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Cognitive and emotional aspects of children's decision-making under risk

A dissertation submitted for the degree of

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Preface

Decision-making is a complex process, involving several cognitive components, in which an individual needs to evaluate and interpret events in order to choose between alternatives of action (Von Winterfeld & Edwards, 1986). To make this choice, the individual realizes a series of strategies and mental operations in order to process the information in her possession to achieve a final result (Payne, Bettman, Coupey & Johnson, 1992).

Very often, decision-making can involve choosing between a safe and a risky option. When individuals prefer risky options, they implement behaviors associated with a certain probability of unpredictable and uncertain results. The term "uncertainty" refers to situations where the individual is unaware of the probability of the various outcomes that may arise from her choice (Lopes, 1983). Some authors (Ellsberg, 1961; Huettel, Stowe, Gordon, Warner & Platt, 2006; Platt & Huettel, 2008) highlighted the distinction between two types of uncertainty: 'ambiguity', which refers to situations where the probabilities associated with the outcomes of a choice are unknown, and 'risk', which refers to situations where the outcomes associated with a choice are unknown, but the chances associated with each of them are known (Knight, 1921).

The expression "risk propensity" is used to describe a behavioral tendency to take risky choices linked to a high probability of loss and therefore unpleasant results. This characteristic is typically assessed by tasks where subjects have to choose between a "safe" option, corresponding to a certain reward, and a "risky" option, corresponding to a reward that can be obtained with a certain degree of probability. Since the 17th century, philosophers and researchers have described models that predict how individuals make their decisions in uncertain situations (Platt & Huettel, 2008). According to the expected utility theory, individuals should choose the option with the highest expected utility, given the relationship between the utility of the reward and the probability of obtaining it. According to this model, a rational decision maker should be indifferent when choosing between a safe and risky option, both linked to the same outcome (Von Neumann &

Morgenstern, 1944). However, laboratory experiments have shown that individuals prefer to avoid risks, showing risk aversion (e.g., Kahneman & Tversky, 1979; Kacelnik & Bateson, 1996), although it is well documented that pathological gambling is a widespread phenomenon among adult population (Bastiani et *al*., 2013).

Recently, risk propensity has been also investigated in children with the aim of detecting the onset of potentially risky behaviors. In situations where there is a small chance of a large loss, children are more likely to choose the risky option than the safe one, whereas adults behave in the opposite way (Harbaugh, Krause & Vesterlund 2002), thus indicating that risk proneness changes with age. This is evident since early childhood: when administering the *Children's Gambling Task*, one of the most popular gambling tasks, Kerr & Zelazo (2004) showed that four year old children have a better performance (in terms of more favorable choices) than three year olds. This finding, confirmed by other studies (Crone, Bunge, Latenstein & van der Molen, 2005; Crone & van der Molen, 2007; Bunch, Andrews & Halford, 2007; Gao, Wei, Bai, Lin & Li, 2009; Steelandt, Broihanne, Romain, Thierry & Dufour, 2013), is in line with the maturation of the orbitofrontal cortex and executive functions, that take place during the first years of life.

The present research is part of a larger project, carried out in collaboration between the University of Rome "Sapienza" and the Institute of Science and Technology of Cognition of CNR in Rome. The general aim is to evaluate risk propensity in preschool and school-aged children, in adult humans and in capuchin monkeys (*Cebus apella*), a South-American primate species. Specifically, this thesis investigated risk propensity in a sample of 183 children, aged four-eight years old.

The thesis is divided into four chapters: the first chapter aims to illustrate the theories explaining decision-making under risk and focuses in particular on the factors underlying children’s ability to make choices in uncertain situations; the second chapter explores the role of emotions on children’s risky preferences; the third chapter describes the research performed with preschoolers and school-aged children aiming to elucidate the development of children's decision-making under risk. Finally, in the fourth chapter the results of the research are discussed in the light of the most relevant literature.

Chapter One – Decision making under risk

1.1 Introduction

In everyday life, individuals must constantly make decisions among multiple options, judging and balancing their costs and benefits, and often they do not know what consequences will follow from their choices, and this lack of knowledge is called *uncertainty* (Platt and Huettel 2008). Some authors distinguished two types of uncertainty, *ambiguity* and *risk* (Ellsberg 1961, Huettel et *al*. 2006, Platt and Huettel 2008). Ambiguity characterizes the situations open to several interpretations, in which individuals do not know which probabilities are associated with each choice. Instead, risk regards all the situations in which the decision maker is aware of the probabilities associated with each possible outcome, but the outcome remains unknown (Knight, 1921; Paulsen, 2012), for example, we accurately know that we have ⅙ chance of winning if betting on one face of a dice throw. A popular television game, *Deal or No Deal*, illustrates an example of a situation that requires a choice between a safe and a risky option. The players have to choose between 20 boxes, each containing different prizes unknown to the participants. At the end of the game, with only two boxes left, the player has to decide if accepting the sure offer made by the banker, usually corresponding to the half of the larger prize left, or taking the risk to see the content of his own box. How people make this kind of decision is the focus of the following paragraphs, in particular how children face situations which require the choice between a risky and a safe option.

1.2 Defining decision-making under risk

How people deal with risk is a debated issue that interests scholars from different disciplines, from philosophers to economists, from psychologists to biologists, for centuries. In fact, this topic affects several fields of everyday life such as economic investments, pension investments, medical and long-term care insurance, and medical treatments. In particular, psychologists and neuroscientists are interested in risky choices because of their close relationship with gambling behaviour, described as an "*activity that involves an element of risk or chance whereby money or a valued object is either won or lost*" (Ladouceur et *al*., 2000), which is growing widely across different backgrounds and cultures, (O'Keeffe, 2012; Proctor 2014). Thus, it is urgent to better understand which factors lead to the development of this maladaptive behaviour.

Nevertheless, it is not still clear how human beings make decisions under risk. In fact, it is a complex phenomenon, influenced by several factors, such as contexts, gender, personality of the decision maker and, moreover, it is investigated by different methods and theorical perspectives, which often lead to mixed results.

1.2.1 Normative models of risk: the Expected Value and the Utility Value models

In the 17th century, the famous philosopher Blaise Pascal developed the first rational model of risky choice, the *Expected Value Theory* (EV), introducing the concept of expected value, which is defined as the combination of value and probability:

$$EV\ (X) = \sum p(x) \cdot x$$

where *x* is the outcome and *p* is the probability that the outcome occurs.

According to this model, an individual should choose the option with the highest expected value, when presented with a choice between two uncertain options.

Since this model was not applicable to the so-called *St. Petersburg Paradox,* discovered by the mathematician Nicolaus Bernoulli (1738), it was rejected. The St. Petersburg game describes a particular gambling activity, in which a random variable has an infinite expected value. In particular, the player pays a fixed entry fee and she has to bet on the toss of a coin. If the face chosen by the player (e.g. tails) comes up at the first toss, the game stops and the player wins only what she paid to play. If the head comes up, the coin is tossed again; even this time if the tails comes out the game ends but this time the prize is duplicated, while if head comes up again the player goes forward. If at the third toss tails comes up, the prize is duplicated again and so on. It is clear that this game can last indefinitely, so any amount of money we are willing to pay to play will always be too little. A rational gambler should be incline to pay any price of entry, even if this price can result too high for a rational player.

In order to resolve the *St. Petersburg paradox*, Bernoulli introduce the concept of *utility*, defined in terms of satisfaction or "goodness", to replace the concept of expected value(Bernoulli, 1738). Thus, according to the Bernoulli's model, people should choose the option with the highest *expected utility* (EU):

$$EU\ (X)= \sum p(x)u \cdot x$$

where u represents the *utility* of obtaining outcome x and p is the probability that outcome x occurs.

Starting from Bernoulli's formulation, John Von Neumann and Oskar Morgenstern (1944) defined an expected utility function over gambles. In their model, the utility of each outcome is calculated according to the probability that the decision will lead to that outcome and the utility of an outcome is also index of which alternatives is preferred by the decision-maker. Following von Neumann and Morgenstern's studies, Leonard Savage (1954) proposed axiomatic foundations of the theory of subjective expected utility, that rely on decision maker's acts and related consequences (Surowik, 2002). In his work, he claimed that people's choices can be considered the result of the combination of the utility function, as described above, and the subjective belief that there is a probability of each outcome. Thus, the option preferred by the decision-maker should be the one with the highest expected utility. Savage's theory also explained why different people may make different decisions: in fact, they may have different utility functions or different beliefs about the probabilities of different outcomes, which may influence their preferences. As stated by the author himself, the subjective Expected Value Theory presented several limits and there are empirical proofs that it violates its axioms (*Allais' Paradox*, Allais, 1953; *Ellsberg's Paradox*, Ellsberg, 1961). Differently from von Neumann and Morgenstern's theory of games, which seems to be more applicable to games in which payments and choice strategies are known because of the construction of the game, Savage's theory of subjective utility seems more suitable for decision problems in which a single person has to formulate his subjective convictions about payments and strategic intentions of his opponents (Surowik, 2002).

In the light of the models described above, it is possible to identify different steps that lead an individual to make her decision. First of all, people think about all the possible outcome associated to the risky options; then these outcomes are seen in function of their probabilities to occur. At this point, it is possible to provide a measure of the value of each risky options in order to choose the one with the greater value (Weber 2010). However, what these models overlook is the importance of the context in which these decisions take place (Weber & Johnson 2008).

1.2.2 Rank-dependent utility

Despite the models described above represent an interesting normative guide for rational decision making, they result inadequate to describe real behaviour; in fact, people's decision under risk is far from being rational. In this scenario, non-expected utility theories consolidate their position; among these, worth of mention is the *Rank-Dependent Expected Value Theory* (RDEV), proposed by Yaari and Menahem (1987) and derived by the choice model known as *Rank-Dependent Utility Model* (Quiggin, 1982), in which people's preferences depends on the rank of the final outcome through probability weighting. The main feature of these models is that the decision-maker implements a transformation that subjectively weights objective probabilities. This operation can lead to some weighting effects, such as the inflation of small probabilities and the devaluation of large probabilities. The central idea of rank-dependent decision was later incorporated by Daniel Kahneman and Amos Tversky into the *Prospect Theory*, and the resulting model was referred to as *Cumulative Prospect Theory* (CPT) (Tversky & Kahneman, 1992). In the Cumulative Prospect Theory, people make decisions by referring and weighing probabilities to a certain reference point rather than to the final outcome.

1.2.3 Prospect Theory and Regret Theory

According to a different perspective, emotions and the framing of the choice strongly influenced people's decisions under risk. Kahneman & Tversky (1979) provided the most famous empirical evidence of the influence of the frame of choice. They asked participants to make a series of decisions about health treatments to prevent the spread of a new Asian disease, which could kill a population of 600 people. The experiment consisted of two conditions: (1) in one condition, the choice was between a "safe" program that would save 200 lives and a "risky" program with a 1/3 chance of saving 600 people; (2) in the second condition, the choice was between a "safe" program that would cause 400 people to die and a risky one with 1/3 chance that nobody would die. According to the normative models, the two conditions were mathematically identical, but the condition affected participants' response. They preferred the "safe" program when they considered the problem in terms of saved lives (first condition), whereas they preferred the "risky" program when they reasoned in terms of lost lives. This result is the basis of the *Prospect Theory* (PT), according to which humans are generally risk averse for gains, whereas they are risk prone for losses.

Prospect Theory has become the most popular alternative to the *Expected Utility Theory*. It differs from *Expected Utility Theory* in three major ways: (a) it contemplates subjective probability weighting, (b) it allows a reference point defined over outcomes, and the use of different utility functions for gains or losses, and (c) it contemplates that the disutility of losses weighs more heavily than the utility of comparable gains.

Expectations about the outcome of a choice affect the decision-maker, who will be incline to compare what she has achieved with what she could have achieved if she had made a different choice (*counterfactual reasoning*). Thus, a feeling of *regret* could emerge in the case the unchosen option provides a better outcome (Camille et *al*. 2004, Coricelli, Dolan & Sirigu, 2007). Loomes & Sugden (1982) and Bell (1985) proposed the *Regret theory,* according to which, it is the will to avoid an unpleasant feeling like regret to condition the choices of the decision maker. Thus, the authors proposed the following equation, integrating this emotion into the expected utility function:

$$U(x,y) = v(x) + \Psi\,[v(x) - v(y)]$$

The function Ψ represents the regret function, v(x) is the value of the selected option and v(y) is the value of the unchosen option; thus, the utility of a choice is due to the expected utility of the selected option and of the anticipated regret.

These theories, the Prospect Theory and the Regret Theory, have the value to consider both objective and subjective aspects of a decision, such as frame and emotions.

1.2.4 Bounded rationality

Another position in contrast to the normative models was held by the Nobel Prize Herbert Simon, who criticized the assumption of normative models regarding a decision maker with full knowledge of a problem, infinite time to decide, and unlimited computational power to find the optimal solution to a decision problem. He proposed the concept of *bounded rationality* (1956), which involves both cognitive capacities and structures of the environment. In this scenario, the decision mechanisms cannot be universal, but domain-specific and closely linked to the environment in which they operate (*ecological rationality*, Gigerenzer & Todd, 1995). Bounded rationality and ecological rationality seemed to describe real decisional situations in a better way than the standard normative model.

1.3 Risk preferences across lifespan

I have described above the economic models that provided assumptions and theoretical frameworks regarding how humans should behave when facing situations that require a choice between a sure and a risky option. I now move to describe how this process changes during the child's development.

With the increasing availability of new legalized gambling opportunity, also children can engage in gambling activities created for adults. As a consequence, 3-6% of adolescents have serious gambling problems and another 10-15% are at risk of developing them (Derevensky, Gupta & Baboushkin, 2007). Thus, the ability to correctly estimate risk and to make advantageous decisions is essential to avoid the possible negative consequences, such as financial ruin, addiction, injury, and so on, caused by risky behavior, and a better understanding of the development of adaptive decision-making skills over the lifespan is extremely helpful in order to create communication programs to prevent the above problems. Unfortunately, the developmental trajectory of the ability to deal with risk is still not well understood.

The response to risk situations changes in the course of human lifespan, even if particular attention has been devoted to adolescents, since it was documented an increase in risk-taking behaviors due to the several transformations of the brain during adolescence (Byrnes, Miller & Schafer, 1999; Kerr and Zelazo, 2004). However, recent studies highlighted different pattern of response in risky situations in contrast with previous findings about children and adolescents less risk averse than adults (Harbaugh et *al*., 2002; Levin and Hart, 2003; Levin, Weller, Pederson & Harshman, 2007; Burnett, Bault, Coricelli & Blakemore, 2010; Rakow and Rahim, 2010). Paulsen and colleagues (2011) administered a risky choice task to young children (six- to eight-years-old), adolescents (15- to 16-years-old), and young adults (18- to 32-years-old), in order to describe the developmental trajectory of human behavior in risky situations. Participants had to face different kinds of decisions: i) *Risk-Safe* choices between a safe option and a risky one with the same expected value; ii) *Risk-Risk* choices between two risky options with different expected value; iii) *Safe-Safe* choices between two safe options. The results of this study demonstrated an age effect: children were risk prone when facing a choice between a safe option and a risky one, whereas adults were risk averse in the same condition; finally, adolescents performed at an intermediate level between children and adults. The risk level, that characterized the choice situation, affected risk proneness, depending on age. In fact, children preferred to choose risky options when the level of risk increased, whereas adolescents and adults acted in the opposite way. This data may be explained by the fact that children consider the winning probability to a greater extent than the losing probability, contrary to adults.

Other studies confirmed this general pattern of a decreasing risk preference with age (Harbaugh et *al*., 2002; Levin and Hart, 2003). Weller and colleagues (2011) described the developmental trajectory of risk taking, from childhood through older adulthood, by testing 734 participants (from 5 to 85 years old) with the Cups task, which consisted of 54 trials that combined two domains (gain/loss), three levels of probability (.20/.33/.50) and three levels of outcome magnitude for the risky option (2/3/5 quarters) compared to 1 quarter for the sure option. In the gain domain, participants had to choose between a sure option, consisting of a winning of one quarter, and a risky option which provided the gain of multiple quarters or no quarters at all. In the loss domain, participants had to choose between a sure option, consisting of a loss of one quarter, and a risky option, which provided the loss of multiple quarters or no quarters. Weller and colleagues (2011) found an age effect depending on the domain: in fact, in the gain domain the preference for the risky options decreased across lifespan, whereas, it was not true in the loss domain, in which the preference for the risky option remained constant across ages. From these findings, it seemed that the sensitivity to the changes in the expected value between options increased until the elderly adult group, who exhibited some decline in performance. Finally, Weller and colleagues claimed that the ability to estimate the expected value does not appear until the mid-20s: in fact, their findings seemed to confirm that children were not able to use this factor to make their decisions.

