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The Role of Probabilistic Reasoning Abilities on Adolescent Risk Taking

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Abstract: The aim of this work was to investigate the role of the cognitive system and the affective system on adolescents' risk taking in gambling tasks characterized as different on the basis of information given to decision makers. In Study 1, we explored the role of probabilistic reasoning and sensation seeking on decision making in a *non-risky context (Non-Gambling Task)* and a *risky context (Gambling Task)* in which no preliminary information were given to participants. Results showed that adolescents referred to probabilistic reasoning only in the *Non-Gambling Task*. In Study 2, we explored the role of probabilistic reasoning and sensation seeking in risky situations with preliminary information given to participants. Specifically, we compared a risky context characterized by *high-emotional arousal (Game of Dice Task)*, in which a feedback after each decision was given, with one characterized by *low-emotional arousal (Game of Dice Task – Modified version)*, without feedback. Probabilistic reasoning characterized adolescents' decision making regardless of feedback. Findings showed that adolescents' decision making was solely linked to the cognitive system in the non-risky situation, and the affective system overcomes the cognitive system in situation of risk. Moreover, providing information about the task might interfere with the imbalance between the two systems.

Keywords: adolescents, risk taking, gambling, decision making, probabilistic reasoning, sensation seeking.

Introduction

Adolescence is characterized by risky behavioral decisions such as driving without seatbelts, carrying weapons, using illicit drugs and alcohol, and engaging in unprotected sex (Reyna, Chapman, Dougherty, & Confrey, 2012). Recent neurobiological models suggested that two distinct brain systems (i.e., dual-system theory) are involved in decision making and risk taking in adolescence (see Sommerville, Jones, & Casey, 2010, for more details): A *cognitive control system* or cognitive system and a *socio-emotional system* or affective system (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011). Some differences can be identified between them. While the cognitive system is the neural basis of *deliberating processing*, which is effortful and controlled, and operates according to formal rules of logic (Weber, Shafir, & Blais, 2004), *affecting processing* is spontaneous and automatic, and operates by principles of similarity and contiguity. The cognitive system is also the neural basis of *inhibitory control*, a mechanism that can block affective impulses and therefore enables deliberative decision making even in affect-charged situations (Cohen, 2005; Knock & Fehr, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004). On the contrary, the affective system influences behavior by *affective impulses* (Weber et al., 2004). Finally, the two systems have been shown to mature at different speeds. The affective system matures rapidly at puberty, whereas the cognitive system matures later and more gradually over the course of adolescence (Casey, Jones, & Hare, 2008; Steinberg, 2008).

During adolescence, the two systems affects youth's decision making process. In fact, the cognitive system supports decision making process through the inhibition of impulsive behavior, whereas the affective system relies on subjective evaluation that only takes into account potential

rewards of the risky choices. Due to both the relative maturity of brain structures (i.e., amygdala, ventral striatum, nucleus accumbens) that govern the affective system and the immaturity of the cognitive system (i.e., lateral prefrontal cortex), adolescence is a unique time period in which there is an imbalance between these two distinct brain systems (e.g., Casey et al., 2008; Somerville et al., 2010). Due to this imbalance, adolescents may be more likely to take risks when compared to adults (Chein et al., 2011). In fact, according to these kind of explanations, adolescent risk taking is the result of a competition between the phylogenetically younger cognitive system and the phylogenetically older affective system (Casey et al., 2008; Cohen, 2005; Steinberg, 2008).

Based on dual-system models' research, two relevant claims describing decision making in adolescence can be drawn. The first one is that deliberating processing abilities mature earlier than the potential for inhibitory control in the cognitive system (Keating, 2004; Kuhn, 2006). The second one is that the difference in maturational speed between the cognitive and the affective system is assumed to result in a developmental imbalance between the systems during adolescence, with the affective system being easily triggered, for example by the expectation of a reward (Galván et al., 2006; Galván, Hare, Voss, Glover, & Casey, 2007) or the presence of peers (Gardner & Steinberg, 2005). Thus, the very active affective system is not yet sufficiently counterbalanced by the still-maturing cognitive one.

Following these claims, two consequences can be derived, as follows. First, as deliberating processing abilities mature earlier than the potential for inhibitory control in the cognitive system, adolescents can be expected to show a good functioning of deliberating processes in the absence of affective involvement. On the contrary, they can be expected to do not control affective impulses in situations of affective involvement, despite good deliberating processing abilities. Second, since the affective system is not yet sufficiently counterbalanced by the still-maturing cognitive system, adolescents can be assumed to be more susceptible to risk taking in situations of higher emotional arousal.

Starting from these premises, the general aim of this work was to investigate the role of the two systems on adolescents' risk taking in different probability-related decision making gambling tasks (in line with literature: see Figner, Mackinlay, Wilkening & Weber, 2009; Schonberg, Fox, & Poldrack, 2011). In fact, one such example of risky decision making where the imbalance between cognition and affect is evident is in gambling.

