a focus on gain or on avoidance of high-frequent loss. Second, we aim to investigate adolescents’ level of performance in a three-dimensional cognitive decision-making task. Third, we aim to explore the link between performance on both tasks; that is, we investigate whether adolescents’ performance on the affective task is associated with their reasoning level on a matched cognitive task.

To this end, an affective and a cognitive decision-making task were administered to a large sample of adolescents (ages 13–15). The affective task is the Hungry Donkey Task (HDT; Crone & Van der Molen, 2004), which is a child-adapted version of the IGT. In this task, choices are characterized by frequency of loss, amount of loss and amount of constant gain. Feedback on gains and losses is presented after each choice. The cognitive task is the Gambling Machine Task (GMT; Jansen et al., 2012). In this task, participants have to choose between two gambling machines that differ, similar to the HDT, in frequency of loss, amount of loss, and amount of constant gain. In contrast to the HDT, no feedback is provided.
In sum, the HDT is used for a characterization of adolescents’ decision-making in an affective situation. In addition, the GMT is used for a detailed assessment of adolescents’ reasoning level in a predominantly cognitive situation. Since both tasks involve a similar comparison of choice dimensions, they require equally complex reasoning capacities. A comparison between the two tasks will therefore allow us to determine whether performance in affective situations could be explained by adolescents’ complex reasoning abilities, or whether other factors, like an imbalance between emotional and control processes, are more prominent.

2.2 Method

Participants
One hundred and seven adolescents (ages 13–15, Mean Age = 13.7 years) from a secondary school participated in this study. This sample included participants from different educational levels: 53 adolescents were involved in a low-level vocational track (Mean Age = 13.6 years, 26 female) and 54 adolescents in a medium- to high-level track (Mean Age = 13.7 years, 28 female). The primary caregivers of the participants were informed about the experiment and were provided with an opportunity to exempt their child from participating. All procedures were approved by the local ethics committee. Intelligence scores were obtained by using the Standard Raven’s Progressive Matrices (SPM)\(^1\) test (Raven et al., 1985). A speeded version of the task was used in which participants were given 20 minutes to answer as many problems as possible in the test (Hamel & Schmittmann, 2006). Raven scores did not differ between adolescents from different educational levels (\(F(1, 96) = 2.4, p = .12\)).

Hungry Donkey Task (HDT)
Ninety-four\(^2\) adolescents performed the HDT, a child adapted computerized version of the IGT (Crone & Van der Molen, 2004). The stimulus display consisted of four doors: A, B, C, and D, and a donkey sitting in front of those doors. Participants were told to assist the hungry donkey by collecting as many apples as possible by clicking with the mouse on one of the four doors. Upon clicking on one of the doors, the stimulus display was replaced by an outcome display showing the number of apples gained and the number of apples lost. A horizontal bar on the screen represented the total number of apples won or lost, as indicated by a number and color change. The participants began with zero apples, and their total number was updated every time a door was chosen.

The HDT had the same relative proportions of wins and losses as the IGT. However, the absolute numbers of wins and losses were reduced by a factor 25. Doors A and B were characterized by a high constant gain of four apples. Door A had a high loss in 50% of the trials (8, 10, 10, 10 and 12 apples) and B a very high loss in 10% of the trials (50 apples). Doors C and D were characterized by a low constant gain of two apples. Door C had a low loss in 50% of the trials (1, 2, 2, 2, and 3 apples) and D a high loss in 10% of the trials (10 apples). The HDT choice options thus differed on three dimensions: frequency of loss (FL), amount of loss (AL), and amount of constant gain (CG).

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\(^1\) Nine adolescents did not complete the Raven SPM due to absence or procedural errors.  
\(^2\) Thirteen adolescents did not complete the HDT due to class absence.
Doors A and B provided an equivalent net loss and were, therefore, disadvantageous in the long run. In contrast, doors C and D provided an equivalent net gain and were, therefore, advantageous in the long run. Note that the detailed properties of each door were not presented to the participants, but instead had to be inferred based on the presented gains and losses.

The HDT consisted of 200 trials. Two versions of the task were used that counterbalanced the relative position of the advantageous and disadvantageous doors. In one version, the doors were presented on screen in the order A, B, C, D. In the other version, the doors were positioned in the order C, D, A, B. Participants were randomly assigned to one of the two versions of this task. Participants were tested individually, using 17-inch computer screens on which the stimuli were presented. Instructions were read out loud by the experimenter (see the Appendix) and no time limit was present.