Taken together, the above studies highlighted age-related changes in risky decision-making from early childhood to adulthood, but did not specifically investigate why children show a different decision-making behavior under risk than adults.

1.4. How children deal with risk

1.4.1 Age-related changes in children's decision-making under risk

During childhood the brain undergoes rapid transformations due to the maturation of the executive functions (EF), and increasing risk-taking behaviors (Kerr and Zelazo, 2004; Harms, Zayas, Meltzoff & Carlson, 2014). Recent findings have identified two classes of EF: (i) *cool EF*, relying on the dorsolateral prefrontal cortex, which refers to the control of thought and action under neutral situations; (ii) hot EF, relying on the orbitofrontal cortex, which refers to emotionally salient situations (Metcalfe and Mischel, 1999).

Recently, there has been growing interest in the ''*hot*'' affective aspects of EF, in particular during decision-making. The most widely used measure to assess affective decision-making involves gambling tasks, and in particular the Iowa Gambling Task (Bechara, Damasio, Damasio & Anderson, 1994). Kerr and Zelazo (2004) created an age-appropriate version of the Iowa Gambling Task, the Children's Gambling Task (CGT), to detect age-related changes between three and four years of age in the development of hot EF. The material of this task consisted of two decks of 50 cards each, that differed from each other due to the texture drawn on the surface (one was covered by vertical stripes, the other was in black dots on a white background). On the front side of each card, either happy or sad faces could appear: the number of happy faces indicated the number of rewards (M&M's) won, whereas the sad faces indicated the losses. Over trials, one deck of cards was advantageous, providing a net gain, and the other deck was disadvantageous, providing a net loss. The number of rewards won was fixed across trials, whereas the number of loss was variable. Twenty-four children between three and four years of age completed the task and the results revealed age-related changes in the ability of making advantageous choices, in fact, four year-olds performed better than three-year-olds, and their ability improved across trials contrary to three-year-old children. According to the authors, this difference could be due to three possible factors: (i) improvement in the functionality of orbitofrontal cortex (OFC) neurons over years, useful to understand the different features of the decks; (ii) immaturity of the OFC of the three-year-olds, which caused the impossibility to develop somatic markers associated with disadvantageous choices; (iii) incapacity of three-year-olds to integrate two dimensions (gains and losses) to make their decisions. Steelandt and colleagues (2013) confirmed the general improvement of rational decision making between three and eight years of age, which is consistent with the development of EF and of different brain functions involved in decision-making. In their task, children were presented with six cups containing a piece of cookie. In these cups, the cookies could be bigger, equal or smaller than the initial piece given to children. At the beginning of the trial, the experimenter showed to the child a medium-sized piece of cookie and asked her if she preferred to keep it or exchange it with one of those contained in the cups. If the child exchanged the initial item, she received the content of a random cup. According to these authors, the worse performance of three year-old children was due to a judgment error: they apparently summed up the content of all the six cups , which led to a framing effect. A framing effect refers to the impact of the frame on the subjective interpretation of information, and by frame we mean the form given to the information itself; it’s the case of a decisional situation that elicits different choices depending on whether we reasons in terms of gain or loss (Reyna and Ellis, 1994). This contrasts with the assumption of rationality, according to which preferences remain the same even if the features of a same option are differently described (Tversky and Kahneman, 1986).

Reyna and Ellis (1994) investigated the origins of framing effects and how they affect children ability to process the information linked to risky situations. They tested 111 children (aged four, eight, and eleven years old) with a spinner game consisting of two blocks of nine problems each: one block of gain frame problems and the other of loss frame problems, in which the level of reward and the level of risk were varied. The authors found that preschoolers paid attention only to quantitative information to make their decisions; thus, they systematically modulated their preferences according to the magnitude of the outcome and to the level of risk (such as in the study of Schlottmann and Anderson, 1994; Schlottmann, 2001; Levin and Hart, 2003; Levin et *al*., 2007). In contrast, older children showed a different response pattern, called “reverse framing”, in that they demonstrated greater preference for gambling in the gain than in the loss frame, contrary to adults tested in this type of task.

Bunch and colleagues (2007) explained the results obtained by Kerr and Zelazo (2004) in terms of Complexity and Cognitive Control theory (CCC theory) and in terms of Relational Complexity theory (RC theory). According to the CCC theory, the improvement of the rules integration system occurs over time, hence the lack of ability of three year-old children to coordinate the different information regarding the decks, contrary to older children. The RC theory, instead, is based on the different dimensions that characterized the decisional problems and on the relations between these dimensions, which can affect the final decisions. To test their hypothesis, Bunch and colleagues administered to 72 children, from three to five years old, the classical version of the CGT with a ternary relationship (decks, gains and losses) in addition to two less complex versions (involving a binary relationship), in which the decks differed only for the losses or only for the gains, keeping the other variable constant. The main result was that, in the ternary relationship, younger children chose less cards from the advantageous desk, but they performed successfully in the less complex version of the task. Thus, the authors addressed this result to the complexity of the task rather than to the lack of development of somatic marker (contrary to what reported by Kerr and Zelazo, 2004). The performance of four-year-old children was at an intermediate level; however, analyzing their individual scores, a great heterogeneity emerged. Finally, five year-old children demonstrated to be able to succeed even in the most complex task. Andrews and Moussaumai (2015) drawn the same conclusion, demonstrating the importance of the knowledge of the task and the training on the simpler binary relationship versions on the ability of performing successfully in the ternary relationship version of CGT. The importance of experience was also discussed by Garon and Moore (2004), which confirmed the main effect of age, by demonstrating that six year-olds performed better, showing a larger number of advantageous choices in the CGT, than the younger groups. This study also highlighted that children with greater experience in the task achieved an even better performance within their age groups (this evidence was further confirmed by the same authors later on; Garon and Moore, 2007).

Other authors examined the role of complexity of learning the gain/loss schedule, that is, the ability to anticipate future outcomes (Crone et *al.*, 2005, 2007; Gao et *al.*, 2009), drawing the same results of Kerr and Zelazo (2004) and Bunch and colleagues (2007) regarding the rapid development of affective decision making between three and four years of age. Crone and colleagues (2005; 2007) tested children with a gambling task, the “Hungry Donkey Task” (HDT), which required a choice between four doors on a computer screen. Behind each door there was a variable number of apples to feed a hungry donkey; children could choose to open one of the four doors with the goal of winning as many apples for the donkey as possible. Two doors (A and B) were disadvantageous over time, providing respectively frequent small losses and infrequent large losses; the remaining doors (C and D) were advantageous over time, yielding respectively frequent tiny losses and infrequent small losses. Their findings demonstrated that the frequency of punishments played a key role in children’s decision making under uncertainty, depending on age: in fact, young children chose advantageously if punishments were frequent, rather than when they were unpredictable and infrequent and overall, preschoolers could hardly calculate exact net gains and losses under uncertainty, since the punishment magnitudes were variable across trials. Thus, these authors claimed that the reason of poor performances in a gambling task was the insensitivity to future outcomes rather than the task complexity, as claimed in previous study (Bunch et *al*., 2007; Andrews and Moussaunami, 2015; Garon and Moore, 2004, 2007) .

In order to clarify developmental changes in the ability to consider both frequency of losses and the final outcome in decision making under risk, Aite and colleagues (2012) administered the Soochow Gambling Task (SGT) (that required the choice between four decks of cards, two disadvantageous, two advantageous) to three different groups: children from seven to nine years of age, adolescents of 12 and 13 years of age and adults from 18 to 32 years of age. The authors found that all participants preferred decks with infrequent punishments, but only adults were able to integrate this information about the frequency of punishments with the final outcome; furthermore, adults implemented the win–stay/loss–stay strategy more frequently than children and adolescents, when switching between decks. Children and adolescents seemed to consider only the frequency of the punishments to make their decisions, showing difficulties in making advantageous choices by preferring the decks associated with infrequent losses even if they led to a worse final outcome.

Analyzing the switching behavior, adults switched their choices less frequently after losses than children and adolescents, thus this study showed a direct connection between shifts and advantageous choices. The loss-stay strategy adopted by adults was interpreted by the authors as a tolerance to loss, which could help them to learn faster the features of each option.

Along these lines, Mazur and Kahlbaugh (2012) examined preschoolers' response patterns and strategies, comparing their performance in the Monty Hall Dilemma to those of adult humans and pigeons. Seventeen preschoolers, between 37 and 57 months of age, were presented with the Monty Hall dilemma on a laptop computer in which the bottom portion of the screen was divided into three "doors". When children chose a door, a happy picture, corresponding to a winning reward or a unhappy picture, corresponding to a loss, could appear. There was evidence that, overall, preschoolers adopted a sort of strategy, although it did not turn out successful. Only 31% of the sample exhibited the capacity to switch throughout the experiment, the remaining participants adopted a constant strategy (staying or switching strategies) from the beginning to the end of the experiment, nevertheless the condition of the task.

1.4.2 Neural bases of children's decision-making under risk

Age-related differences in adaptive decision making could be explained by research in developmental neuropsychology, which suggests that during childhood and adolescence there are pronounced changes in patterns of decision making associated with functional maturation of the prefrontal cortex, which is presumed to be the latest to mature (Luna and Sweeney, 2001). According to this research perspective, impaired decision making may be due to an immaturity of the ventromedial prefrontal cortex (VMPC); in fact, individuals with bilateral VMPC lesions demonstrated a pattern of non-adaptive decision making, taking risks without considering EV differences in gambling tasks (Weller, Levin & Denburg, 2011). Crone and van der Molen (2004) demonstrated that young children show a similar pattern of choice, in fact, as ventromedial prefrontal patients seemed to be unable to anticipate future outcomes. In the following years, the same authors wanted to replicate their experiment with three age groups (children aged 8-10 years, children aged 12-14 years and adolescents aged 16-18 years), who performed the Hungry Donkey Task, while their heart rate and skin conductance changes were recorded (Crone and van der Molen 2007). Analyzing these physiological aspects, it was demonstrated that, overall, heart rate slowed and skin conductance raised while experiencing a loss, but only the younger group (8-10 year-old children) failed to make advantageous choices, and this was also true for patients with VMPFC damage (Bechara, Tranel, Damasio & Damasio, 1996).

Other authors (Van Leijenhorst, Crone & Bunge, 2006; Carlson, Zayas & Guthormsen, 2009; Paulsen, McKell Carter, Platt, Huettel & Brannon, 2012; Van Duijvenvoorde, et *al*., 2015) attempted to identify brain areas involved in the emotional and cognitive components of adaptive decision-making. According to these studies, the development of these areas could be at the basis of the risk-averse behavior. In adults, orbitofrontal cortex (OFC), posterior parietal cortex (PPC), ventral striatum (vSTR), anterior insula and amygdala have been identified as the fundamental regions for understanding all the aspects that characterized the decisional problem in risky situations, i.e. expected values and probabilities (reviewed in Platt and Huettel, 2008). Paulsen and colleagues (2012) tried to replicate their previous findings (Paulsen, Platt, Huettel & Brannon, 2011), including a new analysis, investigating brain areas differently involved in children and adult decision-making. In this study, 17 children (five-eight years old), 17 adolescents (14-16 years old) and 16 adults (18-35 years old) were tested in a risky-decision task during functional magnetic resonance imaging data acquisition, that detected an increasing activation with age in some areas of prefrontal and parietal cortex, during decision-making under risk. Frontal regions that showed increasing activation with age were anterior insula, vmPFC, anterior cingulate, frontal pole, OFC, amygdala and hippocampus; however, considering only the safe bet trial there was not a difference between children and adults. Furthermore, the authors detected differences in the activation of the different areas between sure bet and risky bet: during the risky bet trial the activation of anterior cingulate cortex, vmPFC, caudate and OFC was correlated with risk aversion, whereas the same result was not found in the sure bet trial. Additional knowledge about the neural areas underlying developmental changes in decision-making is provided by the study of van Leijenhorst and colleagues (2006), comparing performances of 9-12 year-olds and young adults in a gambling task, focusing their attention on two important dimension: risk estimation and feedback processing. The authors analyzed the activation of different brain regions regarding these two aspects of the decision-making: orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), and midbrain for risk estimation; ventrolateral prefrontal cortex (VLPFC) and medial prefrontal cortex (PFC) for feedback processing. If it is true that these regions of interest showed different patterns of activation between adults and children, the same cannot be said if analyzing the data concerning the whole brain, which did not detected any difference depending on age, regarding the risk estimation and feedback processing For both risk anticipation and negative feedback processing, ACC and lateral OFC were more engaged in children than in adults, demonstrating that children had more difficulties to make their decision under risk than adults. The different activation of the brain regions involved, in particular the lateral OFC and ACC, provides new evidence in favor of the important role that these different processes play in the development of decision-making over childhood.

So far, from neuropsychological data it seems that children perform gambling tasks similarly to patients with VMPC lesions; in this scenario, the only exception is represented by the study of Carlson and colleagues (2009). They investigated individual differences in affective decision-making, by taking into account another electrophysiological correlate of children's performance on a gambling task (HDT), the Event Related Potential (ERP). Specifically, they considered the P300 component (which is the focus of the analysis of feedback effects) and SPN, i.e., the stimulus-preceding negativity (which is sensitive to reward or punishment properties of an anticipated outcome). They found that children had difficulty in making advantageous decisions, as expected (Crone and van der Molen, 2004, 2007; Crone et *al*., 2005), but contrary to their previous study (Crone and van der Molen, 2007) they noticed that 8-year-old participants improved their performance across trials. Despite this improvement, children's choices were influenced by information about the frequency of punishments (in line with previously discussed research): they significantly preferred the infrequent-punishment options, contrary to adult VMPFC patients, who chose most often the disadvantageous options, which yielded to the larger immediate rewards.

A recent study (van Duijvenvoorde et *al*., 2015) is worth of particular mention for its original approach to the investigation of the processes underlying risky choices over development, by applying a risk-return model to the risky choices of children, adolescents and adults in a fMRI-compatible version of the Columbia Card Task (CCT). According to the authors "*this approach allowed to decompose risky decisions into their constituent features, to isolate and identify which of them, in particular, drives the decisions of children and adolescents at the behavioral level, and to understand how the developing brain is involved in this process*". Eight 11 year-old children, 16–19 year-old adolescents, and 25–34 year-old adults were presented with fMRI-adjusted version of the CCT, that consisted of several trials, which required a series of decisions about turning over cards (that could provide both losses or gains). The task ended when the participant decided to stop turning over cards or she turned over a loss card, which led to reset her amount. In different trials, the probability and amounts of gain and loss were manipulated. In addition, the participants were required to accomplish the behavioral risk–return decomposition, that estimated the expected value and the effect of risk on the decision to take or to stop taking a card. Furthermore, imaging acquisition was registered across trials. At the neural level, there were noted activations in the thalamus, anterior insula, dmPFC, and lateral PFC, corresponding to changes in risky behavior. In addition, van Duijvenvoorde and colleagues (2015) highlighted substantial differences between individuals, particularly children and adolescents, confirming some previous evidences regarding a peak in early or late adolescent risk taking (Burnett et *al*., 2010), in contrast with other authors that observed decreasing risk-taking levels from childhood to adulthood (Levin and Hart, 2003; Levin et *al*., 2007). This finding, and the multidisciplinary approach proposed by van Duijvenvoorde and colleagues (2015), could provide the basis for future studies on the development of risky decision making.

1.4.3. Cognitive components underlying children's risk propensity

All the above studies considered the age-related changes in decision-making under risk as a general index of both the maturation of executive functions and the development of decision-making neural circuits that occur in the preschool years. Nevertheless, it is still unclear which are the cognitive components that may affect the development of risk propensity. Recently, some authors tried to address this issue by focusing on several cognitive structures, such as working memory, inhibitory control and attentive processes (Garon and Moore, 2007; Heilman, Miu & Benga, 2009; Smith, Xiao & Bechara, 2012; Van Dujvenvoorde, Jansen, Bredman & Huizenga, 2012; Mata, Sallum, Miranda, Bechara, Malloy-Diniz, 2013; Beitz, Salthouse, Davis, 2014; Harms et *al*., 2014; Audusseau & Juhel, 2015). All these studies confirmed the rapid development in affective decision-making between three and four years of age, but not all authors agree on which cognitive components underlie this process.

Garon and Moore (2007) found developmental changes in future-oriented decision making from 3.5 to 4.5 years of age in a gambling task and in a delay of gratification task. These authors found a correlation between the performances in the two tasks only for 3.5-year-old children. These children, contrary to the 4.5-year-olds, needed reminders about the features of each decks, perhaps due to a limitation in working memory. However, when they received this information, they performed similar to 4.5 year-olds.