Excessive gambling has become a growing problem among adolescents and a recent review found alarming rates of problematic and pathological gambling (see Scholes-Balog, Hemphill, Dowling, & Toumbourou, 2014). Research has suggested that *cognitive* factors based on misunderstanding the nature of probability including a set of erroneous beliefs, irrational thoughts, and misperceptions (e.g., Delfabbro, Lahn, & Grabosky, 2006; Delfabbro, Lambos, King, & Pugliese, 2009; Donati, Primi, & Chiesi, 2013; Turner, Zangeneh, & Littman-Sharp, 2006), and *affective* factors, such as sensation seeking (e.g., Donati et al., 2013; Gupta & Derevensky, 1998; Nower, Gupta, & Derevensky, 2004), are associated with excessive gambling. Specifically, adolescent pathological gamblers, relative to non-pathological gamblers, are more prone to mistaken views about randomness and erroneous probabilistic reasoning, tend to hold erroneous beliefs about their chance of winning, are susceptible to biases related to gambling outcomes, and have higher levels of sensation seeking.

Since the cognitive and the affective systems seem to represent respectively 'thinking' and 'affect' domains (Reyna & Rivers, 2008), we considered probabilistic reasoning ability as '*thinking variable*' and sensation seeking as '*affect variable*'. Given that risk taking was measured through gambling tasks, we chose those variables on the basis of the above-described predictive role of probabilistic reasoning (e.g., Delfabbro et al., 2006; Delfabbro et al., 2009; Donati et al., 2013;

Turner et al., 2006) and sensation seeking (Donati et al., 2013; Gupta & Derevensky, 1998; Nower et al., 2004) on adolescent problem gambling behavior.

We also aimed to explore the role of the two systems on adolescent risky decision making in gambling tasks characterized as different on the basis of information given to decision makers. More in detail, from Brand's model of decision making under risk (e.g., Brand, Kalbe, Labudda, Fujiwara, Kessler, & Markowitsch, 2005; Schiebener, Zamarian, Delazer, & Brand, 2011), we know that different kind of decision making situations can occur in everyday life. Specifically, this model claims that as the level of information arises, the risk involved in the decision-making situation becomes more explicit: Decision making under *explicit* risky conditions occurs when decisions can be made on the basis of some knowledge about the situation and associated consequences. On the contrary, when a person cannot know these preliminary information, decision making occurs in a situation of *implicit* risk taking.

Following Brand's model of decision making under risk, one of the characteristics that differentiates risk taking tasks was the presence of explicit preliminary information about task contingencies (including for example the presentation of the number of the task trials and the explanation of potential consequences of each choice option). Based on this claim, we analyzed *implicit* situations of risk, intended as *non-informed* risky situations, since no preliminary information about the task contingencies were given (Study 1), and *explicit* situations of risk, intended as *informed* risky situations, since preliminary information about the task were given (Study 2).

Study 1

The aim of the Study 1 was to explore the role of the cognitive system and the affective system on adolescents' decision making in an implicit situation of risk, i.e. a gambling condition without preliminary information. More specifically, we wanted to explore whether the role of probabilistic reasoning ability on adolescents' decision making changed between a *non-risky context* (non-gambling condition) and a *risky context* (gambling condition). Our hypothesis was that adolescents would use their probabilistic reasoning abilities only in the non-gambling condition, whereas sensation seeking would affect adolescents' decision making in the gambling condition.

Concerning the measurement of decision-making abilities, in order to analyze adolescents' choices in non-risky and risky situations, we developed two versions of an equivalent decision-making task. Specifically, in the first version of the task, adolescents were solely requested to reason in probabilistic terms on a series of coin tosses sequences, while in the following version, they were asked to bet money on the same outcome sequences. Risky decision making was conceptualized as the tendency to commit the *gambler's fallacy*.

The gambler's fallacy is one of the biases related to the representativeness heuristic, which indicates a tendency for people to base their judgment of the probability of a particular event on how much it represents the essential features of the parent population or of its generating process (Gilovich, Griffin, & Kahneman, 2002; Kahneman, Slovic, & Tversky, 1982). This fallacy occurs when individuals believe that even short strings of random events must correspond with their perception of what constitutes randomness, leading to beliefs that particular outcomes are "due" (Tversky & Kahneman, 1971). For example, when tossing a fair coin, after a series of heads, people have the feeling that a tail should follow, because this corresponds more to their expectation of having a mix of heads and tails, rather than a long sequence of just heads (Morsanyi, Primi, Chiesi, & Handley 2009). We considered the tendency to commit the gambler's fallacy as a risk-taking measure since several studies showed that the susceptibility to commit this bias characterized adolescent problem gamblers (e.g., Delfabbro et al., 2009; Donati et al., 2013; Skoukaskas & Satkeviciute, 2007; Turner, Macdonald, Bartoshuk, & Zangeneh, 2008).

Method

Participants

Participants were 148 adolescents (62% males, mean age=15.9 years, $SD=1.59$) who attended high school in Italy (Tuscany). Written informed assent was provided by students and written informed consent was provided by the parents if the student was a minor.

Instruments

Measures. Probabilistic reasoning ability was measured with the *Probabilistic Reasoning Questionnaire* (PRQ, Primi, Morsanyi, & Chiesi, 2014). Using Item Response Theory (IRT), the PRQ was designed to measure proportional reasoning and basic probabilistic reasoning skills, which are deemed necessary to reason normatively and avoid heuristic strategies. The scale consisted of 16 multiple-choice probabilistic reasoning questions. Items included simple, conditional, and conjunct probabilities, and data were presented both in frequencies and percentages (for examples: “A ball was drawn from a bag containing 10 red, 30 white, 20 blue, and 15 yellow balls. What is the probability that it is neither red nor blue?” a. 30/75; b. 10/75; c.45/75; and “60% of the population in a city are men and 40% are women. 50% of the men and 30% of the women smoke. We select a person from the city at random. What is the probability that this person is a smoker?” a. 42%, b. 50%, c. 85%). A single composite score was computed based on the sum of correct responses.