**HDT Analysis**
Door choices were analyzed on two levels: (1) across individuals, by considering average choices for each of the four doors and (2) individually, in order to study variations in choice strategies in our adolescent sample. For the latter, we applied model-based cluster analysis (for an application, see Huizenga et al., 2007). This model-based cluster analysis consisted of two stages. First, this analysis compared different clustering solutions according to their Bayesian Information Criterion (BIC) in a stepwise manner (Fraley & Raftery, 2003). If a one-group solution provided the best description, then the estimation procedure was stopped. If the two-group solution provided a better fit, then two- and three-group solutions were compared. This process was repeated until the best solution was found according to the BIC. Second, given this optimal solution, each participant was assigned to his or her most probable latent group. Based on this assignment, each group was consequently characterized by its mean scores on the original variables: doors A, B, C, and D.

**Gambling Machine Task (GMT)**
One-hundred and three adolescents completed the GMT, a paper-and-pencil task designed to assess decision rules in a three-dimensional cognitive decision-making context (Jansen et al., 2012). The task consisted of four blocks of seven item-types in which participants had to compare two gambling machines and had to decide whether Machine A or Machine B was most profitable or whether the machines were equally profitable.

Similar to the HDT, each machine was characterized by a frequency of loss (FL), an amount of loss (AL), and an amount of constant gain (CG). Each machine contained 10 balls that were either white (neutral) or grey (losing). The number of grey balls in the machine coded the frequency of loss and the number displayed on the grey balls depicted the amount of loss. Constant gain was displayed on the machine and was the amount of points that was always gained when starting the machine. The participant was instructed to imagine that the machine delivers the constant gain if the machine is started and that, after shaking the balls, the machine draws either a white or a grey ball. Thus, if the machine would draw a grey ball, a constant gain was obtained, and the amount depicted on the ball was lost. If the machine would draw a white ball, a constant gain was again obtained, yet no points were lost.

The values of FL, AL, and CG were similar to the values used in the HDT. Thus, frequency of loss could be either 10% (1 grey, versus 9 white balls) or 50% (5 grey, 5 white balls).

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3 Four adolescents did not complete the GMT due to class absence.
Amount of loss could be either –50, –10, or –2 and amount of constant gain was either 2 or 4. Contrary to the HDT, no feedback on performance was provided. The GMT was administered classically as a paper-and-pencil test on another day than the HDT. Instructions were read out loud by the experimenter (see the Appendix). Two example items were used. These items were chosen such that all decision rules would arrive at the same choice. On average, participants needed 15 to 20 minutes to complete the GMT. The GMT was followed by the speeded Raven SPM.

**Decision Rules and Item Types**

Performance on the GMT is described by level of used decision rule. First, decision rules can vary in complexity, which refers to the number of choice dimensions considered. Further, decision rules can differ in saliency of a specific choice dimension, which refers to the order in which dimensions are considered. That is, each choice dimension (FL, AL, or CG) can be either dominant, first subordinate, or second subordinate. A combination of complexity and saliency differences results in 17 hypothesized decision rules. These hypothesized decision rules can thus consist of (a) considering only one dimension (FL, AL, or CG); (b) any order of two dimensions (for example: FL, AL or FL*AL) or an integration between the two dimensions FL*AL; (c) any order of three dimensions (for example: FL, AL, CG) or an integration between these three dimensions (correct calculation rule: CG-(FL*AL)). Participants using a one-dimensional decision rule would only consider their dominant dimension and make their response accordingly.

Participants using a two-dimensional decision rule would consider their dominant dimension first, and, if values on that dimension are equal, consider their subordinate dimension to reach a decision. Participants using a three-dimensional decision rule would also consider their dominant dimension first and, if equal, their subordinate dimension. However, if the choice options are also equal on their subordinate dimension, these participants will consider their second subordinate dimension to reach a decision. Participants using an integration rule were expected to either multiply dimensions FL and AL to reach a decision (Dunn et al., 2006) or to use the correct integration rule, that is, to calculate the expected value accurately: CG-(FL*AL).