Memory was considered an important factor in the developmental improvement of advantageous decision-making by other authors as Hongwanishkul and colleagues (2005), Van Duijvenvoorde and colleagues (2012) and Audusseau and Juhel (2015). In a wider study about the development of executive functions, Hongwanishkul and colleagues (2005) administered to 98 children, from 3 to 5.9 years of age, several tasks to assess the *cool* and *hot* aspects of the executive functions. Their results confirmed the rapid changes during the preschool years in both hot and cool aspects; moreover, there was a positive correlation between performance in a memory task, The Self-Ordered Pointed task (SOPT) (Petrides and Milner, 1982), and in the CGT.

Van Duijvenvoorde and colleagues (2012) compared decision making between a standard, non-informed condition and a new, informed condition, in which explicit information on the choice properties was presented. Two hundred and ninety-three children (ages 7–9, ages 9–11, and ages 11–13), adolescents (ages 12–14 and 14–17), and young adults (ages 18–29) were presented with a modified version of the Iowa Gambling Task, in two versions: (i) a non-informed condition, in which no information on the choice properties was presented, and (ii) an informed condition, in which all the information about gains, losses and probabilities was given to the participants. The results showed that decreasing the load on long-term and working memory highly influenced children's ability to decide advantageously; in fact, children's advantageous choices significantly improved in the informed compared to the non-informed condition. This finding indicated that both long-term memory and working memory are important factors underlying the development of advantageous decision making. However, it is important to note that other processes, such as inhibitory control (as described by Heilman et *al*., 2009), not only long-term and working memory, could intervene in this kind of situations.

Audusseau and Juhel (2015) drew the same conclusions: the efficiency of children's working memory is a prerequisite for making advantageous choices in uncertain situations. In their study, participants were required to complete two tasks: the CGT (Kerr and Zelazo, 2004) and The

Self-Ordered Pointed task (SOPT) (Petrides and Milner, 1982) to measure the efficiency of executive working memory. The results showed that the acquisition speed was inferior for the participants, who had to carry out a secondary task in addition to the CGT, compared to the control group, and overall, children who completed the secondary task performed lower than participants tested in the control condition. Furthermore, children who showed a higher efficiency in working memory were the ones who acquired more rapidly an adaptive choice behavior. The speed of acquisition of the adaptive choice behavior depended on children's age group: older groups showed a significantly higher speed of acquisition compared to the younger ones. Finally, age affected also the entire performance, in fact, younger children were less likely to choose from the advantageous deck than the older children.

In the attempt of examining the effects of cognitive processes (i.e., shifting, inhibition, working memory, fluid reasoning, processing speed, language, intelligence, attentive processes) on decision-making under risk, different authors (Heilman et *al*., 2009; Smith et *al*., 2012; Mata et *al*., 2013; Beitz et *al*., 2014; Harms et *al*., 2014) provided evidence in contrast to the findings reported above. In addition to a gambling task, these authors administered batteries of tests to participants, including the Raven's Coloured Progressive Matrices Test (Raven, Raven and Court 1998) and the Repetition and Comprehension of Instructions subtests from the Romanian version of NEPSY (Korkman, Kirk & Kamp 1998) to assess inductive reasoning, working memory and language development (in Heilman et *al*., 2009), the Wechsler Abbreviated Scale of Intelligence (Wechsler 1999), the Wisconsin Card Sorting Task (Grant & Berg 1948) to assess set shifting, the TMT-B (Reitan 1971) to measure speed of processing and attention, the above-mentioned SOPT (Petrides & Milner 1982) to assess the capacity for response inhibition and working memory load, the Conner's Continuous Performance Test (Conners, 2002), a go/no go task used to measure motor inhibition/impulsivity and sustained attention (in Smith et *al*., 2012), the Columbia Mental Maturity Scale (Burgemeister, Blum & Lorge 1972) to assess the general reasoning ability (in Mata et *al*., 2013), the Attention Network Task (McCandliss, Sommer, Raz & Posner 2002) to evaluate the efficiency and independence of attentional networks, the Dimensional Change Cart Sort (Kirkham, Cruess & Diamond 2003) to measure set shifting (in Harms et *al*., 2014), the Matrix Reasoning, a shortened version of the Wechsler Adult Intelligence Scale-Third Edition (Wechsler, 1997), the Wisconsin Card Sorting Task, the classical Stroop Task (Stroop, 1935), and the N-back Task (Kirchner 1958) to assess working memory updating (in Beitz et *al*., 2014).

All these studies confirmed previous findings about the improvement of decision-making in risky situations during development, but none of them found any correlation between the measures evaluated and the performance on the gambling task. Among these studies, the work by Beitz and colleagues (2014) is especially interesting for its attempt to describe differences in affective decision-making throughout lifespan, from five to 89 years of age. The results of this study confirmed that IGT performance increased from childhood to adulthood and underwent a decline in old age. Moreover, children showed different pattern of response compared to adolescents and adults: (i) children and adolescents seemed to be more impulsive than adults; in fact the latter demonstrated to be able to consider both loss and gains to make their choices; (ii) children preferred high net outcome less than young and middle-aged adults and low frequency decks less than middle-aged and older adults. Finally, the results of this study were in contrast to the already discussed study by Bunch and colleagues (2007), in fact, Beitz and colleagues (2014) did not attribute the same importance to the loss frequency regarding children's preferences in risky situations.

1.4.4. Expected value and probability understanding in risky situations

The expected value (i.e., the product between the amount of an option and the probability of getting it) and probability understanding are prerogatives to deal with risky decisions and it is still debated by researchers when these abilities emerge in the human development and whether a poor performance on gambling tasks may be due to a lack of understanding of the above aspects (as claimed by Steelandt et *al*., 2013). To date, the scenario seems heterogeneous and full of contrasting elements. Schlottmann and Anderson (1994) and Schlottmann (2001) provided evidence in favor of a functional understanding of probability and expected value in young children. Schlottmann and Anderson (1994) tested the understanding of the concept of expected value with a Roulette Type Spinner game, which provided a reward only if the spinner stopped on the red sector of a circular disk. To accomplish this type of task, the use of a multiplication rule was necessary, in order to integrate probability and value of the reward. However, this rule is not expected to emerge before 7 or 8 years of age, therefore younger children have to implement different strategies to make their decisions. In addition, the authors proposed a more complex version of this task, called the two-prize game, in which two different prizes were foreseen for both red and blue sectors, increasing the difficulty to integrate the probability and the value for each outcome.

Schlottmann and Anderson (1994) found a clear evidence of an understanding of the expected value and probabilistic foundations by the age of eight years old; nevertheless, the youngest children showed the ability to consider both prize and probability to make their choices. To sum up, the authors claimed that children are able to reason in a probabilistic way, in particular, in their study, the three older age groups followed the multiplication rule, whereas the younger children used an addition rule to complete task. In 2001, Schlottmann confirmed her previous results, contributing to the growing evidence for children's intuitive reasoning competence.

A year later, Harbaugh and colleagues (2002) tried to explain the risk attitude in terms of the Cumulative Prospect Theory, according to which the value of a gamble is determined by individually weighted probabilities and values. Assuming that people tend to be risk-averse for gain and risk-prone for losses, Harbaugh and colleagues (2002) investigated how people react to variation of probability. Participants from age five to 64 were presented 14 free choices between a simple gamble and a certain outcome with real and salient payoff (tokens for children, which could be used to buy toys and games, and money for teenagers and adults). The experimenter gave children 50 tokens and told them that they could lose or win some during the task, by choosing a series of cards, with the probabilities for the gamble depicted on them. Participants, and especially children, deviated from the Cumulative Prospect Theory model and their risky choices increased with probability of winning and decreased with probability of losing, compared to adults. These findings demonstrate that children clearly used probability weights to make their decisions.

The above studies showed that children as young as four years of age are able to make inferences on basic probabilistic reasoning problems and are capable of engaging in probability calculations in simple tasks. In this scenario, a study by Denison and Xu (2014) is worth of a special mention: they aimed to evaluate if even infants under one year of age are able to use probabilities to guide their action and reach their targets. They tested 24 10- to 12-month-old infants in four experiments, in which participants were shown an attractive object and an unattractive one; to assess infant's favorite object, the authors noted the first one to which the infant crawled. These object were contained in jars, which were covered while the experimenter randomly removed one object from each jar, hidden from infant eyes. The goal of this task was to evaluate if infants were able to understand which jar was more likely to provide the favorite object. Four experiments were performed. In Experiment 1, infants saw populations of 12 attractive to four unattractive objects versus 12 attractive to 36 unattractive objects, so there was an equal number of attractive objects in each population, but a different probability of obtaining them. In Experiment 2, attractive objects were more numerous in the less probable population. In Experiment 3, the authors investigated the heuristic used by children to make their inferences, analyzing how they consider the quantity of the unattractive objects compared to the proportions of attractive objects. In this experiment, infants had to choose between a sample from one of two populations with three types of objects: attractive, unattractive and neutral. Finally, Experiment 4 tested the level of sophistication in infants' probability reasoning, by proposing two jars, one containing a population of 60 attractive and 15 neutral objects and the other containing population of 60 attractive and 40 neutral objects. Overall, the results of the four experiments showed that infants (i) used proportions to predict outcome of random event, (ii) were able to use proportions of attractive objects to guide their prediction and action, (iii) attempted to obtain a preferred object, rather than to avoid a not-preferred object, and, finally, (iv) provided evidence for probabilistic reasoning based on proportions, by searching the favorite object in the sample from the 60:15 population, and not in the sample from the largest population. Overall, this study highlight important abilities of infants below 12 months of age to make rudimental probabilistic inference to fulfil their goals even in uncertain situations.

Contrary to previous findings (Schlottmann and Anderson,1994; Schlottmann, 2001), Levin and colleagues (2007) showed that young children (aged five to seven years old) were significantly less responsive to expected value differences than their parents and older children (aged eight to 11 years old), by making more risky choices when they were disadvantageous. In this study, the youngest age group was less able to consider EV differences between the options than adults, both in gain and loss domains. Although earlier studies (Harbaugh et *al.*, 2002; Schlottmann and Anderson, 1994; Schlottmann, 2001) demonstrated that young children could consider both probability and outcome information in making risky choices, Levin and colleagues (2007) demonstrated that children were not able to make advantageous choices due to their inability to understand changes in probability.

1.4.5 Gender differences in children's decision-making in risky situations

The pioneering study by Slovic (1966) aimed to identify gender differences on children's risky decision-making task. The task, proposed to children, consisted in a panel of 10 small switches, nine of which were "safe", providing one spoonful of M&M's candies, whereas the tenth was a "disaster" switch, which could cause the loss of all the candies already won. Children (1047 volunteer participants, aged six to 16) were asked to pull one of the switches and to decide whether to pull another switch or to stop and keep the rewards earned. The results showed a significant difference between girls and boys by the age of 11, when girls seemed to be more cautious than boys, and performed better by making more advantageous choices than boys. However, this study had one severe limitation about participants, who were only those children who volunteered to play a risk-taking game, although it had the merit to introduce the debate on gender influences on children's decisions.

Garon and Moore (2004) showed a better performance in female children: in their study, female participants (three-four-six years old) chose more frequently from the advantageous decks and were more aware of the task than their male peers; thus, they seemed driven by a conscious knowledge and were more sensitive to frequent loss phenomena than males, as in Carlson and colleagues (2009) and van Duijevenvoorde and colleagues (2012). Bunch and colleagues (2007) and Heilman and colleagues (2009) found the same better performance of female children only when they were three-years old. In contrast, Gao and colleagues (2009) found a better performance of male children (three-four-five years old) in terms of more advantageous choices. This result is consistent with previous findings obtained by Kerr and Zelazo (2004), Crone and colleagues (2005) and Crone and van der Molen (2007). Finally, Aite and colleagues (2012) and Mata and colleagues (2013) did not reveal any significant gender differences in affective decision-making tasks.

1.4.6. Children's decision-making under risk in clinical populations

Clinical studies on children's decision-making has mainly focused on attention deficit and hyperactivity disorder (ADHD) populations. ADHD is a severe developmental disorder, characterized by a persistent pattern of inattention and/or hyperactivity-impulsivity that negatively impacts on social, academic or occupational functioning (DSM-V, 2013). It is also defined by an abnormal sensitivity to reinforcement and a diminished sensitivity to negative outcomes. On these basis, some authors (Geurts, van der Oord & Crone, 2006; Garon, Moore & Waschbusch, 2006; Luman, Oosterlaan, Knol & Sergeant, 2008; Masunami, Okazaki & Maekawa, 2009; Gong et *al*., 2014) tried to identify differences between ADHD children and typically developing children in tasks requiring decision-making in uncertain situations. Assuming that children with ADHD have less sensitivity to unfavorable outcomes, they prefer immediate gratification and they have high sensitivity to rewards, then they should choose more the disadvantageous option than the advantageous one, compared to the control groups, and their decisions should be guided by the rewards' information.

Overall, with the only exception of the study by Geurts and colleagues (2006), children with ADHD are less sensitive to rewards and punishments, which lead them to implement dysfunctional decision making strategies (Masunami et *al*., 2009). In particular, when the magnitude and frequency of rewards and punishments were manipulated, ADHD children presented different patterns of response than control peers. Luman and colleagues (2008) proved that ADHD children paid more attention to the frequency of the punishments rather than their magnitude and the future consequences of their choices. Overall, all sample, control group and ADHD children, improved its performance throughout the task. These authors also examined heart rate (HR) and skin conductance (SC) responses to reinforcement, to detect whether impaired decision-making may be explained by different psychophysiological responses to penalty and rewards. The results showed that ADHD children exhibited a dysfunctional SC patterns and their HR accelerated more than in controls following a reinforcement.

In contrast, Geurts and colleagues (2006) did not find any difference between children with ADHD and typically developing children in response strategy and reward sensitivity during decision-making. In this study, all children improved their ability to make advantageous choices during the task and this capacity was evident in the reversed version of the Hungry Donkey task, in which children received only punishments in the first two trials, which allowed children to discriminate the options faster than in the classical version. Considering the frequency, children seemed to make more advantageous choices when the punishments and the rewards were more frequent. In the classic version of the task, all children preferred the options associated with infrequent punishments even if larger, whereas on the reversed task they chose more the options associated with more frequent, but small, rewards. The only difference between the two groups concerned the number of switches in the standard gambling task, in which ADHD children made less switches than controls. Furthermore, Geurts and colleagues (2006) did not find any correlation between ADHD children's performance in this task and inhibitory control deficits, which is consistent with previously described studies (Heilman et *al*., 2009; Smith et *al*., 2012; Mata et *al*., 2013; Harms et *al*., 2014; Beitz et *al*., 2014). Within the ADHD population some differences were found: (i) ADHD children with anxiety/depression show the same pattern of response of typically developing children; (ii) ADHD-alone children demonstrated impaired performances, no form of improvement and had lower awareness of the game (evaluated by an awareness test, consisting in four questions about the features of the decks) than control children and ADHD-anxiety/depression groups. The authors addressed this result to two possible reason: (i) more responsiveness to loss by children with internalizing disorders; (ii) high level of anxiety could help children to discriminate faster which decks were advantageous or disadvantageous (Garon et *al*., 2006; Masunami et *al*., 2009).

Gong and colleagues (2014) investigated, for the first time, two brain signals, Feedback-Related Negativity (FRN) and Late Positive Potential (LPP) depending on the effect of reward or punishment and punishment magnitude (small vs. large). The participants were divided in three groups: ADHD-Combined (ADHD-C) and ADHD-Inattentive (ADHD-I), and typically developing children (TD), and they all completed the Children's Gambling Task. This study revealed that the FRN signal increased in case of large losses compared to small losses and gains, only in TD and ADHD-C children, but not ADHD-I children. This result demonstrated that these children were highly influenced by external negative feedbacks. Furthermore, TD and ADHD-C children shared another characteristic: in fact, they resulted more sensitive to the punishments and their magnitude than the ADHD-I children.

1.5 Conclusion

From the above literature review it emerges that different authors approached the study of the mechanisms underlying risk propensity by using different methodologies, often achieving conflicting results and diverging conclusions. Thus, the analysis of the literature carried out in the previous paragraphs does not provide definitive answers to all questions, but it stresses two key points in the study of human decision making under risk: (i) risk propensity is not a stable trait, but evolves from childhood to adulthood, (ii) the maturation of executive functions and emotional regulation may decrease risk-taking behaviors.

The above findings suggest that the construct of risk propensity is multifaceted and multi-determined and thus it is impossible to pinpoint a single factor as the causal factor. Moreover, the mechanisms underlying this construct are not yet well defined, given the multiplicity of theoretical and methodological approaches that have tried to answer this question.

The above heterogeneous scenario and the difficulty in the interpretation of the empirical data reviewed are partly due to the lack of a general theoretical account to which the various studies can refer, since different theorists provided different models of decision-making under uncertainty (see paragraph 1.2), and it is still unclear which one is the most suitable to describe this process. The classical duality between the *Expected Utility Theory* (EUT) and the *Prospect Theory* (PT) must be overcome in favor of a model that allows the co-existence of the different theories, in order to explain the heterogeneity in responses and to identify which people behave according to what theory and in which circumstances. Harrison and Rutstrom (2009) satisfied this need, by proposing a mixed model which permits the co-existence of each theory.