Sensation seeking was measured through the *Brief Sensation Seeking Scale* (BSSS, Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002; Italian version: Primi, Narducci, Benedetti, Donati, & Chiesi, 2011). It contains eight Likert-type items using a 5-point scale ranging from *strongly disagree* to *strongly agree*, yielding a maximum score of 40. Higher scores represent high levels of sensation seeking. An example of an item is “*I would love to have new and exciting experiences, even if they are illegal*”. Past studies have shown that the BSSS has adequate reliability and validity (Hoyle et al., 2002; Primi et al., 2011).

Tasks. In order to compare non-gambling and gambling situations, two versions of an equivalent paper and pencil task were developed (Table 1).

	Non-Gambling Task	Gambling Task
Coin Toss Sequences	What is the likelihood of Tails at the 7 th toss?	You have €10. How much do you bet on Tails at the 7 th toss?
H-H-T-H-T-T		
T-H-T-H-H-H		
H-T-H-T-T-T		
H-H-T-T-T-T		
T-H-T-T-H-H		
T-T-H-H-H-H		

Table 1. Non-Gambling and Gambling Tasks

The first version was the *Non-gambling Task*. In this task, participants were presented with six different outcome sequences consisting in six coin tosses (T = Tails, H = Heads). For each sequence, they were asked to indicate the likelihood of Tail if a seventh toss would be made. One point was given to each wrong response so that higher scores corresponded to low normative reasoning. After participants had compiled this first task, the *Gambling Task* was administered. In this task, participants were presented with the same outcome sequences as the *Non-gambling Task*, but, for each sequence, they were asked to indicate how much money, from a minimum of €0 to a maximum of €10 (available for each sequence), would bet on Tails if a seventh toss would be made. A net score

was calculated by subtracting the average amount of money bet on the first, the third, and the fourth sequence (i.e. those sequences which make more likely to bet on Tails according to the gambler's fallacy bias) from the average amount of money bet on the second, the fifth, and the sixth sequence (i.e. those sequences which make less likely to bet on Tail according to heuristic strategies). Thus, higher scores corresponded to high levels of susceptibility to the gambler's fallacy.

Procedure

Following methods of other studies (e.g., Panno, Lauriola, & Figner, 2013; Panno, Pierro, & Lauriola, 2013), participants were tested at two separate sessions, which were framed as two unrelated studies. In the first session, they completed the PRQ and the BSSS. The measures were administered in the classroom by professional trained experimenters. In the second session, each participant completed the *Non-Gambling* and the *Gambling Task* in a paper and pencil form.

Results

In line with the hypothesis, results showed that adolescents referred to probabilistic reasoning ability only in the *Non-Gambling Task*. Specifically, probabilistic reasoning ability was significantly and negatively related to the gambler's fallacy in the *Non-Gambling Task*, indicating that adolescents' performance was related to their reasoning abilities in the non-risky situation. On the contrary, the ability to reason with probability was no more significantly related to the performance in the *Gambling Task*, in which the susceptibility to the gambler's fallacy was significantly and positively related only to sensation seeking (Table 2).

Gambler's fallacy	Probabilistic reasoning	Sensation seeking
Non-Gambling Task	-.23*	.11
Gambling Task	.02	.22*
M (SD)	10.74 (3.16)	26.71 (5.70)

Table 2. Correlations between probabilistic reasoning ability, sensation seeking, and gambler's fallacy in the *Non-Gambling* and *Gambling Tasks*. (* $p < .05$)

Discussion

This study shows that probabilistic reasoning ability characterized adolescents' decision making only in the absence of risky conditions. This result suggested that without a potential winning money, only the cognitive system was activated. On the contrary, once the situation became risky, i.e. it changes from a 'neutral' to an 'affective-charged' context by the introduction of a potential winning money, only sensation seeking influenced adolescents' performance, thus suggesting that the affective system overcame the cognitive one in this kind of situation.

In terms of dual-system models, findings indicate that adolescents seem to use deliberating processes in the absence of affective involvement, but they do not seem to control affective impulses in situations of affective involvement. This finding is in line with what stated by the *fuzzy-trace theory* (Chick & Reyna, 2012; Reyna & Brainerd, 1995; Rivers, Reyna, & Mills, 2008), that assumes that risk taking in adolescence can be caused by a maturational lack of inhibition, particularly in situations of heightened emotional arousal. Moreover, our findings are also consistent with the *revised imbalance model* (Casey et al., 2008; Casey, Hare, & Galván, 2011; Galván, 2012), that claims that if it is true that adolescents are quite capable of rational decisions (Reyna & Farley, 2006), in emotionally salient situations, the affective system overcomes the cognitive system. Further, the neural imbalance typical of adolescence also interact with the context in which potentially risky decisions can be made: risky choices are largely influenced by the context in which

they are presented (Galván, 2012). Indeed, individuals, especially adolescents, engage in risky choices because the context offer them a reward (Galván, 2012). It has been shown that neural systems that underlie reward are also those that precede risky decision making (Kuhnen & Knutson, 2005; Matthews, Simmons, Lane, & Paulus, 2004), suggesting a neural link between reward sensitivity and risk taking.