Participants’ responses (machine A, equal, or machine B) were recoded into accuracy scores, such that the correct response is defined as choosing the machine with the highest expected value or choosing equal, in case the choice options do not differ in expected value. Each hypothesized decision rule resulted in a distinct accuracy pattern on the seven item types that were included in the task. These seven item types consisted of three simple item types, and four more complex item types. In simple item types, the presented machines only differed on one dimension, either in frequency of loss [FL], amount of loss [AL], or constant gain [CG]. Thus, the most profitable machine (and correct response) was the one with, respectively, the lowest frequency of loss, the lowest amount of loss, or the highest constant gain.

In complex item-types, the presented machines differed on two or three dimensions. For example, in the first complex item-type [AL, CG], the dimensions amount of loss and constant gain differed between the two machines, while frequency of loss did not differ. Whereas one machine had the lowest amount of loss, the other had the highest constant gain. In this item type, the most profitable machine was the one with the lowest amount of loss. This is indi-
cated by printing this dimension in bold face. On the second complex item-type \([\text{fl}_\text{CG}]\), choice dimensions frequency of loss and constant gain differed between the machines and the most profitable machine was the one with the lowest frequency of loss. On the third complex item-type \([\text{fl}_\text{AL}]\), choice dimensions frequency of loss and amount of loss differed between the presented machines. However, the expected value of both machines, and thus the correct response, was “equal”. On the final complex item-type, all choice dimensions differed between the presented options, \([\text{fl}_\text{AL}, \text{CG}]\), and the most profitable machine was the one with both the lowest amount of loss and the highest constant gain. For further information on the expected response patterns for these different item types, see Table 1. Note that other complex item-types exist. However, these seven item types are sufficient to distinguish between all hypothesized decision-rules.

To be able to assess consistency of responses, which is an important criterion for rule use (Reese, 1989), each block of seven item types was repeated four times during the task. Block 1 and 2 contained unique items, and block 3 and 4 were mirrored items of the first two blocks.

**GMT Analysis**

We expected to find a maximum of 17 decision rules on the GMT, although a more restricted number was more probable and alternative rules were not excluded beforehand. We used latent class analysis (Everitt & Hand, 1981) to detect groups of participants in the data, based on similarity in their response patterns.

Our application of latent class analysis involved four steps. First, models with 1 to 17 latent groups were estimated. For each model, the estimation algorithm was run 100 times, with different starting values, and the solution with the best fit was selected. Second, the solutions for the models with 1 to 17 groups were compared by means of the BIC (Leisch, 2004) and the model with the lowest BIC was selected. Third, we calculated the Euclidean distance between the response pattern of each latent group in the selected model and each response pattern of the hypothetical rules and decided which hypothetical rule matched the response pattern of each latent group best. Fourth, we calculated the probability for each participant that she/he belonged to a particular latent group (the so-called a-posteriori probability) and subsequently assigned each participant to his or her most probable latent group.

**2.3 Results**

**Affective Decision-Making Task: HDT**

Consistent with previous research, the final 60 trials of the HDT were selected for further analyses, and grouped in 20 trial blocks (Crone & Van der Molen, 2004; Huizenga et al., 2007). To ensure that choice behavior had stabilized, a block door repeated measures ANOVA (with use of Greenhouse-Geisser correction) was performed on the last three task blocks. Results showed no significant block by door interaction \((F(4.8, 512.9) = 2.0, p = .08)\). Subsequently, we considered the last 80 and the last 100 trials in a similar repeated measures ANOVA to check whether behavior stabilized earlier in the task. For the last 80 trials \((F(6.7, 706.4) = 2.3, p < .05)\) and last 100 trials \((F(8.5, 899) = 2.7, p < .05)\), a significant block by door interaction was found, indicating that choice behavior only stabilized in the last 60 trials of the task.
The average number of choices for doors A, B, C, and D, for the last 60 trials of the task, is presented in Figure 1. A repeated measures ANOVA, including a Deviation contrast, was used to test whether the average number of choices for each door deviated from chance level responding. The results indicate that adolescents opted for door B ($F(1, 93) = 32.1, p < .001$), and door D ($F(1, 93) = 17.2, p < .001$) above chance level, where doors B and D were preferred equally ($t(1, 93) = .865, p = .40$). Door A and C were chosen below chance level ($F(1, 93) = 144.9, p < .001; F(1, 93) = 10.8, p < .005$, respectively), and door A was chosen less often compared to door C ($t(1, 93) = –3.4, p < .005$).