These authors demonstrated that both theories, EUT and PT, contribute to the decision process, thus, it is impossible to identify the factors, of one or the other theory, that characterize the choice behavior under risk. This statistical framework could represent the potential bridge between economy and psychology, and to prove that, Andersen and colleagues (2010) proposed the *SP/A model.* The SP part is referred to the process implemented by the decision-maker of evaluating the security and the potential of a lottery, which is identical to the RDEV principle reviewed earlier (see paragraph 1.2.2). In contrast, the A part regards the “aspirations” of the agent of the choice. Applying this conceptualization to the famous game show *Deal or no Deal*, Andersen and colleagues (2006) demonstrated which components of the model explained participants’ responses (the A part was predominant over the SP part) and their trend during the game, according to different game situations. In 2008, Andersen and colleagues replicated their results, carrying evidence in favor of a greater weight attributed to the A criterion and, at the same time, of the implementation of both parts.

In light of this new theoretical and statistical structure, the studies reported above could be reviewed and replicated.

The empirical data reviewed in the previous paragraphs have the undeniable value to shed light on the development and on the difficulties to study risk propensity in children. However, this argument remains an open issue and, for this reason, it is important to continue to explore this topic from early childhood in order to understand the ontogeny of human decision-making. All the open questions could represent the basis for future research, hopefully guided by a unique theoretical structure, which takes into account the various theories without considering them in opposition to each other, with the final aim of identifying the latent processes of decision-making under risk and achieving solid results.

Chapter Two - Emotional aspects of risky decision-making

2.1 The role of emotions in the decision-making

Traditionally, in the research on risk proneness, several authors focused their attention on the cognitive components, that drive and influence individual choices in contexts where individuals are asked to choose between a safe and a risky option, neglecting the role that emotions play in this process. However, the relationship between emotion and decision-making in risky contexts is not negligible and it can be investigated according to two different perspectives. As Schwarz (2000) states, the relationship between decision-making and emotion is pre-eminent and bi-directional: the positive or negative outcome of a decision can profoundly affect the feelings of the decision-maker and his ability to choose.

Some researchers analyzed how emotional reactions to past experiences influence the occurrence of potentially risky behaviors (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Damasio & Lee, 1999; Bechara, Damasio, Tranel & Damasio, 2005; Damasio, 1994). According to these authors, the risk of carrying out potentially harmful behaviors is higher in individuals who have previously experienced positive emotions following a choice with an uncertain outcome than those who, in the same situation, have experienced negative emotions. Damasio (1994) and Bechara and colleagues (1999; 2000) proposed the somatic marker hypothesis to support the idea that the positive or negative consequences, experienced in the past, affect decision-making in risky situations. According to this hypothesis, the inability to recall the emotions experienced in the past determines the incapability to make favorable choices in risky conditions. Bechara and colleagues (1994; 1999; 2000; 2005) tested this hypothesis by using the experimental protocol of the "Iowa Gambling Task".

The results of this experiment showed that the control group of adult participants preferred the advantageous decks, probably driven by negative emotions resulting from the large losses associated with the choice of risky cards. Conversely, participants with injuries in the brain areas underlying emotional processes (amygdala and prefrontal ventromedial cortex), significantly preferred cards of the disadvantageous deck. The fact that the latter did not have cognitive deficits and were, from this point of view, quite similar to the participants of the control group, supported the hypothesis that emotional processes underlie risky decisions.

The second research perspective investigates the role of emotional dysregulation, with particular reference to high levels of impulsivity and anger, in taking on risky behaviors (Cauffman & Steinberg, 2000; Cooper, Wood, Orcutt & Albino, 2003; Eisenberg et *al*., 2001; Silk, Steinberg, & Morris, 2003; Steinberg & Scott, 2003). The focus of these authors is often on the relationship between emotional regulation and impulsivity, defined as the inability to inhibit a dominant response while pursuing a cognitively relevant goal (Rothbart & Bates, 1998). It was observed that children with more inhibitory and self-control abilities seem to become adolescents and adults with high social and academic skills, capable of delaying gratification and tolerating frustrations (Metcalfe & Mischel, 1999; Mischel & Mischel, 1983; Mischel, Shoda, & Peake, 1988; Mischel, Shoda, & Rodriguez, 1989; Sethi, Mischel, Aber, Shoda & Rodriguez, 2000); on the contrary, high levels of impulsivity are associated with risky behaviors, external behavioral disorders and antisocial behavior (Miller & Byrnes, 1997; Eisenberg et *al*., 2001; Cauffman & Steinberg, 2000; Steinberg, 2004; Cooper, Agocha & Sheldon, 2000; Cooper et *al*., 2003). In this scenario, Cooper and colleagues (2000; 2003) tried to create a bridge between the two above-mentioned research perspectives. Through self-report questionnaires administered to 1666 young adults between the ages of 18 and 25, these authors demonstrated that the desire to avoid negative emotions experienced in the past, as well as impulsivity and personality factors, such as extroversion and neuroticism, are involved in decision-making in risk situations.

2.3 Social and emotional influences on children's decision making under risk

In adult humans, decisions under risk are affected by several external and internal factors, such as the context of the choice and the emotions associated with decisions, but it is still not clear which are the situational and dispositional characteristics that may predict and affect children's behavior.

Miller and Byrnes (1997) tested the self-regulation model (SRM) of risk taking. According to SRM, the factors associated with a risk-taking behavior were overconfidence, impulsivity, peer influences and insensitivity to outcomes. In their study, the authors performed two experiments, to evaluate the effect of different factors on children's decision-making under risk. In the first experiment, they manipulated two contextual factors (presence versus absence of peers and content of the task: one task involved math and physical skills, whereas the other involved probability) and examined the role of six personal factors (age, gender, impulsivity, self-sufficiency, fear of failure, child's assessment of her own ability). Usually, these factors have different weights according to age and gender. Regarding gender, some differences emerged: boys, in the peer-absent condition, showed greater risk taking correlated with higher impulsivity and lower anxiety, whereas girls, in the same condition, resulted less impulsive and more reflective, and, overall, peers' presence influenced children's choices. Furthermore, boys who were more self-sufficient took more risks, contrary to girls. In the second experiment, children were given four new skill tasks (spelling, basketball, and two social skill tasks) and two new probabilistic tasks, and, again, the effects of gender and age were investigated. In addition, the authors examined the role of other factors, that could be possibly correlated with risk taking: interest, beliefs about the desirability of success on a task, beliefs about the aversion to failure on a task, and the role of sensation seeking. In this second experiment, the only difference emerged in the basketball and dice tasks, in which boys performed better than girls; in the other cases, this gender difference was not significant. For the probabilistic tasks, an age-related difference emerged: 11-12 year-old children selected the riskiest option more than the 9-10 year-olds. The risky preferences were significant correlated with some personal traits measured in the skill tasks, such as higher ratings of ability, competitiveness, interest in thrill and adventure seeking, whereas these correlations were not so strong in the two probabilistic tasks. Furthermore, interests and ability beliefs resulted correlated with each other, as well as being correlated with risk-taking. In summary, this study revealed that gender, ability beliefs, interest, thrill, adventure seeking, and peer presence were significant predictors of risk taking, demonstrating that this is a multifaceted construct that cannot be explained by a single factor.

A longitudinal study of Levin and colleagues (2007) has contributed to increasing the knowledge about the role of situational factors and has helped to individuate what personal characteristics may predict and reveal decision-making processes over development. Participants were child–parent pairs (children were six-eight years old) who performed the risky decision-making task described by Levin and Hart (2003). In this previous study, (i) children were more risk prone than their parents, (ii) both children and parents preferred the risky option to avoid losses than to get gains, (iii) children were more risk prone if their parents were too, (iv) personality traits, such as shyness and impulsivity, could predict children's decision-making under risk. Based on these results, Levin and colleagues (2007) tested the same children, aged 9–11 years old, and their parents in the same risky decision-making task to evaluate the stability of their decisions. Longitudinal data revealed that children were more risk prone than adults, as previous findings, and, the data detected in the first experiment resulted predictive of the choice behavior expressed three years later. The results of this study are important to understand which characteristics could predict and affect choices and to lay the basis for future research aimed at investigating which components of decision-making emerge at an early age.

Vitaro and Wanner (2011) investigated whether low anxiety/low inhibitory control could predict early engagement in gambling activities more than disinhibition/high impulsivity. In addition, the authors evaluated the role of parent gambling on their children's risk taking behavior.

Participants in this study were children aged six, seven and eight years old, who were tested again when they were 10 years old, their parents and teachers. Children completed a self-report questionnaire to assess their involvement in gambling problems and K – ABC by Cahan and Noyman (2001), an intelligence test. Parents were administrated the South Oaks Gambling Screen by Lesieur and Blume (1987), which investigated their participation in gambling activities. Finally, teachers were administered the Child Social Behavior Questionnaire by Tremblay, Vitaro, Gagnon, Piche´ and Royer (1991) in order to measure anxiety and impulsivity of their pupils. Results showed that impulsivity predict early gambling already by the age of 10 for both genders, whereas a low level of anxiety predicted early gambling, but only in boys. The authors found interesting results about the lack of a link between anxiety and impulsivity, and, surprisingly, they did not found a correlation between parents' gambling and children's involvement in gambling activities, neither an interaction with children's dispositional traits. Although in this study only impulsivity and anxiety are taken into account as dimensions affecting risky decision making (ignoring other possible relevant variables), and it has been used only an abbreviated scale to assess parent gambling problems, these findings are important for promoting prevention programs focusing on children's personal dispositions and parent gambling.

Some authors (O'Connor, McCormack & Feeney, 2012; Weisberg and Beck, 2011; O'Connor, McCormack & Feeney, 2014; O'Connor, McCormack, Beck & Feeney, 2015) investigated how experiencing regret affects and leads children to adaptive decision-making in uncertainty situations. O'Connor and colleagues (2012) presented children (four to nine years old) with a choice between two boxes in two conditions: (i) in regret trials, children always received the less attractive prize, (ii) in the baseline trial, both prizes were equally attractive. After receiving the prize, children had to rate their feelings on a 5-point scale, then they saw the alternative prize in the unchosen box, and they had to express again whether they felt happier, sadder or neutral about their choice. Results showed that by the age of six, children expressed to feel sadder in regret trials, thus this was interpreted as evidence of the feeling of regret from this age.

To test implications of this emotion for children’s decision-making, O’Connor and colleagues (2014) gave children (five-seven-nine years old) the same box choice task and then returned the next day to present children with the same choices. According to the authors, children who experienced regret on Day 1 should change their choices on Day 2, and furthermore the authors considered adaptive decision makers those children who were inclined to pay a small cost to switch their choices on Day 2, but not in baseline trials. Results showed that children who experienced regret on Day 1 were significantly more likely to switch on Day 2; thus, the authors concluded that the experience of regret led to better decision making in this task.

In a study of regret using a similar box choice task, Weisberg and Beck (2011) argued that the experience of regret should be affected by the level of responsibility for the outcome. In this study, the outcome was determined by the child’s choice or the roll of a dice. The results indicated that six- and seven-year-old children experienced regret when they received unfavorable outcomes following their choice, rather than following the roll of a dice. Both O’Connor and colleagues (2014) and Weisberg and Beck (2011) did not examine the impact of other children’s negative emotions, such as frustration, on decision making, which may have the same association with decision making as regret. O’Connor and colleagues (2014) claimed that the experience of regret directly affected children’s subsequent decisions; however, other authors asserted that predicting future regret and trying to avoid it (i.e., anticipating regret), rather than its experience, was the real mechanism underlying adaptive decision-making.

This hypothesis was tested first by Guttentag and Ferrell (2008) and then by McCormack and Feeney (2015). In their studies children were told that they had to choose between three boxes; inside each box there could be a good reward, a medium reward or nothing (although all three boxes provided a medium reward). Then, the experimenter removed one of the boxes, and children had to choose between the two remaining boxes. After receiving the medium reward, containing in the chosen box, children were asked to express their feeling on a 5-point scale and then to predict how they would feel if the larger reward was in the unchosen box. Children were able to accurately predict that they would feel sadder by the age of eight years, contrary to the evidence provided by O'Connor and colleagues (2012), in which nearly all six- and seven-year-olds experienced regret. Thus, there was a delay of at least one year between experience and anticipation of regret. With the purpose of integrating these evidences, O'Connor and colleagues (2015) administrated the experienced regret task on Day 1 (Weisberg and Beck, 2011), the choice switching task on Day 2 (O'Connor et *al*., 2014), and then the anticipated regret task (Guttentag & Ferrell, 2008; McCormack & Feeney, 2015). The authors replicated O'Connor and colleagues' (2014) finding since, even in this latter study, adaptive choices in the switching task on Day 2 were associated with the feeling of regret experienced by children on Day 1. These findings were also similar to those obtained by Weisberg and Beck (2011); in fact, children felt sadder when they made the decision, than when the outcome was determined by the experimenter's dice throw. According to O'Connor and colleagues (2015), this discrepancy was possibly due to the intervention of other negative emotions, such as frustration. Thus, these findings demonstrated that the experience of such emotions, rather than their anticipation, underlies better decision making.

Finally, an interesting contribution was provided by Derevensky and colleagues (2007), who showed that children (by the age of 10) had false beliefs about the influence of personal skills on the outcome of random events. In their study, 174 children were asked to answer to (i) a gambling activity questionnaire (consisting of 15 questions on the frequency and type of gambling activities in which they participated) and (ii) a cognitive perception questionnaire, which evaluated the participants' perception about the involvement of skill and luck in gambling and no-gambling activities. Then, after filling the questionnaires, children accomplished a gambling task and they were asked, again, to fill the questionnaire after one and four weeks. The data collected before the performance in the gambling tasks, showed that children thought that both personal skills and luck concurred to the success in gambling activities; whereas, after playing the task, their perception about the importance of personal skills decreased in favor of a greater involvement of luck.

2.4 A new approach to study emotional states: the infrared thermography

Thanks to technological advances, skin temperature can be assessed by cameras with infrared thermography, that permit to record the functioning of the autonomic nervous system, constituting an effective method of detecting emotional states.

Infrared thermography is a non-invasive and ecological technique, which does not require direct contact with the individual’s body and allows the observation of physiological emotional responses during spontaneous situations (e.g., play or social interactions), by measuring the spontaneous thermal irradiation of the body. It is based on infrared image capture, which graphically map the temperature of all bodies by refined instruments, known as thermal imaging cameras, capable of obtaining and recording the thermal distribution and its variation in real time, getting a "colored" image, in which each color indicates the temperature of the body in a specific time interval. The strength of these instruments lies in their ability to capture the radiation emitted by the subject, while avoiding contact, ensuring that she is not exposed to radiation of any kind and allowing her to move spontaneously, allowing to overcome the disadvantages of some invasive techniques used in neuroscience. To accurately record temperature, it is necessary to make sure that any temperature variation is not the result of external interferences, so it is very important to accurately prepare the experimental setting where recording takes place, trying to avoid other sources of direct irradiation or ventilation. In addition, some parameters of the camera have to be set: (i) emissivity, referring to the amount of thermal radiation emitted by an object compared to the perfect black body one, which for human skin is around 1; (ii) the reflected temperature; (iii) the distance between the subject and the front of the camera's optics; (iv) the relative humidity

(Ioannou, Gallese & Merla, 2014).

Infrared thermography has many application (e.g., in medicine, engineering, in the industry and military fields). In humans, some areas of the face, the so-called regions of interest (ROI), are considered crucial to detect temperature variations (figure 1). Most of the studies using this technique found that the activation of the sympathetic nervous system corresponds to a temperature decrease in the nose region; in the same way, a decrease in temperature was noted above the upper lip and the jaw area as a result of the activation of the sudoripara gland; on the contrary, in these cases the temperature rises in the area of nose, forehead and between the eyes. Cooling of the cheeks, on the other hand, seems to be caused by the adrenergic system, which interacts with adrenaline (Ioannou et *al*., 2014). The emotions most investigated, by measuring if ROIs' temperature elevates or decreases, are startle response, empathy, guilt, embarrassment, sexual arousal, stress, fear, anxiety, pain and joy (see Ioannou et *al*., 2014, for a review of these studies).