Study 2

The aim of the Study 2 was to explore the role of the cognitive system and the affective system in an *explicit* risky situation, i.e. a gambling condition with preliminary information given to participants. More specifically, we wanted to explore whether the role of probabilistic reasoning ability on adolescents' decision making changed between a risky context characterized by *high*-emotional arousal and a risky context with *low*-emotional arousal. In order to design these two different situations, a feedback after each choice was provided in the *high*-emotional arousal situation, while no feedback was provided in the *low*-emotional arousal situation. We based this decision on Figner et al. (2009)'s results in investigating risk taking in adolescents using the *Columbia Card Task* (CCT). Providing feedback (the "hot" CCT) was found to trigger more affective decision making, while receiving any feedback about the result of the decision until the end of the session (the "cold" CCT) resulted to trigger predominantly deliberative information processing.

Our first hypothesis was that adolescents would use probabilistic reasoning ability in both the risky situations. Indeed, from Brand and colleagues' research on decision making under conditions of risk (e.g., Brand et al., 2008; Brand et al., 2009; Schiebener et al., 2011), we know that the decision making performance in an explicit risky context is linked to cognitive functions such as logical ability, executive functions (i.e. categorization, set shifting, and rule learning), and knowledge of probabilities. Our second hypothesis was that sensation seeking would only affect adolescents' decision making in the high-emotional arousal condition, i.e. when feedback was provided.

Concerning the decision making task, in order to test our hypothesis in a context of explicit decision making under risk, we used the *Game of Dice Task* (GDT, Brand, Fujiwara et al., 2005) (Figure 1), a neuropsychological task in which individuals have to decide among different alternatives that are explicitly linked to a specific amount of gain or loss and have obvious winning probabilities that are stable over time. Therefore, individuals have the chance to calculate the risk associated with each alternative from the very beginning of the task. As such, probabilistic reasoning ability should help in recognizing which option can be more likely and in reasoning about the likelihood of the different options. Disadvantageous performances on this task have been associated with impaired decision-making process in clinical populations, such as adult pathological gamblers (e.g., Brand, Kalbe, et al., 2005), adolescent pathological Internet gamers (Pawlikowski & Brand, 2011), and adolescents with attention-deficit/hyperactivity disorder (Drechsler, Rizzo, & Steinhausen, 2008).

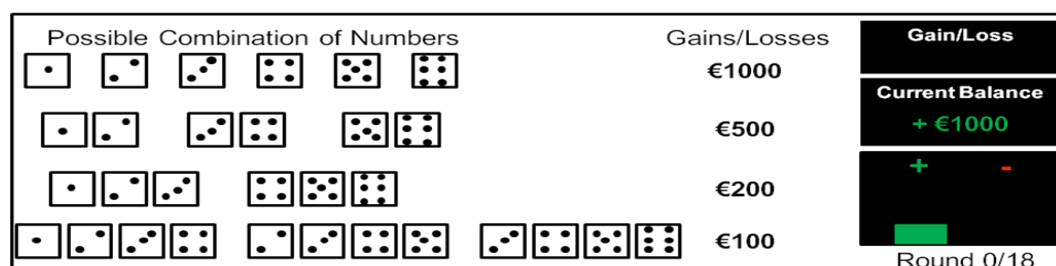


Figure 1. The Game of Dice Task (GDT, Brand, Fujiwara, et al., 2005).

Method

Participants

Participants were 201 adolescents (61% males, mean age=16.5 years, $SD=1.60$) who attended high school in Italy (Tuscany). Written informed assent was provided by students and written informed consent was provided by the parents if the student was a minor.

Instruments

Measures. As in the first Study, probabilistic reasoning was measured with the PRQ (Primi et al., 2014), and sensation seeking was revealed through the Italian version of the BSSS (Primi et al., 2011).

Task. In order to compare high- and low-emotional arousal situations, two versions of the same computerized task were administered. The *Game of Dice Task* – original version (GDT, Brand, Fujiwara, et al., 2005) was used to measure risky decision making in high-emotional arousal situation. Before beginning this task, participants were instructed to maximize their fictitious starting capital of €1,000 within 18 throws of a single virtual die. They were explicitly briefed about the rules of the game and the amounts of money associated with each of the possible options. In each trial, before the die is thrown, participants must bet on the outcome of the die throw choosing among one of the given options: a single number, or combinations of two, three, or four numbers. If they choose one of the six possible single number options (from “1” to “6”, winning probability = 0.17), they receive a fictitious gain of €1,000 when the chosen number is thrown but a fictitious loss of €1000 when one of the five other numbers not chosen is thrown. Choosing one of the three possible combinations of two numbers (“1,2” – “3,4” – “5,6”, winning probability = 0.33) is linked to a gain of €500 when one of the numbers included in the chosen combination is thrown, but a loss of €500 when one of the numbers not included in those combinations is thrown. A further alternative is to choose one of the two possible combinations of three numbers (“1,2,3” – “4,5,6”, winning probability = 0.50) linked to a potential gain/loss of €200. Finally, participants may choose one of the three possible combinations of four numbers (“1,2,3,4” – “2,3,4,5” – “3,4,5,6”, winning probability = 0.67) that will lead to a gain of €100 in the event that one of the four numbers chosen is thrown, but a loss of €100 when one of the numbers included in the other two combinations not chosen is thrown. In total, the participants can choose each of the 14 different alternatives (clustered in four groups) in each trial. The winning probabilities and amounts of gains and losses associated with each alternative remain stable during the entire task. After each throw, the gain or loss in money is indicated on the screen accompanied by a distinct sound (the jingle of a cash machine for a gain; a dull tone for a loss). The current total capital and number of remaining rounds are also displayed on the computer screen. In line with other studies (e.g., Brand, Kalbe et al., 2005; Brand, Labudda, & Markowitsch, 2006; Brand & Schiebener, 2013; Starcke, Tuschen-Caffier, Markowitsch, & Brand, 2010), the frequency of choosing the *risk-disadvantageous* or *high risky* choices (one single number and the two number combinations: winning probability of 0.33 or lower resulting in frequent and high losses in the long run) was calculated as a measure of risk taking. Thus, the higher the score, the more disadvantageous was the performance in terms of decision making.