These results show that adolescents, on average, sample most from doors characterized by infrequent loss (B & D) and do not demonstrate a preference for the high reward doors (A & B). Therefore, these results support the notion that adolescents generally focus more on avoiding frequent loss than on obtaining high gains. Further, an Age group (13, 14–15-year-olds) × Gender × Educational level (low, high) ANOVA showed that these factors did not significantly influence choice behavior in the HDT (all $p$’s > .1). Last, Raven scores were not correlated with choice performance on the HDT (all $p$’s > .1).

**Individual Differences on HDT**

To obtain insight into the variability in our adolescent sample on the HDT, we performed a model-based cluster analysis on the amount of A, B, C, and D choices in the last 60 trials. Results from this analysis revealed three groups in our adolescent sample, named group 1, 2, and 3. Group 1 ($n = 23$) refers to a guessing group, as the means for the different doors are all close to chance (means: A(15), B(16), C(13), D(16)). Group 2 ($n = 7$) refers to a correct-rule group, as the means reveal a preference for doors C and D, which are the advantageous doors (means: A(4), B(7), C(28), D(21)). Group 3 ($n = 64$) refers to a group that opts for the infrequent loss doors B and D (means: A(7), B(23), C(11), D(19)). Furthermore, $\chi^2$-analyses
indicated that Age group \( (p = .22) \), Gender \( (p = .39) \), and Educational level \( (p = .25) \) did not significantly differ between these three groups.

In sum, the results from this analysis show that in the HDT most adolescents (68%) seemed to apply a one-dimensional choice strategy and focused on the options with low-frequent loss. The second largest group (24%) displayed a guessing choice strategy, choosing each door equally often. Only a small subset of our sample (7%) displayed an advantageous choice-strategy by choosing both advantageous doors.

**Cognitive Decision-Making Task: GMT**

**Consistency analysis**
First we determined whether the probability of correct responses across the four blocks of the GMT was consistent for each of the item types. The values for Cronbach’s alpha of each item type was high (all \( \alpha \)'s > .72), thereby meeting the criterion of consistency (Reese, 1989) and homogeneity (Jansen & Van der Maas, 1997). Hence, sum scores (scores added across the four blocks) were used in subsequent analyses.

**Descriptives**
The mean percentage of ‘correct’ choices on the GMT, across all item types, was 73% (SD = 14, MIN = 39%, MAX = 100%). The percentages correct differed significantly per item type \( (F(6, 97) = 35.22, p < .001) \). For the simple item types, mean percentages correct choices were \([fl]: 94\%\); \([al]: 92\%\); \([cg]: 66\%\). Mean percentage correct for the complex item types were: \([al_cg]: 83\%\), \([fl_cg]: 88\%\), \([fl_al]: 41\%\), and \([fl_al_cg]: 44\%\).

**Individual differences on GMT**
Latent class analysis indicated that a model of seven groups described the GMT data optimally. Group size, expected and estimated response patterns per item type are shown for each group in Table 1. The final column indicates the best fitting hypothesized decision rule. Participants in the first group \( (n = 6) \) showed a response pattern that corresponded most to the use of a one-dimensional decision rule: CG. Participants in the second group \( (n = 6) \) showed a response pattern that corresponded most to the use of a two-dimensional decision rule: AL,CG. The third \( (n = 13) \) and fourth \( (n = 18) \) group showed high similarity in their response patterns and were both matched to the same two-dimensional decision rule: FL,AL. The fifth group \( (n = 6) \) showed a response pattern that corresponded most to the use of a two-dimensional integration rule: FL*AL. The sixth group \( (n = 27) \) showed a response pattern that corresponded most to the use of the three-dimensional rule: FL,AL,CG. Participants in the final group \( (n = 27) \) showed a response pattern that corresponded most to the use of the correct integration rule: CG-(FL*AL).