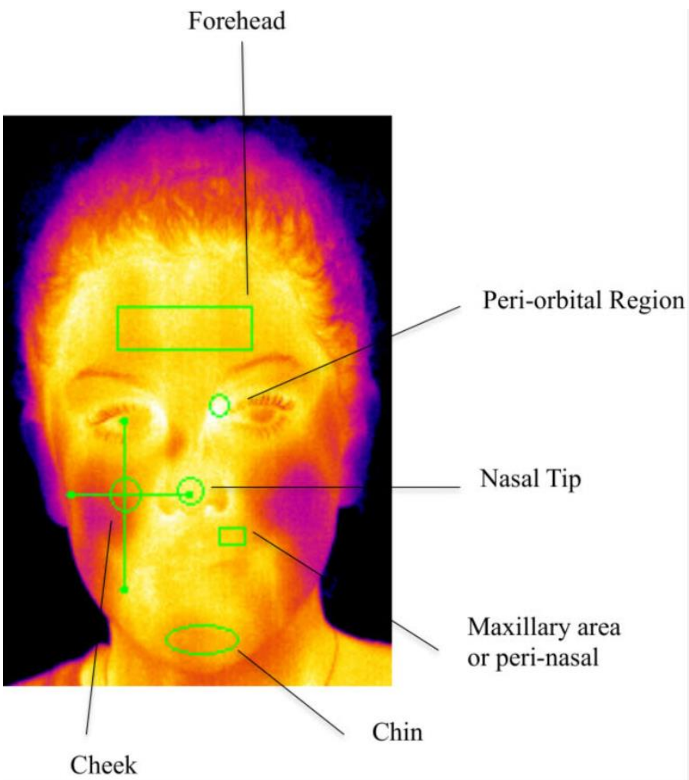

Figure 1. Thermal representations of the ROIs (Berkovitz, Kirsch, Moxham, Alusi, & Cheesman, 2013).

Thermal infrared imaging is a valuable method for studying adults' sympathetic activity in stressful laboratory settings, for detecting potential gender differences of emotional responses to infants, for analyzing emotional states caused by gazing and social proximity, and finally for investigating sympathetic activity in clinical populations, such as patients with motor and intellectual disabilities (Engert et *al*., 2014; Esposito et *al*., 2015; Ioannou, et *al*., 2014; Suzuki et *al*., 2012).

In children's emotional development literature, infrared thermography has been used to evaluate emotions, such as empathy in mother-child interaction (Ebisch, Aureli, Bafunno, Cardone, Romani & Merla, 2012; Aureli, Grazia, Cardone & Merla, 2015), guilt (Ioannou et *al*., 2013) and joy (Nakanishi & Imai-Matsumura, 2008). Ebisch and colleagues (2012) studied maternal empathy during the *Mishap* paradigm. The experimenter gave the child what they called their favorite toy, which was earlier manipulated to be broken when playing with it. The authors distinguished five phases of the experiment: (i) "presentation", when the experimenter invited the child to play with the toy; (ii) "playing", when the child was left alone in the room to play; (iii) "mishap", when the toy was broken; (iv) "re-entrance" of the experimenter; (v) "soothing" of the child, when the experimenter showed the child how to fix the toy and reassured her it was not her fault. Meanwhile, her mother watched the entire experiment in a separate room through a one-way mirror, unaware of the manipulation of the toy. Thermal data were recorded both on children and mothers, to evaluate how maternal empathy reflects onto the physiological level during a stressful situation experienced by their children. The authors detected facial temperature variations both for children and mothers, which indicated a sort of synchrony of their responses at physiological level. The mishap paradigm was also used by Ioannou and colleagues (2013) to assess guilt behavior in early childhood and their results confirmed the findings of the previous study. The authors observed a decrease in the temperature of the nasal tip in the mishap phase, as an indication of a sense of guilt, followed by an increase in the temperature of the same area during the soothing phase, due to the activation of the parasympathetic system, as a result of the reassurance of the experimenter.

Aureli and colleagues (2015) used thermoimaging when administering the *Still-Face* paradigm to three- to four-month-old infants. This procedure consists in three moments of a facial-facial interaction: (i) a normal mother-child interaction; (ii) the '*still face'* moment, when the mother takes on a neutral expression and she is no more responsive to the child; (iii) the moment when the mother resumes the interaction. Then, the authors added a fourth moment of playing. They also collected behavioral data through the Infant and Caregiver Engagement Phases system. The results confirmed a parallelism between physiological and behavioral responses: children showed no signs of discomfort or stress during the still-face moment and no decrease in facial temperature, generally considered an emotional stress index. In contrast, a temperature increase has been recorded in support of the parasympathetic system activation as a result of children's greater interest in the surrounding environment, and it is also confirmed by the behavioral data, which showed that children drove their attention outward as a result of the interruption of the interaction with their mothers.

Finally, a further confirmation of the validity of infrared thermography in detecting emotional responses is provided by the study of Nakanishi and Imai-Mutsumura (2008), which showed that the ROIs temperature of 2-to-10 month-old infants decreased significantly as a result of joyful expressions, such as laughter.

All the above studies showed that infrared thermography is a reliable technique for detecting emotional variations, as confirmed by behavioral data; hence, infrared thermography is especially suited to integrate physiological elements in the research of socio-emotional development, especially in children. In fact, this is a non-invasive technique that allows to infer emotional states based on physiological observations of peripheral vasoconstriction, preserving an ecological environment.

Chapter Three – Experimental Study

3.1 Introduction

The abilities to properly assess risk and to make advantageous choices are essential to avoid negative consequences, such as addictions, injuries, diseases and so on, caused by risky behaviors. Thus, a thorough understanding of the development of adaptive decision behavior can be extremely useful to create early intervention programs. Unfortunately, the trajectory of the development of the ability to deal with situations that require a choice between a safe and risky option is not yet fully understood.

The underlying mechanisms of this construct are still not well-defined, nor are the cognitive, social or emotional factors involved in risky decision-making at different ages. The multiplicity of theoretical and methodological approaches which have tried to answer these questions, have often provide conflicting results. The analysis of the literature carried out in the previous chapters does not provide definitive answers to all questions, but highlights what are three key points in the study of human decision making under risk: (i) risk propensity is not a stable trait, but evolves from childhood to adulthood, (ii) the maturation of executive functions and emotional regulation may decrease risk taking behaviors in the course of development, (iii) emotions and social context do affect children's decision making under risk.

Three year-old children, compared with older ones, appear to make irrational choices, which can lead them to negative and disadvantageous consequences. Already by the age of four, children begin to make more advantageous choices, as five- and six year-olds indeed do. This changes have been explained by taking into account the rapid maturation of executive functions and neural areas underlying decision-making that occurs in these years. Whereas it is quite clear which brain regions underlie decision making (orbitofrontal cortex, posterior parietal cortex, ventral striatum, anterior insula, amygdala, dorsolateral prefrontal cortex, posterior parietal cortex and ventromedial prefrontal cortex; Crone and van der Molen, 2004, 2007; Van Leijenhorst et *al*., 2006; Carlson et *al*., 2009; Paulsen et *al*., 2012; Van Duijvenvoorde et *al*., 2015), it is still unclear what cognitive components are involved in decision-making under risk. In fact, not all authors agree in attributing an important role to the same components: for example, Hongwanishkul and colleagues (2005), Garon and Moore (2007), Van Duijvenvoorde and colleagues (2012) and Audusseau and colleagues (2015) consider as essential the role that working memory plays in potentially risky situations, helping children to make the most optimal decisions to achieve their purpose. In contrast, other authors found no correlation between children's performances in memory tasks and gambling tasks, or between the latter and any other cognitive functions such as reasoning skills, language, inhibitory control and attention processes (Heilman et *al*., 2009; Smith et *al*., 2012; Mata et *al*., 2013; Beitz et *al*., 2014; Harms et *al*., 2014).

Factors that can potentially affect children's success in tasks requiring a choice in risky situations are the complexity of the task, the sensitivity to the frequency and magnitude of rewards or losses, the expected value and probability understanding. Bunch and colleagues (2007) and Andrews and Moussaumai (2015) observed that, when reducing the demands of the task, children's performance improves in terms of a greater number of advantageous choices; however, other authors (Crone et *al*., 2005, 2007; Gao et *al*., 2009) claim that a low performance can be caused more by insensitivity to future outcomes rather than to task complexity. All authors agree that children's decision-making is more influenced by the frequency of the punishments rather than by their magnitude. As for the knowledge and the understanding of the principles of probability and expected value, the results are contrasting. Weller and colleagues (2011) and Steelandt and colleagues (2013) believe that this understanding does not occur during childhood and that this lack of understanding leads children to be less cautious in their choices and more risk-prone. Disagreeing with this view, Harbaugh and colleagues (2002), Levin and colleagues (2007), Schlottmann and Anderson (1994), Schlottmann (201l), and Denison and Xu (2014) provided evidences in favor of an early understanding of probabilistic concepts, emerging early in childhood; therefore, according to these authors, the reasons of a lower risk aversion in children should be attributable to other factors and mechanisms. Girotto and colleagues (2016) in a recent study found that three- and five-year-olds were able to made optimal choices in tasks that did not require forming probabilistic expectation, but that only five-year-olds were able to make optimal choices in tasks involving an evaluation of chance, suggesting caution in interpreting infant's ability to understand probability.

Overall, the debate about emotions and social influences involved in decision making in risky situations is still open. In this context, the scenario is more homogeneous; in fact, the authors who dealt with this issue (Miller and Byrnes, 1997; Levin et *al*., 2007) achieved similar results, by identifying overconfidence, impulsivity, a low level of anxiety, adventure seeking, and peer influences as the potential factors associated with increased risk propensity, interacting independently from each other with decision-making processes. Impulsivity and low inhibition (expressed by a low level of anxiety) are predictors of potentially risk-taking behaviors already at the age of 10 (Vitaro and Wanner, 2011). Finally, recent studies in the field of emotional developmental research identified the feeling of regret as a possible factor that can guide children towards more careful and/or advantageous choices (O'Connor et *al*., 2012; Weisberg and Beck, 2011; O'Connor et *al*., 2014; O'Connor et *al*., 2015; Guttentag & Ferrell, 2008; McCormack and Feeney, 2015).

The above results suggest that the construct of risk propensity is multi-determined and thus it is impossible to pinpoint a single factor, either cognitive, emotional or social, as the causal factor determining it. The contrasting results provided by previous works, even within the same area of research, are possibly due, on one hand, to the lack of a theory of reference (although this gap was partially filled by the theoretical model proposed by Andersen and colleagues, 2010), and on the other hand, to the fact that authors are inclined to focus only on one process of decision-making under risk at a time (i.e., expected utility vs emotions). In this latter case, the authors neglect the existence of more than one latent process, that could actually have a weight on the ability to make a choice between a risky and a safe option and thus could explain part of the obtained results.

In the light of the results emerging from the literature, the present study aimed to investigate, through a new experimental paradigm adapted from the research on risk propensity in non-human primates (Heilbronner, Rosati, Stevens, Haren & Hauser, 2008; De Petrillo, Ventricelli, Ponsi & Addessi, 2015), both the cognitive and the emotional processes involved in children's decision-making under risk. One of the strengths of this experimental procedure is that children are tested with an experimental paradigm that does not rely on the linguistic explanation of the task; furthermore, from this task it is possible to get indicators that allow a subtle analysis of the implicit strategies of choosing.

3.2 Aims

The aim of the present research was to assess risk proneness in four, five, six, seven and eight year old children. To this end, each child was administered (i) the Probabilistic Choice Task, adapted from a paradigm used with non-human primates (Heilbronner et *al*., 2008; De Petrillo et *al*., 2015) and used here for the first time with children; (ii) a classical gambling task, the Children's Gambling Task (CGT) (Kerr and Zelazo, 2004); (iii) a simple bet task. In the Probabilistic Choice task and in the Bet Task, children were required to express their emotion following the outcome of their choices on the 5-point rating scale (Wiseberg and Beck, 2011). In addition, children completed two control tests: the BIN 4-6 battery and the Peabody Picture Vocabulary Test, to control for the influence of both linguistic understanding and mathematical reasoning on the ability to choose in uncertain situations (see below for a detailed description of all tasks).

The administration of the Probabilistic Choice Task, previously used in experimental protocols with non-human primates, allowed to understand whether biases in risky decision making are shared between humans and other non-human primates, or whether they are more recent acquisition possibly culturally determined. In addition, this research aimed to evaluate how emotions, linked to the choice outcome in a gambling task, can affect the ability of children to make decisions under risk (O'Connor et *al*., 2012; Weisberg & Beck, 2011; O'Connor et *al*., 2014; O'Connor et *al.*, 2015, Guttentag & Ferrell, 2008; McCormack & Feeney, 2015). To this end, thermal images were recorded for a sub sample of children, using an infrared camera, to investigate children physiological responses to the proposed stimuli. To my knowledge, this is the first study that used the infrared thermography to assess children's emotional reactions in a decision-making task. Children's emotional responses were analyzed taking into account the outcomes of their choices, comparing behavioral and physiological measures, with particular emphasis on their role on children's risky preferences.

Taking into account the probabilities, I hypothesized that children were able to make more choices from the advantageous deck in the CGT and that they preferred the risky option more in the Advantageous condition of the Probabilistic Choice Task, in which the probability associated to obtaining the larger reward was higher than in the other two conditions. This ability to make advantageous decisions is supposed to change and improve during development, also as a function of an improvement of numerical skills. Furthermore, I assumed to detect differences in the performances in the two above mentioned tasks, due to the concept of loss inherent in the CGT, but absent in the Probabilistic Choice Task, in which I supposed to observe a greater number of risky choices. Finally, I expected a correspondence between the answers provided by children to the 5-point rating scale and changes at the physiological level, as expression of emotional states, which could affect the risky preferences of children, depending on age.

3.3 Methods

3.3.1 Participants

I tested 183 children aged from four to eight years old (61 four-year-olds, M= 49,24; 65 five-year-olds, M= 62,08; 29 six-year-olds, M= 74,06; 20 seven-year-olds, M= 84,11; 8 eight-year-olds, M= 94,10), recruited from kindergartens and primary school of the large metropolitan area of Rome: “Casa dei Bambini”, “Istituto Comprensivo Giovanni Battista Valente” and “Asili Infantili Israelitici”. Children belonged to middle-class families (as determined by parental educational level). Parents were provided with a letter describing the general aims and the procedure of the study and written parental consent was obtained for children to participate in the tests and for the video recording.

Each child was tested in two gambling tasks (the Probabilistic Choice Task and the CGT), and in a bet task. In addition, they were administered: a bet task; the Peabody Picture Vocabulary Test, in the Italian version by Stella, Pizzoli and Tressoldi (2000), to measure the level of linguistic comprehension, and the BIN 4-6 battery (Molin, Poli and Lucangeli, 2007), to evaluate numerical skills.

3.3.2 Materials

In the Probabilistic Choice Task, bowls of different color and shape were used: the reward corresponding to each option (safe and risky) was placed under each bowl (Figure 2). The assignment of the bowls to the different options was counterbalanced across subjects. Some participants received real stimuli as rewards (jelly beans or stickers), whereas others received tokens (colored pebbles) that they exchanged with the experimenter to get the real reward (stickers or jellybeans, depending on the reward the child was assigned to) at the end of the test.

Figure 2. Bowls utilized in the Probabilistic Choice Task (Photo by Eleonora Tomei)

In the CGT, the experimental material consisted of two 50-card decks, one with the back covered by white and black vertical stripes, the other covered by black dots on a white background. The front of each card is divided into a white half with depicted smiling faces, corresponding to the number of won rewards, and in a black half, depicting sad faces, corresponding to the number of lost rewards (Figure 3).

Stickers and jelly beans, counterbalanced across subjects, were used as rewards in the Probabilistic Choice Task. In the CGT, only stickers were used as rewards.

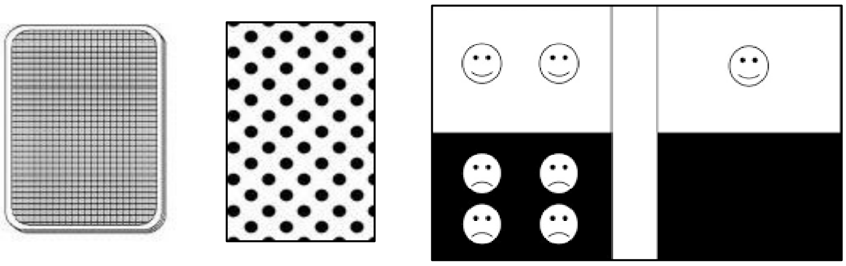

Figure 3. Samples of cards utilized in the CGT

In the Bet Task, a coin with the two sides of two different colors (yellow and green) was used (Figure 4).

Figure 4. Coin utilized in the Bet Task.

3.3.3 Procedure

Children were individually tested in a quiet room of the school they attended. Responses of a sub-sample of 15 children were recorded using an infrared camera and collected in a laboratory of the Department of Dynamic and Clinical Psychology of “Sapienza” University of Rome, suitable to guarantee the thermal conditions required for the use of an infrared camera. All tasks were administrated by two female experimenters, who alternated their role as experimenter and assistant across sessions. The experimenter administered the tasks and the assistant scored children’s performance on the protocol sheet. The entire session was also video-recorded and a DVD of the experiment was given to parents who accepted to participate at the study as a token of participation. Each testing session lasted around one hour. Data collection was carried out between October 2015 and July 2017.