The *Game of Dice Task* – Modified version (GDT-MOD, Brand, 2008) was used to measure risky decision making in low-emotional arousal situation. The modified GDT and the original GDT are similar with the exception that all feedback associated features have been removed from the modified version. This means that the participants cannot see the number thrown in each trial, and gains/losses are not indicated. Additionally, the current monetary balance is fixed to the starting capital (€1,000), and the color bars do not show whether a loss or gain has occurred. Participants also do not hear a tone for gains or losses. The participants see the screen of the original task on a notebook (fixed to the pattern at the beginning of the task) and are instructed in the same way as in the original GDT. They are told that their goal in the game is to win as much money as possible and

to lose as little money as possible. In addition, all alternatives and gain/loss contingencies are explicitly explained and are indicated on the screen throughout the entire task (as in the original GDT). In the modified GDT, participants are told that the dice throws will not be seen on the screen and that they will not be informed about the outcome of each throw. They are also told that the computer will save the responses and that an overall feedback (final balance) will be provided at the end of the game. As in the GDT, the number of risky choices (i.e. one or two combinations choices) was calculated as a measure of risk taking.

Procedure

In line with Study 1, participants were tested at two separate sessions, which were framed as two unrelated studies. In the first session, participants completed the PRQ and the BSSS. The measures were administered in the classroom by professional trained experimenters. In the second session, each participant completed the decision making task in an individual setting on a desktop computer. Participants were randomly assigned to two groups. One group ($n=102$, 60% males, mean age=16.6 years, $SD=1.53$) was administered the GDT (Brand, Fujiwara, et al., 2005), in which feedback was provided, while the other group ($n=99$, 62% males, mean age=16.7 years, $SD=1.58$) was administered the GDT-MOD (Brand, 2008), in which feedback was not provided.

Results

In line with our hypotheses, results showed that adolescents referred to probabilistic reasoning ability in both the versions of the GDT. Specifically, we found that probabilistic reasoning was significantly and negatively related to the frequency of risky choices in the situation with feedback as in the situation without feedback, indicating that adolescents' decision making was related to reasoning abilities regardless of feedback. On the contrary, risky choices were significantly and positively related to sensation seeking only in the situation with feedback, i.e. only in conditions of high-emotional arousal (Table 3).

Risky choices	Probabilistic reasoning	Sensation seeking
<i>GDT (With feedback)</i>	-.24*	.20*
M (SD)	12.71 (2.37)	25.26 (5.95)
<i>GDT-MOD (Without feedback)</i>	-.37**	.06
M (SD)	12.69 (2.17)	23.42 (5.57)

Table 3. Correlations between probabilistic reasoning ability, sensation seeking, and the frequency of risky choices in the GDT and in the GDT-MOD. (* $p<.05$ ** $p<.01$)

Results also showed that the frequency of risky choices was significantly lower in the GDT ($M=4.10$, $SD=4.25$) in comparison to the GDT-MOD ($M=5.78$, $SD=4.71$) ($t(199)=-2.66$, $p<.01$, Cohen's $d=.37$).

Discussion

Probabilistic reasoning characterized adolescents' decision making in explicit risky conditions, regardless of feedback. This finding suggests that the cognitive system was activated in this type of risky situation, in which information about the task contingencies are given to participants from the beginning of the task. Only in condition of high-emotional-arousal, adolescents' decision making was related to the affective system. On the contrary, in condition of low-emotional arousal, the affective system did not affect the decision making process. This is consistent with what claimed by Figner et al. (2009), according to which risky choice scenarios, such

as choices between monetary lotteries without outcome feedback, typically trigger only minor affective processes.

The fact that adolescents' probabilistic reasoning has been found to be related to explicit decision making under risk provides evidence of the importance of probabilistic reasoning in decision making. Specifically, some Authors have said that if probabilities are not well understood it is likely that the choices in a risky situation will be suboptimal or too risk-seeking (Figner et al., 2009; Lauriola, Panno, Levin, & Lejuez, 2014). Among adolescents, proportional reasoning skill, a prerequisite skill for correct probabilistic reasoning, is considered as a fundamental ability for recognizing the most advantageous choice options in decision making tasks (Huizenga, Crone, & Jansen, 2007; Van Duijvenvoorde, Jansen, Visser, & Huizenga, 2010). Also, probability estimation, which entails deciding which choice has the largest chance of resulting in reward, is an important aspect of risk perception in the decision making process (Van Leijenhorst, Westenberg, & Crone, 2008). Finally, probabilistic reasoning was found to mediate the relationship between fluid intelligence and advantageous decision making in the GDT performance among adolescents (Donati, Panno, Chiesi, & Primi, 2014).