These results showed that a slight majority (52%) of adolescents demonstrated use of a three-dimensional decision rule. The first half of this group used a sequential decision rule considering all choice dimensions (26%, rule: FL,AL,CG). The other half showed full probability understanding, by using the correct integration rule (26%, rule: CG-(FL*AL)). Furthermore, a slight minority (42%) of adolescents demonstrated two-dimensional decision rules, whereas only a small subgroup used a one-dimensional rule (6%, rule: CG). Overall, these results indicate that adolescents predominantly use two- or three-dimensional decision rules in the cognitive task. These results also support adolescents’ primary focus on FL, as it is
the choice dimension considered first in most decision rules. Only a small subgroup focused more specifically (and solely) on gain (6%, rule: CG) or on amount of loss and gain (6%, rule: AL, CG).

We further examined effects of age, gender, and educational level on choice behavior. There was a significant relation between Gender and Rule group ($\chi^2(6) = 14.5, p < .05$). Boys tended to use the three-dimensional decision rule FL, AL, CG more than girls (18 male; 7 female). Age group ($p = .7$), Educational level ($p = .56$) and Raven Scores ($p = .26$) did not differ across GMT rule groups.

**GMT and HDT: Comparison of Cognitive and Affective Decision-Making**

A repeated measures ANOVA with HDT door choice as a within subjects variable and GMT rule group as a between subjects variable indicated that the profile of HDT responses did not differ between GMT rule groups ($F(14.8, 204.7) = .88, p = .59$). A post-hoc analysis of HDT choice profiles per GMT subgroup, however, showed subtle differences (see Figure 1). First, the small (6%) one-dimensional rule group “CG” avoided the low-gain door C ($F(1, 5) = 6.6, p = .05$), and showed a trend to predominantly opt for the high-gain door B ($F(1, 5) = 5.6, p = .06$). Second, the small (6%) two-dimensional rule group: “AL, CG”, most strongly avoided the frequent loss door A ($F(1, 4) = 10.8, p < .001$). Furthermore, the rule groups “AL, CG” and “FL, AL1” showed no distinct preference for B, C, or D (all $p$’s >.1). All other rule groups followed the average pattern, by generally avoiding door A, and opting predominantly for the infrequent loss doors B and D. Additionally, we analyzed whether the rule groups on the GMT were related to choice strategy on the HDT (guessing, opting for infrequent loss, or opting for the advantageous doors). A $\chi^2$-analysis showed that rule use on the GMT was not associated with choice strategy on the HDT ($\chi^2(12) = 8.88, p = .7$).

In sum, these results demonstrate that adolescents who used a relatively advanced three-dimensional rule on the GMT (FL, AL, CG; CG-(FL*AL)) did not necessarily use an advanced

### Table 1: Group size and estimated response patterns across item types for each GMT rule group. In parenthesis the response pattern of the matching theoretical decision rule, where 1 is a correct (i.e., highest expected value) and 0 is an incorrect choice. FL: frequency of loss; AL: amount of loss; CG: constant gain.

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decision strategy in the HDT. In the HDT, the majority of adolescents only focused on one-dimension: FL. These results indicate that reasoning level on a cognitive task such as the GMT is not associated with performance on an affective task such as the HDT.

2.4 Discussion

Performance on matched affective (HDT) and cognitive (GMT) tasks was compared to (1) determine adolescents’ level of performance on both tasks separately and (2) determine whether performance on the affective task was associated with reasoning level in the cognitive task. Adolescents’ decision-making ability was expected to differ between these contexts with relatively suboptimal choice behavior in an affective compared to a cognitive decision-making context. Theoretically, these differences were expected based on the different developmental trajectories of the prefrontal cortex and limbic brain regions. These different developmental trajectories would lead to an emotional overshoot during adolescence, which, especially in affective situations, would result in suboptimal decision behavior (Casey et al., 2008).

Results for the affective task (HDT) showed that adolescents in general used a one-dimensional decision rule in which they chose options characterized by infrequent loss. The focus on avoiding frequent loss is consistent with a reactive response style in which adolescents focus on immediate, in this case negative, outcomes (cf. Mitchell et al., 2008). A focus on frequency of loss is also consistent with the finding that frequency of information is coded implicitly and automatically and, therefore, often is a dominant aspect of information processing (Hasher & Zacks, 1984).

Additional analyses on performance variation in our adolescent sample showed that only a small subset of the adolescent sample was able to choose advantageously (7%; opting for C and D) in the affective HDT. Future research should focus on characteristics that distinguish these adolescents from those that do not choose advantageously. Advantageous choice performance in the affective task might, for example, be related to a more mature balance between affective and control processes.