At the beginning of the experimental session, a familiarization phase, in which the child and the experimenter played together spontaneously, was carried out. Between tasks there were short free play break, where the experimenter and the child interacted for a few minutes.

Before starting with the actual administration, the experimenter advised the teacher or the parent, if present, to avoid as much as possible to intervene while the child was performing the tests, in order to avoid any kind of interference or suggestion in the responses. Children were tested in one single session and each child was administered five tasks (please see paragraph 3.3.1).

The Probabilistic Choice Task

In the Probabilistic Choice Task, children were asked to choose between a safe option (four rewards) and a risky option (one or seven rewards). Three experimental conditions were provided, manipulating the chance to obtain the reward when choosing the risky option: (1) Neutral condition, (2) Advantageous condition, and (3) Disadvantageous condition. In the Neutral condition the risky option had a probability of 50% to provide one reward or seven rewards. In the Advantageous condition the risky option had a 67% chance to provide seven rewards and 33% to provide one reward. In the Disadvantageous condition the risky option had a probability of 33% to provide seven rewards and 67% to provide one reward. The reward associated to the safe option corresponded to four rewards in all conditions. A between-subject design was employed and each child was randomly assigned to one experimental condition.

During the experimental session, the child was seated at a table near to the experimenter, whereas the assistant was seated on the opposite side of the table. Two colored curtains separated the child's table area from the assistant so that the child could not see what she did when setting up each trial. A platform, on which the two options were presented, was located on the table between the child and the assistant (Figure 5). At the beginning of the session, the experimenter explained to the child how the test worked. The experimenter showed to the child the two upside-down bowls, explaining that if she selected the safe bowl she was going to win always four rewards (jellybeans, stickers or pebbles), whereas if she selected the risky bowl she could win one or seven rewards. In the Neutral condition the experimenter added that choosing the "risky" bowl would have allowed her to get sometime one and sometime seven rewards; in the Advantageous condition the experimenter said that choosing the "risky" bowl would have given to her many times seven rewards and a few times one reward, and in the Disadvantageous condition, the experimenter told the child that choosing the "risky" bowl would have given to her many times one reward and a few times seven rewards. To facilitate the child's comprehension of the task demands, the experimenter indicated with gestures the number of rewards associated with each upside-down bowl. Half of the subjects started the familiarization trials with the risky option and the other half with the safe option.

Each session started with four familiarization trials, with only one option available, followed by 10 free-choice trials, in which children could choose between the safe and the risky option, for a total of 14 trials per session. The position of the risky option (right or left) was pseudo-randomized across trials. Each trial began when the experimenter opened the curtain allowing the child to see the two bowls (in experimental trials) or a single bowl (in the familiarization trials). The child could choose one of the two options (or, in the familiarization trial, the only option available) by lifting the chosen bowl and taking the reward underneath it. A plastic container was given to the child to accumulate his/her rewards. As soon as the child made her choice, there was a 10-second interval, during which the experimenter refrained from making verbal comments and interacting with the child.

Figure 5. The figure depicts a child performing the Probabilistic Choice Task in the food condition (Photo by Eleonora Tomei).

At the end of the task, to assess children's level of awareness of the task, they were asked two questions. First, the experimenter indicated the "safe" bowl and asked: "How many rewards can you find below it?"; then, she showed her the "risky" bowl and asked the child the same question.

Emotional Self-rating

In the Probability Choice Task, ten seconds after the child's choice the experimenter showed her the 5-point rating scale (Weisberg and Beck 2011, Figure 6), and asked: "Could you show me how happy or sad are you of winning 'x' rewards?" and the child had to point an arrow to the smile that best represented her feeling. Then, the experimenter told the child: "Now I'm going to show you what you could have won" and then she showed her the content of the unselected bowl, taking care to keep the reward just received by the child in view, saying: "If you chose this bowl you would have won 'y' stickers". Then, the experimenter asked her again: "And now, how happy or sad are you of winning 'x' instead of 'y'?"

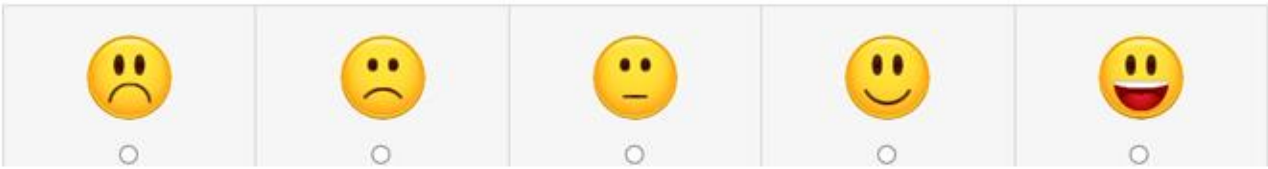

Figure 6. The 5-point rating scale (Weisberg and Beck, 2011)

Training on Emotional Recognition

The experimenter showed the child the 5-point rating scale and asked the child to indicate first the very happy face and then the very sad one. If the child did not respond correctly, the experimenter asked her to retry, saying: "What is the really, really sad / happy face?"

Then, the child was explained how to use the arrows underneath the scale to indicate the emotion experienced along the continuum. Starting from the neutral face, the experimenter moved the arrows to the left, showing the saddest smileys, then moved them to the right towards the happiest ones. Children had to perform a two sessions in the training phase: in the first session, five rewards were given to the child and, starting from the neutral face, she was asked to point the arrows on the smile that best represented how happy or sad she was of having received those rewards. Subsequently, the experimenter removed four rewards from the child's endowment and showed her again the scale and asked her how she felt now (starting from the face the child had previously indicated). For both correct and incorrect answers, a feedback was given to the child. If she did not provide the correct answers, the training phase continued with another five trials, in which the children faced different situations where they could win, lose or get the same number of rewards.

The Children's Gambling Task

In the Children's Gambling Task, the child had to select a set of cards from an advantageous and a disadvantageous deck. During the experimental session, the bottom half of each card was covered with a post-it, which the experimenter took away during the test to reveal the magnitude of the loss. In both decks the number of rewards that could be won remained fixed, whereas the amount of rewards that could be lost varied; the advantageous deck cards provided a win of one reward and a loss of zero or one reward (with an average payout of five rewards per ten cards); the disadvantageous deck cards provided a win of two and a loss of zero, four, five or six rewards (with an average loss of five rewards per ten cards). Each child faced six demonstration trials and fifty experimental trials. The decks were placed on a table in front of the child. A plastic container, where the child could accumulate her rewards, was placed between the decks.

At the beginning of the session, the experimenter gave ten rewards to the child and showed her, in the training tests, how to select the cards by choosing three consecutive cards from each deck. For each choice, the rewards were provided to the child or withdrawn depending on the faces represented on each card. At the end of the demonstration session, the experimenter encouraged the child to choose the cards from the deck she preferred to try to maximize her rewards. The test ended with the choice of the fiftieth card; if the child interrupted the test in earlier, it was considered valid if the child made at least 45 choices.

Figure 7. The figure depicts a child performing the Children's Gambling Task.

<u>BIN 4-6 Battery</u>

The BIN 4-6 battery (Molin, Poli and Lucangeli, 2007) was developed to analyze the various components at the basis of mathematical learning, in order to identify strengths or weaknesses of the child and reinforce, in a targeted way, any area that results at risk.

The battery consists of 11 tests related to four areas of investigation:

Semantic Area

- Comparison of quantities
- Comparison of Arabic numerals

Counting Area

- Forward and backward Enumeration
- Seriation of Arabic numerals

- Completion of numerical series

Lexical Area

- Matching name-number
- Reading numbers written in Arabic code
- Writing numbers

Pre-syntactic area

- Correspondence between Arabic numerals and quantities
- One-to-many
- Magnitude order

The Bet Task

In this task, the experimenter showed the child a coin with one green side and one yellow side and asked her to bet on one of the two faces to win five rewards. The experimenter explained her that in case of extraction of the face that she did not choose, she would have to give up five of her rewards, obtained in the previous tasks (Probabilistic Choice Task and CGT). Then, the experimenter performed a test toss, in which there were no wins or losses, and subsequently asked the child to throw the coin for five experimental trials. Before each toss, the experimenter asked the child if she wanted to stop or to continue with the game. After each toss, the experimenter waited for ten seconds without commenting or interacting with the child and then showed the child the 5-point rating scale (Weisberg and Beck 2011), asking her: "Could you show me how happy or sad you are to have chosen ‘yellow/green’?". The child had to point the arrow to the smile corresponding to her emotion.

Peabody Picture Vocabulary Test

The revised version of the Peabody Picture Vocabulary test (PPVT-R), developed by Dunn & Dunn (1981) and adapted for the Italian population by Stella, Pizzoli, & Tressoldi (2000), is an instrument used for evaluating receptive vocabulary in children.

The experimenter and the child sat next to each other. In front of the child was placed the book containing the 175 tables useful for the test. Before starting the test, the examiner calculated the chronological age of the child, and then she showed her the training table A saying "I would like you to look at some figures with me. Look at all the figures on this page, I'll say a word and then I want you to point out with the finger the figure of the word I said. Let's try. Put your finger on .... ". If the child gave a correct answer, the training continued with table B and if the child still answered correctly, the experimenter went on with table C.

For the training tables, if the child pointed at an incorrect drawing, before moving to the next table the experimenter indicated the correct answer. The item needed to be repeated until the child gave the correct answer, before moving on to the next table.

After the training was completed, the experimenter went on to the expected starting point according to the child's age, indicated in the recording sheet, and said: "Now I'll show you other figures. Every time I say a word you have to find the best figure. I'm not sure you know the meaning of all the words but I want you to look at them carefully and choose what you think is right. Tell me .... "

The experimenter gave the child an approval whatever the child response was, but differentiated between correct and incorrect answers with phrases such as "This is a good response", "Good", "Very good", in the case of a correct answer, and with phrases like 'I understand', 'Okay', in the case of incorrect answers. During the test, the experimenter had to keep an equally positive tone, encouraging a response in case the child found it difficult. The test ended when the child made six errors in eight consecutive responses. The total score was computed by subtracting from the last item administered (ceiling item) the number of errors made between the basal item (the last item of the first series of eight consecutive correct responses) and the ceiling item. This score was then standardized for analysis purposes.

3.3.4 Order of tasks presentation

For each age group, the order of presentation of the two gambling tasks was counterbalanced across subjects, whereas the last three tasks were administered in a fixed order. Thus, a first group of children received the CGT as the initial test, followed by the Probabilistic Choice Task, the BIN test, the Bet Task and then the Peabody test; a second group of children received the Probabilistic Choice Task, followed by the CGT, the BIN test, the Bet Task, and finally the Peabody test.

3.4 Data coding

3.4.1 Behavioral data coding

For all tasks, the assistant scored participants' responses by paper and pencil, and coding was subsequently scored from videotapes.

For the Probabilistic Choice Task, the primary dependent variable for the Probabilistic Choice Task was the proportion of choices of the risky option (the number of risky choices divided the number of trials). Moreover, the following variables were coded:

- Latency to choose
- Task Awareness Question 1: child's response to the question "How many rewards can you find below it?" in relation to the safe bowl; a score of two was assigned if the child gave the correct answer. If she was wrong or did not remember, a score of zero was assigned.
- Task Awareness Question 2: child's response "How many rewards can you find below it? related to the risky bowl; a score of two was assigned if the child gave the correct answer, a score of one if the answer was partially correct and a score of zero if the child was completely wrong or did not remember.

For the Children's Gambling Task, for analysis purposes the 50 trials were divided into five blocks of 10 trials each. The dependent variable was the proportion of advantageous choices per block minus the proportion of disadvantageous choices per block, which yielded a difference score ranging from -1 to 1 for each block.

For the Bet Task, the dependent variables were the percentage of toss performed (maximum five) and the winning frequency, i.e., the number of winning matches divided by the number of games played.

For the BIN battery, the dependent variables were the scores obtained by children in each area and the total score realized in all the eleven tests.

For the Peabody Picture Vocabulary Test, the following variables were coded:

- Raw score: number of correct answers in the critical range, obtained by subtracting the number of wrong answers from the total number of items the child responded to.

- Standardized score: score obtained using the raw score and the chronological age of the child, referring to the normative table provided by the manual.

Furthermore, the emotional correlates of the Probabilistic Choice Task and the Bet Task were evaluated. The smiles of the 5-point rating scale were assigned a numerical code, ranging from one, corresponding to the saddest face, to five corresponding to the happiest face. The variables scored for the emotional evaluation were:

- Emotion 1: emotion expressed by the child after choosing an option (from one to five);
- Emotion 2: emotion expressed by the child after seeing the alternative option (from one to five);
- Coherence of emotional responses given the outcomes of the choices: it was assigned a score of one to coherent responses and a score of zero to incoherent responses;
- Switching: number of times the child decided to change her first choice, trying to select the unchosen option.

Finally, from the video analysis, it was possible to score four major classes of behavior exhibited by children during the 10 seconds following each of their choices:

- Waiting strategies, such as: looking around, looking at the experimenter, drumming fingers on the table.
- Positive expressions, such as: laughing, smiling, exulting.
- Negative expressions, such as: snorting, banging the fist on the table.
- Self-directed behaviors, such as: scratching, touching herself.
- Manipulation of experimental material, such as: playing or touching experimental material, including the bowls, the coin and the rewards.

3.4.2 Thermal data coding

In order to investigate the autonomic response of children to the stimuli presented in the Probabilistic Choice Task, the facial temperature of a sample of 15 children was recorded, focusing on the temperature variations of the nasal tip area, which has been proved to be one of the most reliable regions to detect the activation of the sympathetic system in response to emotional or stressful stimuli (Nakanishi and Imai-Matsumura,2008; Ioannou et. *al*., 2013; Manini et *al*., 2013; Aureli et *al*., 2015). Using a tracking software, it was possible to obtain thermal signals of specific ROIs. Then these signals were analyzed, by computing the slope of the thermal signal using the Matlab software.

For the Probabilistic Choice Task, three phases were identified: (i) phase 1: the moment before choosing an option, which represents the baseline condition; (ii) phase 2: the moment after seeing the choice outcome; (iii) phase 3: the moment after the experimenter revealed the outcome of the unchosen option.

The dependent variable was the slope of the thermal signals in each phase.

Figure 8. Thermal video image during the Probabilistic Choice Task.

3.5 Reliability

Reliability was calculated on a subsample of 20 subjects. All sessions were independently scored by two trained observers. Reliability was measured by calculating the Pearson correlation coefficient (r) for the latency to choose scored in the Probabilistic Choice Task and by computing the concordance index for all other variables.

For the Probabilistic Choice Task, the reliability for the latency to choose was $r = 0,88$ ($p < 0.001$, $N = 20$), the reliability for proportion of choice of the risky option and for other variables (“Task Awareness Question 1” and "Task Awareness Question 2") was 100%.

For the Bet Task, the reliability for the variables "Percentage of Toss Performed" and "Winning Frequency" was 100%.

For the BIN battery and the Peabody Test, reliability for all variables was 100%.

3.6 Results

This section reports the results obtained on the entire sample. Due to the small number of six-, seven- and eight-year-olds, for analysis purposes the data of these children were treated as a single age group of older children.

The analysis of the emotional correlates was performed only for the Probabilistic Choice Task and the Bet Task.

Parents' level of education was analyzed: the level of education of six-seven-eight-year-olds' parents was significantly lower than the level of education of four- and five-year-olds (Kruskal Wallis ANOVA: maternal level of education: $H(2, N= 156)= 29.52$, $p< 0.01$; paternal level of education: $H(2, N= 153)= 19.86$, $p< 0.01$; Mann Whitney U test: maternal level of education: 4-year-olds' parents vs. 5-year-olds' parents: $Z= -0.55$, $N_1= 52$, $N_2= 49$, $p= 0.59$; 4-year-olds' parents vs. 6-7-8-year-olds' parents: $Z= -4.90$, $N_1= 52$, $N_2= 55$, $p< 0.01$; 5-year-olds' parents vs. 6-7-8-year-olds' parents: $Z= -4.30$, $N_1= 49$, $N_2= 55$, $p< 0.01$; paternal level of education: 4-year-olds' parents vs. 5-year-olds' parents: $Z= -0.98$, $N_1= 52$, $N_2= 48$, $p= 0.33$; 4-year-olds' parents vs. 6-7-8-year-olds' parents: $Z= -4.30$, $N_1= 52$, $N_2= 53$, $p< 0.01$; 5-year-olds' parents vs. 6-7-8-year-olds' parents: $Z= -3.17$, $N_1= 48$, $N_2= 53$, $p= 0.002$).

3.6.1 The Probabilistic Choice Task

The Probabilistic Choice Task was administered to 183 children, 90 males and 93 females (see Table 1 for the sample subdivision in the three experimental conditions).