In terms of *dual-system models*, this study shows that adolescents seem to use deliberating process in situations of explicit risk. This finding is in line with what found by several studies conducted with adults showing the involvement of cognition in decision making under explicit risk (e.g., Brand et al., 2005; Brand et al., 2009; Schiebener et al., 2011). Findings also showed that explicit risky condition seem to lead adolescents to control affective impulses, since the cognitive system is activated even in the presence of feedback and it does not seem to be overcome by the affective system in such emotional arousal condition.

Finally, adolescents were found to choose more frequently the risky alternatives in the task version without feedback. This finding is in line with the study of Brand and colleagues (2009) conducted with healthy adults and revealing that participants who performed the original GDT showed a less disadvantageous decision making performance than those who performed the modified GDT. Consistent with that result, our study confirms that even in adolescents, processing feedback from previous trials may improve performance in a decision-making situation with explicit and stable rules for gains and losses.

General Discussion

This work offers empirical evidence that although adolescents' decision making was solely linked to the cognitive system in the non-risky situation, the affective system overcomes the cognitive system when the decision making situation becomes risky, i.e. when a potential winning money was introduced. Additionally, it suggests that providing information about the task might interfere with the imbalance between the two systems that usually verifies in the presence of risky situations. This would explain why adolescents' decision making in the condition with feedback was related not only to the affective, but also to the cognitive system, while, without feedback, adolescents' performance was solely related to the cognitive system. Moreover, it indicates that providing feedback was associated with less risk taking than not providing it.

From a general standpoint, the present work shows that adolescent decision making seems to be impaired in situations of implicit risk taking, and this impairment seems to be related to a difficulty in inhibiting affective impulses. However, when the risky situation becomes more explicit, i.e. information about the task contingencies are given, adolescents use their cognitive system; moreover, this system seems to be activated even in the situation of heightened emotional arousal, i.e. when a feedback after each choice was provided.

Findings underline the importance of the context in interacting with the imbalance between

the cognitive and the affective system in influencing adolescents' decision making in risky situations (Galván, 2012). Indeed, when the level of information available on the decision-making task became more explicit for adolescents, they showed to refer to their cognitive abilities in terms of probabilistic reasoning skills.

From the educational point of view, the most important finding of this work was that providing explicit information on pros and cons of choice options can lead adolescents to use the cognitive system. However, a cognitive decision making can occur only in situation of low-emotional arousal. Then, preventive interventions designed to reduce adolescents' risk-taking behaviors should be addressed to educate adolescents to approach risk-taking contexts as much as possible as reasoning contexts. In other words, it would be interesting to develop educational interventions aimed not only at promoting the development of adolescents' understanding of probability, for example by providing them real-world experiences with random generators (Morsanyi, Handley, & Serpell, 2012), but also at fostering their tendency to understand all the elements in everyday decision making situations that can be read as information on pros and cons of the different alternatives among which each time they have to decide. This might help them in using their reasoning abilities regardless of risky context.

References

- Brand, M. (2008). Does the feedback from previous trials influence current decisions? A study on the role of feedback processing in making decisions under explicit risk conditions. *Journal of Neuropsychology*, *2*, 431-443.
- Brand, M., Fujiwara, E., Borsutzky, S., Kalbe, E., Kessler, J., & Markowitsch, H. J. (2005). Decision making deficits of Korsakoff patients in a new gambling task with explicit rules: Associations with executive functions. *Neuropsychology*, *19*, 267–277. doi: 10.1037/0894-4105.19.3.267.
- Brand, M., Heinze, K., Labudda, K., & Markowitsch, H. J. (2008). The role of strategies in deciding advantageously in ambiguous and risky situations. *Cognitive Processing*, *9*, 159–173. doi: 10.1007/s10339-008-0204-4.
- Brand, M., Kalbe, E., Labudda, K., Fujiwara, E., Kessler, J., & Markowitsch, H. J. (2005). Decision-making impairments in patients with pathological gambling. *Psychiatry Research*, *133*, 91–99. doi: 10.1016/j.psychres.2004.10.003.
- Brand, M., Laier, C., Pawlikowski, M., & Markowitsch, H. J. (2009). Decision making with and without feedback: The role of intelligence, strategies, executive functions, and cognitive styles. *Journal of Clinical and Experimental Neuropsychology*, *31*, 984–998. doi: 10.1080/13803390902776860.
- Brand, M. & Schiebener, J. (2013). Interactions of age and cognitive functions in predicting decision making under risky conditions over the life span. *Journal of Clinical and Experimental Neuropsychology*, *35*(1), 9-23. doi: 10.1080/13803395.2012.740000.
- Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences*, *1124*, 111-126. doi: 10.1196/annals.1440.010.
- Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, *14*, F1-F10. doi: 10.1111/j.1467-7687.2010.01035.x
- Chick, C. F., & Reyna, V. F. (2012). A fuzzy trace theory of adolescent risk taking: Beyond self-control and sensation seeking. In V. F. Reyna, S. B. Chapman, M. R. Dougherty, & J. Confrey (2012). *The Adolescent Brain: Learning, Reasoning, and Decision Making*. Washington, DC, USA: American Psychological Association.
- Cohen, J. D. (2005). The vulcanization of the human brain: A neural perspective on interactions between cognition and emotion. *Journal of Economic Perspectives*, *19*, 3-24.
- Delfabbro, P., Lahn, J., & Grabosky, P. (2006). It's not what you know, but how you use it:

- Statistical knowledge and adolescent problem gambling. *Journal of Gambling Studies*, 22, 179-193. doi: 10.1007/s10899-006-9009-5.
- Delfabbro, P., Lambos, C., King, D., & Pugliese, S. (2009). Knowledge and beliefs about gambling in Australian secondary school students and their implications for education strategies. *Journal of Gambling Studies*, 25, 523-539. doi: 10.1007/s10899-009-9141-0.
- Donati, M. A., Chiesi, F., & Primi, C. (2013). A Model to Explain At Risk/Problem Gambling among Male and Female Adolescents: Gender Similarities and Differences. *Journal of Adolescence*, 36, 129-137. doi: <http://dx.doi.org/10.1016/j.adolescence.2012.10.001>.
- Donati, M. A., Panno, A., Chiesi, F., & Primi, C. (2014). A mediation model to explain decision making under conditions of risk among adolescents: The role of fluid intelligence and probabilistic reasoning. *Journal of clinical and experimental neuropsychology*, 36(6), 588-595.
- Drechsler, R., Rizzo, P., & Steinhausen, H. C. (2008). Decision-making on an explicit risk taking task in preadolescents with attention-deficit/hyperactivity disorder. *Journal of Neural Transmission*, 115, 201-209. doi: 10.1007/s00702-007-0814-5.
- Figner, B., Mackinlay, R., Wilkening, F., & Weber, E. (2009). Affective and deliberative processes in risky choice: Age differences in risk taking in the Columbia Card Task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 709-730. doi: <http://dx.10.1037/a0014983>.
- Galván, A. (2012). Risky behavior in adolescents: The role of the developing brain. In V. F. Reyna, S. B. Chapman, M. R. Dougherty, & J. Confrey (2012). *The Adolescent Brain: Learning, Reasoning, and Decision Making*. Washington, DC, USA: American Psychological Association.
- Galván, A., Hare, T. A., Parra, C. E., Penn, J., Voss, H., Glover, G., et al. (2006). Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. *Journal of Neuroscience*, 26, 6885-6892.
- Galván, A., Hare, T. A., Voss, H., Glover, G., & Casey, B. J. (2007). Risk-taking and the adolescent brain: Who is at risk? *Developmental Science*, 10, F8-F14.
- Gardner, M., & Steinberg, L. (2005). Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: An experimental study. *Developmental Psychology*, 41, 625-635.
- Gilovich, T., Griffin, D., & Kahneman, D. (Eds.). (2002). *Heuristics and biases: The psychology of intuitive judgment*. Cambridge, UK: Cambridge University Press.
- Gupta, R., & Derevensky, J. L. (1998). An empirical examination of Jacobs' General Theory of Addiction: do adolescents gamblers fit the theory? *Journal of Gambling Studies*, 14, 17-49.
- Hoyle, R. H., Stephenson, M. T., Palmgreen, P., Lorch, E. P., & Donohew, R. L. (2002). Reliability and validity of a brief measure of sensation seeking. *Personality and Individual Differences*, 32, 401-414.
- Huizenga, H. M., Crone, E. A., & Jansen, B. J. (2007). Decision-making in healthy children, adolescents and adults explained by the use of increasingly complex proportional reasoning rules. *Developmental Science*, 10(6), 814-825. doi: 10.1111/j.1467-7687.2007.00621.x.
- Kahneman, D., Slovic, P., & Tversky, A. (Eds.). (1982). *Judgment under uncertainty: Heuristics and biases*. Cambridge, UK: Cambridge University Press.
- Keating, D. (2004). Cognitive and brain development. In R. Lerner & L. Steinberg (Eds.), *Handbook of adolescent psychology* (2nd ed., pp. 45-84). New York: Wiley.
- Knoch, D., & Fehr, E. (2007). Resisting the power of temptations: The right prefrontal cortex and self-control. *Annals of the New York Academy of Sciences*, 1104, 123-134.
- Kuhn, D. (2006). Do cognitive changes accompany developments in the adolescent brain? *Perspectives on Psychological Science*, 1, 59-67.
- Kuhnen, C. M., & Knutson, B. (2005). The neural basis of financial risk taking. *Neuron*, 47(5), 763-

770.