In the cognitive task (GMT), adolescents predominantly used two- and three-dimensional decision rules. These results are consistent with previous research demonstrating that young adolescents are generally able to apply two-dimensional decision rules (Falk & Wilkening, 1998) and extend previous research by demonstrating that only about half of our adolescent sample applied a three-dimensional decision rule. Therefore, more complex reasoning-capacities (three-dimensional reasoning) may still improve into adulthood.

The results from the GMT suggest that participants differed with respect to the complexity of the rule they applied (the number of dimensions considered), with respect to their primary focus (dimension considered first), and also to the kind of decision strategy they used. About a quarter of our adolescent sample used a decision strategy in which they integrated dimensions and seemed to calculate expected values. However, the majority of participants applied sequential rules to reach a decision in the GMT. In decision theory, these kinds of sequential decision strategies are called lexicographic decision heuristics (Luce, 1956). According to decision theory (Luce, 1956), people do not often calculate their most profitable outcome, but rather base their decision on the most important choice characteristic. Fur-
ther research should address the developmental trajectories of integrated versus sequential (heuristic) decision strategies in relation to (dis)advantageous decision-making. For example, fuzzy-trace theory states that as decision-making becomes less computational (integrated) and more heuristic (gist-based) across development, risky decision-making should decline accordingly (Rivers et al., 2008).

Our comparison between the HDT and GMT indicates that performance on both tasks was not associated. Results for the cognitive task showed that most adolescents used two- or three-dimensional decision rules. Dunn et al. (2006) argued that using a two-dimensional decision rule (FL, AL or FL*AL) would already lead to advantageous choice performance in the HDT (opting for D, or C and D). However, most adolescents did not use an advantageous multidimensional decision rule in the affective task and instead focused on only one choice dimension (FL). This difference indicates that performance in affective situations may be more dependent on the balance between affective and control processes than on immature complex reasoning capacities. Alternatively, the need to control affective responses could have interfered with adolescents’ reasoning capacity during affective decision-making.

The GMT was designed with two main objectives. The first aim was to construct a specific set of items wherein each decision rule results in a unique response pattern across item types, thereby allowing for an exact assessment of decision rules. The response patterns of the decision rules detected in the GMT were closely related to the expected theoretical response patterns. Small deviations between empirical and theoretical response patterns were, however, observed. These deviations might be related to the number of participants in the present study. A larger sample size could increase the power to detect heterogeneity within the rule groups found in the present study.

Second, the GMT was designed to construct a predominantly cognitive, low-arousal task with a task structure comparable to the affective decision-making task (HDT). Although the tasks were matched on choice dimensions (reasoning level), other differences remain. Most importantly, the different choice properties (frequency of loss, amount of loss, and constant gain) are not presented clearly in the HDT, and instead have to be inferred from feedback. To limit the influence of learning on our performance comparison, we used the final part of the HDT in which performance had stabilized. A second difference between the HDT and GMT is that the GMT presents two machines with three response options (machine A, B, or equal), whereas the HDT consists of four response options (doors A to D). Choices between four options might be more difficult than choices between three options and therefore this may have induced a more suboptimal decision strategy (Bröder, 2003).

Abstract reasoning skill, as indicated by Raven scores, was not related to HDT performance (cf. Crone & Van der Molen, 2004), or to GMT performance. An important individual factor that could be related to performance on our cognitive task is mathematical ability, as our choice options use numerical values, and responses depend on a comparison of these (numerical) values. Future research on GMT performance might include multiple measurements of cognitive skills, including an assessment of mathematical ability.

Adolescence is often characterized as a period of heightened risk-taking and disadvantageous choice-behavior. This study shows that the quality of adolescent decision-making may depend on whether the task has a strong affective component. More specifically, our findings suggest that deficits in adolescents’ decision-making in affective (arousing) situations are not primarily due to immature cognitive skills, but rather are more likely to result from an
imbalance between affective and affective control processes. Future imaging studies will be important to verify the influence of limbic and control brain-regions in affective versus cognitive decision-making situations. Combining imaging and behavioral results could provide additional insights into the nature of adolescents’ limitations in decision-making in affective situations, as well as potential mechanisms for improving such skills.

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