	4-year-olds	5-year-olds	6-7-8-year-olds
Neutral Condition	33	32	16
Advantageous Condition	14	17	19
Disadvantageous Condition	14	16	22

Table 1. Distribution of children in the three conditions of the Probabilistic Choice Task.

For each experimental condition, the analysis of the distribution of data was performed using the Shapiro-Wilk Test. Data did not result normally distributed (Neutral condition: $W=0.81$, $p< 0.01$; Advantageous condition: $W=0.89$, $p< 0.01$; Disadvantageous condition: $W= 0.94$, $p= 0.02$); thus, non-parametric analyses were carried out.

Considering the whole sample, it was assessed whether the type of reward (stickers/jellybeans), the type of stimulus (stickers/jellybeans/pebbles), and the different environments in which the experiment was carried out (different schools and laboratory) influenced children's risky choices. None of these variables had a significant effect (Mann Whitney U test: <u>reward</u>: jellybeans vs. stickers: $Z= -0.24$, $N_1= 34$, $N_2= 149$, $p= 0.81$; Kruskal Wallis ANOVA: <u>stimuli</u>: $H(2, N = 183) = 1.48$, $p = 0.48$; Mann Whitney U test: <u>stimuli</u>: jellybeans vs. stickers: $Z= -0.46$, $N_1= 34$, $N_2= 58$, $p= 0.65$; jellybeans vs. pebbles: $Z= -0.68$, $N_1= 34$, $N_2= 91$, $p= 0.50$; stickers vs. pebbles: $Z= -1.14$, $N_1= 58$, $N_2= 91$, $p= 0.26$; Kruskal Wallis ANOVA: <u>environments</u>: $H(3, N = 183) = 4.08$, $p = 0.25$; Mann Whitney U test: <u>environments:</u> Casa dei Bambini vs. Istituto Valente: $Z= -1.54$, $N_1= 90$, $N_2= 70$, $p= 0.12$; Casa dei Bambini vs. Asili Israelitici: $Z= -1.27$, $N_1= 90$, $N_2= 5$, $p= 0.20$; Casa dei Bambini vs. laboratory: $Z= -1.24$, $N_1= 90$, $N_2= 18$, $p= 0.21$; Aisli Israelitici vs. Istituto Valente: $Z= -0.60$, $N_1= 5$, $N_2= 70$, $p= 0.55$; Asili Israelitici vs. laboratory: $Z= -0.94$, $N_1= 5$, $N_2= 18$, $p= 0.35$; laboratory vs. Istituto Valente: $Z= -0.16$, $N_1= 18$, $N_2= 70$, $p= 0.87$).

A Kruskal-Wallis ANOVA showed a significant effect of the experimental condition on the children's proportion of risky choice ($H (2, N = 183) = 9.78$, $p = 0.008$). In particular, as shown in Figure 9, children preferred the risky option more in the Advantageous condition than in the Neutral and in the Disadvantageous conditions (Mann Whitney U test: Neutral condition vs. Advantageous condition: $Z= -2.52$, $N_1= 81$, $N_2= 50$, $p= 0.01$; Neutral condition vs. Disadvantageous condition: $Z= -0.80$, $N_1= 81$, $N_2= 62$, $p= 0.42$; Advantageous condition vs. Disadvantageous condition: $Z= -2.90$, $N_1= 50$, $N_2= 62$, $p= 0.004$). No main effects of gender or age were found (gender: $Z= -1$, $N= 183$, $p= 0.32$; age: $Z= 323$, $N= 183$, $p= 0.20$).

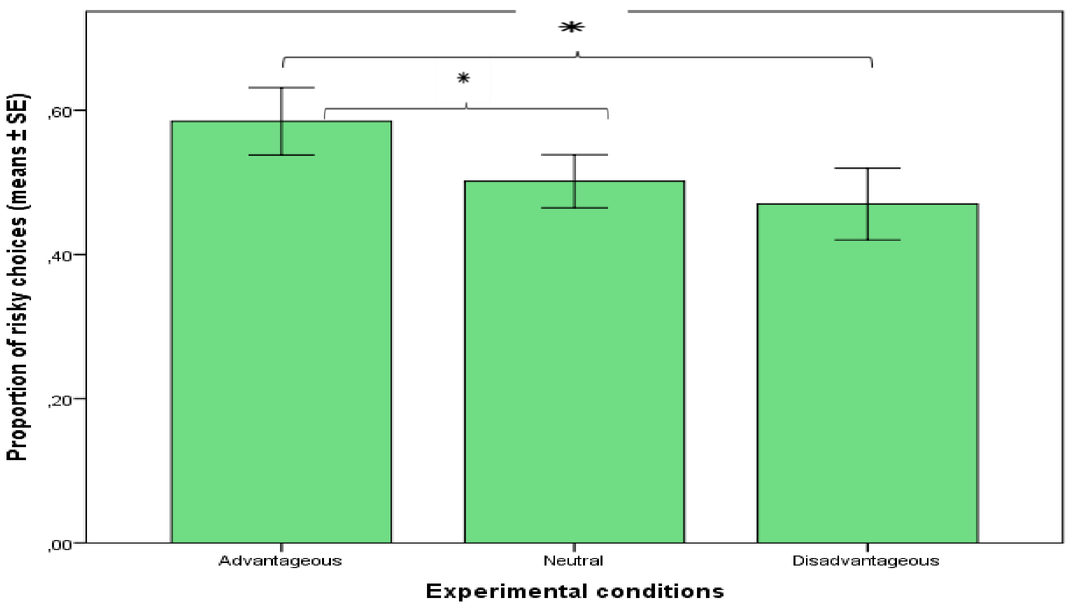

Figure 9. Probabilistic Choice Task: proportion of choice of the risky option in the three experimental conditions.

Children's responses to the two awareness questions presented at the end of the Probabilistic Choice Task were significantly correlated (Spearman correlation: $r_s = 0.17$, $N = 178$, $p= 0.04$). Moreover, the Spearman correlations between children's chronological age and their answers to the two awareness questions showed that older children (5-year-olds and 6-7-8-year-olds) gave significantly more correct responses than four-year-olds (Spearman correlation: first awareness question, $r_s = 0.38$, N = 178, $p < 0.01$; second awareness question, $r_s = 0.51$, N = 178, $p < 0.01$, see Figures 10, 11). When controlling for age, there was no significant correlation between the proportion of choice of the risky option and the two awareness questions (partial correlation: first awareness question, $r_s = 0.13$, N = 175, p= 0.10; second awareness question, $r_s = 0.02$, N = 175, p= 0.76). No correlation was found between the latency to choose and the proportion of choices of the risky option (r_s= -0.01, N= 181, p= 0.88).

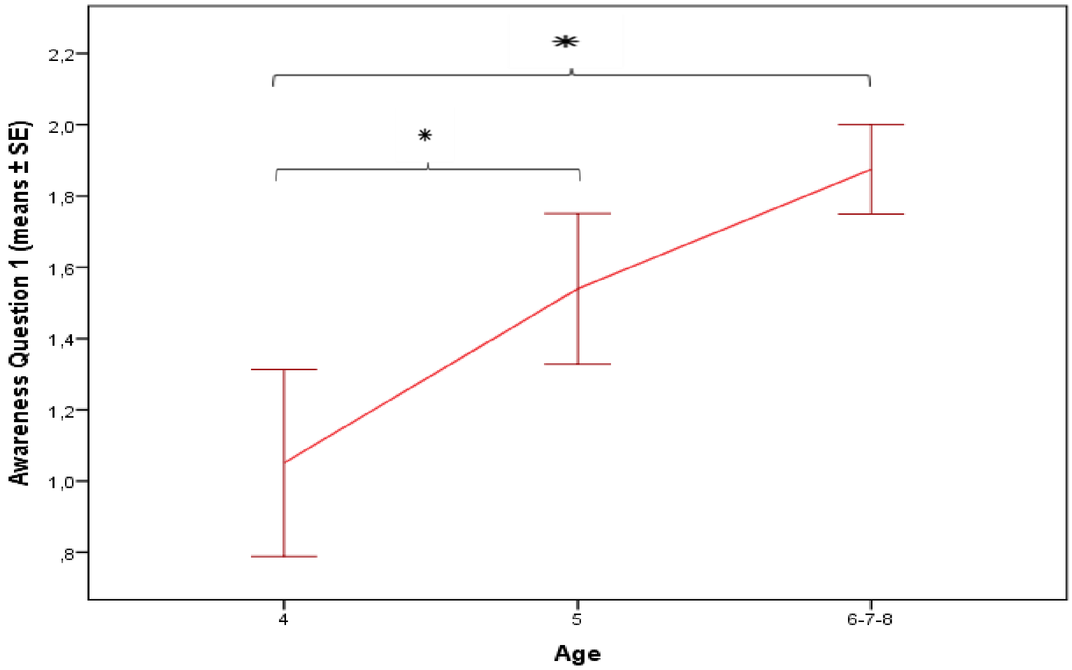

Figure 10. Probabilistic Choice Task: children’s responses to Awareness question1 depending on age.

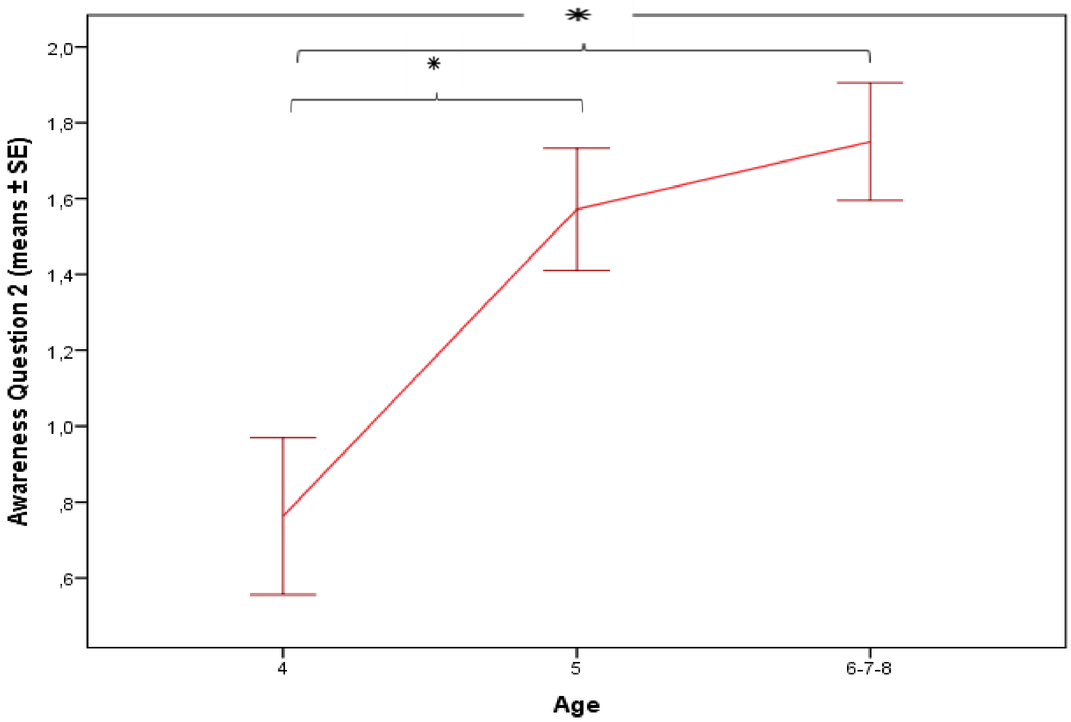

Figure 11. Probabilistic Choice Task: children's responses to Awareness question2 depending on age.

Then, for each experimental condition, the effects of gender and age, type of reward and type of stimulus on the proportion of choice of the risky option were analyzed.

In the Neutral condition, there was no effect of gender (Mann Whitney U test: Z = -1.47, N= 81, p = 0.14), age (Kruskal Wallis ANOVA: H (2, N = 81) = 0.02, p = 0.99; Mann Whitney U test: 4-year-olds vs. 5-year-olds: Z= -0.12, N_1= 33, $N_{2=}$ 32, p= 0.91; 4-year-olds vs. 6-7-8-year-olds: Z= -0.12, N_1= 33, $N_{2=}$ 16, p= 0.91; 5-year-olds vs. 6-7-8-year-olds: Z= -0.05, N_1= 32, $N_{2=}$ 16, p= 0.96), type of reward (Mann Whitney U test: jellybeans vs. stickers: Z= -0.23, N_1= 23, $N_{2=}$ 58, p= 0.82) and type of stimulus (Kruskal Wallis ANOVA: H (2, N= 81) = 0.08, p = 0.96; Mann Whitney U test: jellybeans vs. stickers: Z= -0.23, N_1= 23, $N_{2=}$ 34, p= 0.81; jellybeans vs. pebbles: Z= -0.17, N_1= 23, $N_{2=}$ 24, p= 0.87; stickers vs. pebbles: Z= -0.19, N_1= 34, $N_{2=}$ 24, p= 0.85) on the proportion of choice of the risky option.

There were no significant correlations between children's choices of the risky option and their responses to both awareness questions (Spearman correlation: first awareness question, r_s =

0.03, N = 80, p = 0.78; second awareness question, r_s = 0.07, N = 80, p = 0.55), and between latency to choose and children's choices of the risky option (Spearman correlation: r_s = -0.11, N = 81, p = 0.33).

Following the studies of Rosati and Hare (2013) and De Petrillo, Tonachella and Addessi (2017), the *individual reward sensitivity index* was calculated, by subtracting the number of choices of the risky option following one-reward outcomes from the number of choices of the risky option following seven-reward outcomes, as an index of motivation in order to investigate how previous trial outcomes impacted current trial choice. There was a marginally significant correlation between the individual reward sensitivity index and the proportion of choice of the risky option (Spearman correlation: r_s = -0.31, N = 81, p = 0.06); this correlation was significant when controlling for age (partial correlation: r_s = -0.29, N = 78, p = 0.01). There was not a significant correlation between the individual reward sensitivity index and age (Spearman correlation: r_s = -0.20, N = 81, p = 0.07).

Similarly, in the Advantageous condition, there was no effect of gender (Mann Whitney U test: Z = -0,38, N= 50, p = 0.71), type of reward (Mann Whitney U test: jellybeans vs. stickers: Z= -0.81, N_1= 5, $N_{2=}$ 45, p= 0.42) and type of stimulus (Kruskal Wallis ANOVA: H (2, N= 50) = 1.88, p = 0.39; Mann Whitney U test: jellybeans vs. stickers: Z= 0.00, N_1= 5, $N_{2=}$ 12, p= 1; jellybeans vs. pebbles: Z= -1.10, N_1= 5, $N_{2=}$ 33, p= 0.28; stickers vs. pebbles: Z= -1.05, N_1= 12, $N_{2=}$ 33, p= 0.29) on the proportion of choice of the risky option. Whereas, there was an effect of age (Kruskal Wallis ANOVA: H (2, N = 50) = 5.34, p = 0.07; Mann Whitney U test: 4-year-olds vs. 5-year-olds: Z= -2.04, N_1= 14, $N_{2=}$ 17, p= 0.04; 4-year-olds vs. 6-7-8-year-olds: Z= -0.91, N_1= 14, $N_{2=}$ 19, p= 0.36; 5-year-olds vs. 6-7-8-year-olds: Z= -1.74, N_1= 17, $N_{2=}$ 19, p= 0.08) on the proportion of choice of the risky option (as shown in Figure 12).

A non-parametric t-tests (Wilcoxon Single Sample Test) revealed that 5-year-old children made more choices of the risky option (p = 0.005) than the random level.

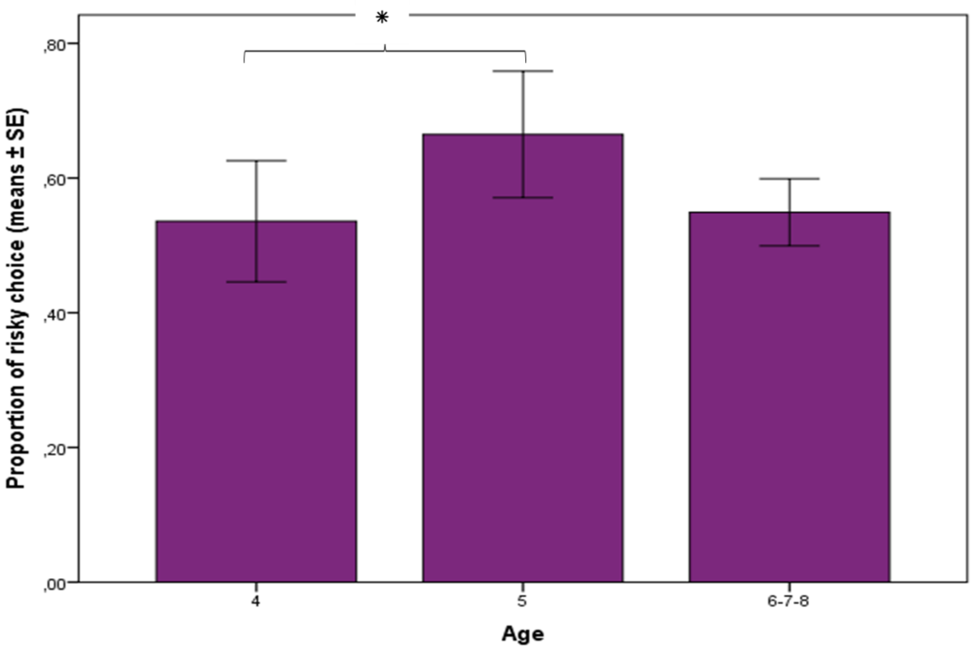

Figure 12. Probabilistic Choice Task: Age differences on the proportion of choice of the risky option in the Advantageous condition.