- Lauriola, M., Panno, A., Levin, I. P., & Lejuez, C. W. (2014). Individual Differences in Risky Decision Making: A Meta-analysis of Sensation Seeking and Impulsivity with the Balloon Analogue Risk Task. *Journal of Behavioral Decision Making*, 27, 20-36. doi: 10.1002/bdm.1784.
- Matthews, S. C., Simmons, A. N., Lane, S. D., & Paulus, M. P. (2004). Selective activation of the nucleus accumbens during risk-taking decision making. *Neuroreport*, 15(13), 2123-2127.
- McClure, S. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2004, October 15). Separate neural systems value immediate and delayed monetary rewards. *Science*, 306, 503-507.
- Morsanyi, K., Primi, C., Chiesi, F., & Handley, S. (2009). The effects and side-effects of statistics education: Psychology students' (mis-) conceptions of probability. *Contemporary Educational Psychology*, 34(3), 210-220.
- Morsanyi, K., Handley, S. J., & Serpell, S. (2012). Making heads or tails of probability: An experiment with random generators. *British Journal of Educational Psychology*, 83(3), 379-395. doi: <http://dx.10.1111/j.2044-8279.2012.02067.x>.
- Nower, L., Derevensky, J. L., & Gupta, R. (2004). The relationship of impulsivity, sensation seeking, coping and substance use in youth gamblers. *Psychology of Addictive Behaviours*, 18, 49-55. <http://dx.doi.org/10.1037/0893-164X.18.1.49>.
- Panno, A., Lauriola, M., & Figner, B. (2013). Emotion regulation and risk taking: Predicting risky choice in deliberative decision making. *Cognition & Emotion*, 27, 326-334. doi: <doi.org/10.1080/02699931.2012.707642>.
- Panno, A., Pierro, & Lauriola, M. (2013). Self-regulation predicts risk taking through people's time horizon. *International Journal of Psychology*. doi: <http://dx.10.1002/ijop.12026>.
- Pawlikowski, M., & Brand, M. (2011). Excessive Internet gaming and decision making: Do excessive World of Warcraft players have problems in decision making under risky conditions? *Psychiatry Research*, 188, 428-433. doi: 10.1016/j.psychres.2011.05.017.
- Primi, C., Morsanyi, K., & Chiesi, F., (2014). Measuring the basics of probabilistic reasoning: the IRT-based construction of the probabilistic reasoning questionnaire. *Proceedings of the 9th International Conference on Teaching Statistics (ICOTS)*, Flagstaff, Arizona, USA.
- Primi, C., Narducci, R., Benedetti, D., Donati, M. A., & Chiesi, F. (2011). Validity and reliability of the Italian version of the Brief Sensation Seeking Scale (BSSS) and its invariance across age and gender. *Testing, Psychometrics, Methodology in Applied Psychology, TPM*, 18, 1-11.
- Reyna, V. F., Chapman, S. B., Dougherty, M. R., & Confrey, J. (2012). *The Adolescent Brain: Learning, Reasoning, and Decision Making*. Washington, DC, USA: American Psychological Association.
- Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Learning and Individual Differences*, 7(1), 1-75.
- Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making implications for theory, practice, and public policy. *Psychological Science In The Public Interest*, 7, 1-44.
- Rivers, S. E., Reyna, V. F., & Mills, B. (2008). Risk taking under the influence: A fuzzy-trace theory of emotion in adolescence. *Developmental Review*, 28(1), 107-144.
- Reyna, V. F., & Rivers, S. E. (2008). Current theories of risk and rational decision making. *Developmental Review: DR*, 28(1), 1.
- Schiebener, J., Zamarian, L., Delazer, M., & Brand, M. (2011). Executive functions, categorization of probabilities, and learning from feedback: What does really matter for decision making under explicit risk conditions? *Journal of Clinical and Experimental Neuropsychology*, 33(9), 1025-1039. doi: <http://dx.doi.org/10.1080/13803395.2011.595702>.
- Scholes-Balog, K. E., Hemphill, S. A., Dowling, N. A., & Toumbourou, J. W. (2014). A prospective study of adolescent risk and protective factors for problem gambling among young adults. *Journal of Adolescence*, 37(2), 215-224. doi:

<http://dx.doi.org/10.1016/j.adolescence.2013.12.006>

- Schonberg, T., Fox, C. R., & Poldrack, R. A. (2011). Mind the gap: bridging economic and naturalistic risk-taking with cognitive neuroscience. *Trends in cognitive sciences*, 15(1), 11-19.
- Skoukaskas, N., & Satkeviciute, R. (2007). Adolescent pathological gambling in Kaunas, Lithuania. *Nordic Journal of Psychiatry*, 61, 86-91.
- Somerville, L. H., Jones, R. M., & Casey, B. J. (2010). A time of change: Behavioral and neural correlates of adolescent sensitivity to appetitive and aversive environmental cues. *Brain and Cognition*, 72, 124-133. doi: [10.1016/j.bandc.2009.07.003](http://dx.doi.org/10.1016/j.bandc.2009.07.003).
- Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review*, 28, 78-106.
- Turner, N. E., MacDonald, J., Bartoshuk, M., & Zangeneh, M. (2008). Adolescent gambling behavior, attitudes, and gambling problems. *International Journal of Mental Health and Addiction*, 6, 223-237. <http://dx.doi.org/10.1007/s11469-007-9117-1>
- Turner, N. E., Zangeneh, M., & Littman-Sharp, N. (2006). The experience of gambling and its role in problem gambling. *International Gambling Studies*, 6, 237-266.
- Tversky, A., & Kahneman, D. (1971). Belief in the law of small numbers. *Psychological bulletin*, 76(2), 105.
- Van Duijvenvoorde, A. C. K., Jansen, B. R. J., Visser, I., & Huizenga, H. (2010). Affective and cognitive decision-making in adolescents. *Developmental Neuropsychology*, 35, 539-554. doi: <http://dx.10.1080/87565641.2010.494749>.
- Van Leijenhorst, L., Westenberg, P. M., & Crone, E. A. (2008). A developmental study of risky decisions on the Cake Gambling Task: Age and gender analyses of probability estimation and reward evaluation. *Developmental Neuropsychology*, 33(2), 179-196. doi: <http://dx.10.1080/87565640701884287>.
- Weber, E. U., Shafir, S., & Blais, A. R. (2004). Predicting risk sensitivity in humans and lower animals: Risk as variance or coefficient of variation. *Psychological Review*, 111, 430-445.