There was no significant correlation between children's choices of the risky option and their responses to the first awareness questions (Spearman correlation: first awareness question, $r_s = 0.20$, $N = 46$, $p = 0.19$) but there was a significant correlation between children's choices of the risky option and the second awareness question (Spearman correlation: $r_s = 0.32$, $N = 46$, $p = 0.03$). However, when controlling for age, the relation turned out non-significant (partial correlation: $r_s = 0.24$, $N = 43$, $p = 0,12$). There was neither a significant correlation between latency to choose and children's choices of the risky option (Spearman correlation: $r_s = 0.18$, $N = 49$, $p = 0.22$), nor between the individual reward sensitivity index and the proportion of choice of the risky option (Spearman correlation: $r_s = 0.17$, $N = 50$, $p = 0.24$). However, the latter correlation was significant when controlling for age (partial correlation: $r_s = 0.30$, $N = 47$, $p = 0.04$). There was not a significant correlation between the individual reward sensitivity index and age (Spearman correlation: $r_s = -0.23$, $N = 50$, $p = 0.11$).

In the Disadvantageous condition, there was no effect of gender (Mann Whitney U test: $Z = -0.26$, $N = 52$, $p = 0.79$), type of reward (Mann Whitney U test: jellybeans vs. stickers: $Z = -0.38$, $N_1 = 6$, $N_2 = 46$, $p = 0.70$) and type of stimulus (Kruskal Wallis ANOVA: $H(2, N = 52) = 0.18$, $p = 0.92$; Mann Whitney U test: jellybeans vs. stickers: $Z = -0.62$, $N_1 = 6$, $N_2 = 12$, $p = 0.54$; jellybeans vs. pebbles: $Z = -0.27$, $N_1 = 6$, $N_2 = 34$, $p = 0.79$; stickers vs. pebbles: $Z = -0.13$, $N_1 = 12$, $N_2 = 34$, $p = 0.90$) on the proportion of choice of the risky option.

A Kruskal Wallis ANOVA showed an age effect on the proportion of choice of the risky option ($H(2, N = 52) = 7.06$, $p = 0.03$). The group of older children made more risky choices than 4- and 5-year-olds (Mann Whitney U test: 4-year-olds Vs 5-year-olds: $Z = -0.28$, $N = 30$, $p = 0.78$; 4-year-olds Vs 6-7-8-year-olds: $Z = -1.99$, $N = 36$, $p = 0.05$; 5-year-olds Vs 6-7-8-year-olds: $Z = -2.42$, $N = 38$, $p = 0.02$; see Figure 13).

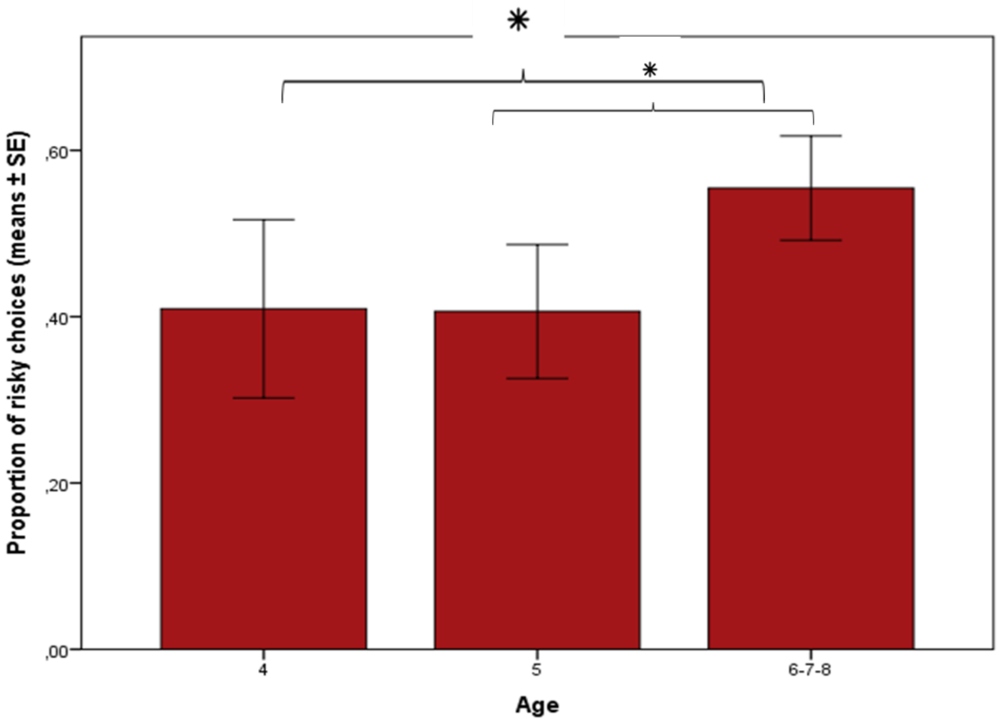

Figure 13. Probabilistic Choice Task: Age differences on the proportion of choice of the risky option in the Disadvantageous condition.

A non-parametric t-tests (Wilcoxon Single Sample Test) revealed that 5-year-old children choose the risky option below the random level in this condition ($p = 0.03$).

There were neither significant correlations between children's choices of the risky option and their responses to both awareness questions (Spearman correlation: first awareness question, $r_s = 0.24$, N = 52, $p = 0.09$; second awareness question: $r_s = -0.03$, N = 52, $p = 0.85$), nor between latency to choose and children's choice of the risky option (Spearman correlation: $r_s = -0.08$, N = 51, $p = 0.56$). There was a significant correlation between the individual reward sensitivity index and the proportion of choice of the risky option (Spearman correlation: $r_s = -0.48$, N = 52, $p < 0.01$); this correlation was significant even when controlling for age (Spearman correlation: $r_s = -0.49$, N = 49, $p < 0.01$). There was also a significant correlation between the individual reward sensitivity index and age (Spearman correlation: $r_s = -0.33$, N = 52, $p = 0.02$): the group of older children were less sensitive to rewards than four- and five-year-olds.

Evaluation of emotional correlates

Considering the whole sample, there was a significant difference between the emotions reported by the children on the 5-point rating scale depending on the outcome of their choice (Friedman's ANOVA: Chi Sqr.= 1041, $p < 0,01$, N= 1105). Children reported to feel sadder when receiving one reward than when they received four or seven rewards; furthermore they declared to feel sadder when receiving four rewards instead of seven (see Table 2). In the same way, significant differences emerged between emotion 2 and the various outcomes as shown in the table below (Table 3). In particular, children reported to feel happier when they received (i) four rewards instead of one, (ii) seven rewards instead of four.

	emotion1_outcome4 - emotion1_outcome1	emotion1_outcome7 - emotion1_outcome1	emotion1_outcome7 - emotion1_outcome4
Z	-10.006[b]	-13.036[b]	-6.379[b]
Significance	0.000	0.000	0.000

Table 2. Probabilistic Choice Task: the table reports the Wilcoxon post-hoc tests for the comparisons of emotions 1 depending on the choice outcome.

	emotion2_outcome7 vs. emotion2_outcome1	emotion2_outcome4_alternative1 vs. emotion2_outcome1	emotion2_outcome4_alternative7 vs. emotion2_outcome1	emotion2_outcome4_alternative1 vs. emotion2_outcome7	emotion2_outcome4_alternative7 vs. emotion2_outcome7
Z	-8.935	-6.027	-2.508	-3.296	-6.759
Significance	0.000	0.000	0.012	0.001	0.000

Table 3. Probabilistic Choice Task: the table reports the Wilcoxon post-hoc tests for the comparisons of emotions 2 depending on the choice outcome.

A Friedman's ANOVA carried out to investigate the coherence of children's responses to the 5-point rating scale depending on the outcome of their choices (interpreted as the ability to report emotions of happiness as a result of favorable results or sadness as a result of unfavorable outcomes) yielded a significant result (Chi Sqr.= 996, p< 0.01); in particular, there were significant differences between: (i) coherence following outcome 4 vs. coherence following outcome 1 (Z= -5.38, p< 0.01); (ii) coherence following outcome 7 vs. coherence following outcome 1 (Z= -8.01, p< 0.01); (iii) coherence following outcome 4_alternative 1 vs. coherence following outcome 1 (Z= -6.40, p< 0.01); (iv) coherence following outcome 4_alternative 7 vs. coherence following outcome 1 (Z= -4.67, p< 0.01); (v) coherence following outcome 4 vs. coherence following outcome 7 (Z= -2.57, p= 0.01); (vi) coherence following outcome 4_alternative 7 vs. coherence following outcome 7 (Z= -3.67, p< 0.01); (vii) coherence following outcome 4_alternative 1 vs. coherence following outcome 4_alternative 7 (Z= -2.46, p= 0.014). In particular, children seemed to be more coherent when they received advantageous outcomes than when they got unfavorable outcomes.

The occurrence of *switching* behavior depended on the children's choice outcomes (Friedman's ANOVA: Chi Sqr.= 1091, p< 0.01): children switched their choice more often when they received 1 or 4 rewards rather than when they obtained 7 rewards (Wilcoxon signed-ranks test: outcome 1 vs. 7: z= -2.67, p= 0.008; outcome 4 vs. 7: z= -4.08, p< 0.01; see Figure 14).

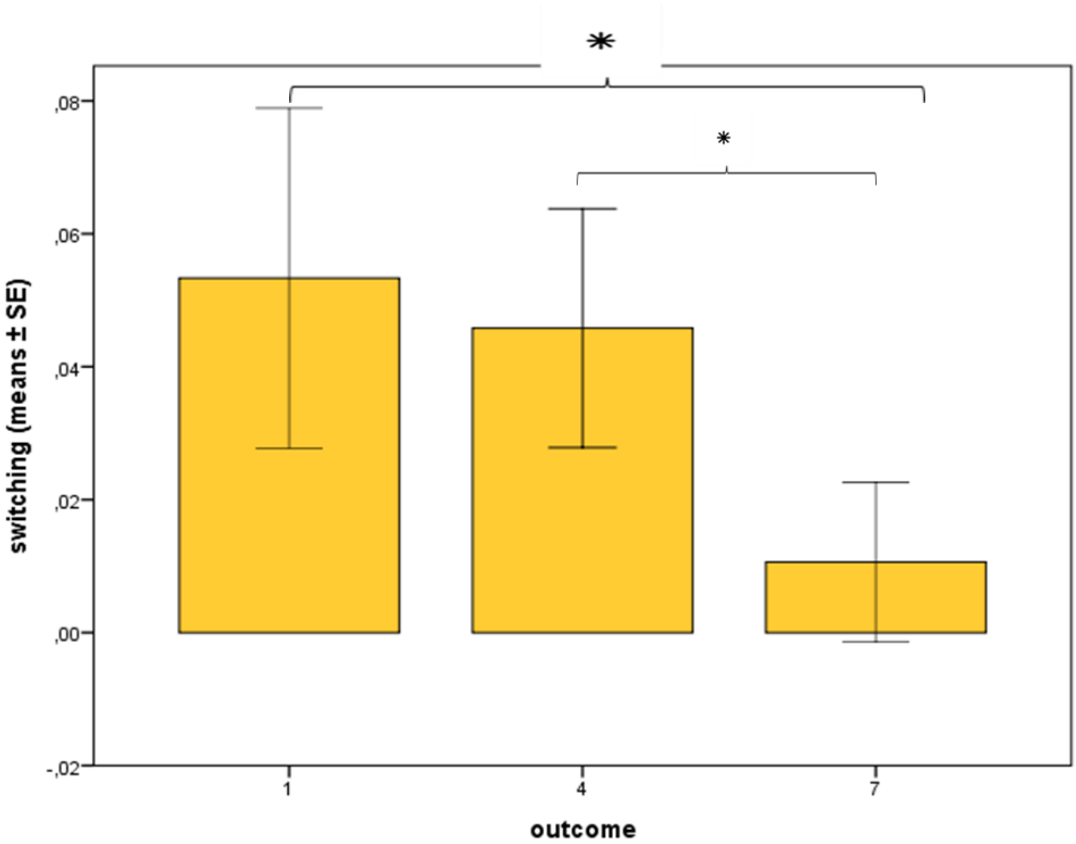

Figure 14. Probabilistic Choice Task: Switching behavior depending on the outcome of children's choice

There was no overall effect of condition on the frequency of switching (Kruskal Wallis ANOVA: H= 4,15, p= 0,13); however, children performed more switching in the Disadvantageous condition than in the Advantageous condition (Mann Whitney U test: Z= -1.94; p= 0.05; see Figure 15).

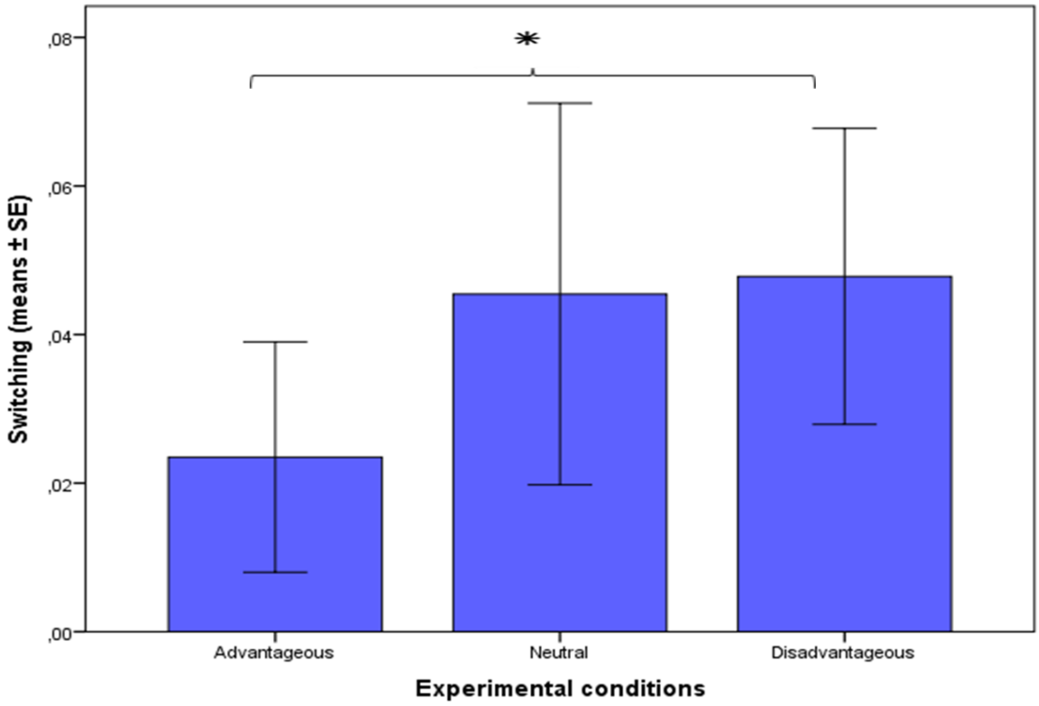

Figure 15. Probabilistic Choice Task: Switching behavior in the three experimental conditions

The correlations between the latency to choose and emotion 1 depending on the different outcome (1,4,7) were not significant (Spearman correlation: latency to choose and emotion 1 for outcome 1: r_s= 0.04, N= 343, p= 0.50; latency to choose and emotion 1 for outcome 4: r_s= 0.04, N= 525, p= 0.06; latency to choose and emotion 1 for outcome 7: r_s= 0.06, N= 327, p= 0.25). Also the correlations between the frequency of switching behavior and emotion 1 depending on the different outcomes were not significant (Spearman correlation: switching and emotion 1 following outcome 1: r_s= -0.004, N= 300, p= 0.94; switching and emotion 1 following outcome 4: r_s= 0.03, N= 526, p= 0.49; switching and emotion 1 following outcome 7: r_s= 0.04, N= 282, p= 0.47).

From the video analysis, five categories of children's behavior after choice were identified: (i) waiting strategies (34%); (ii) positive expressions (9%); (iii) negative expressions (2%); (iv) self-directed behavior (3%); (v) manipulation of experimental materials (43%) (as shown in Figure 16).

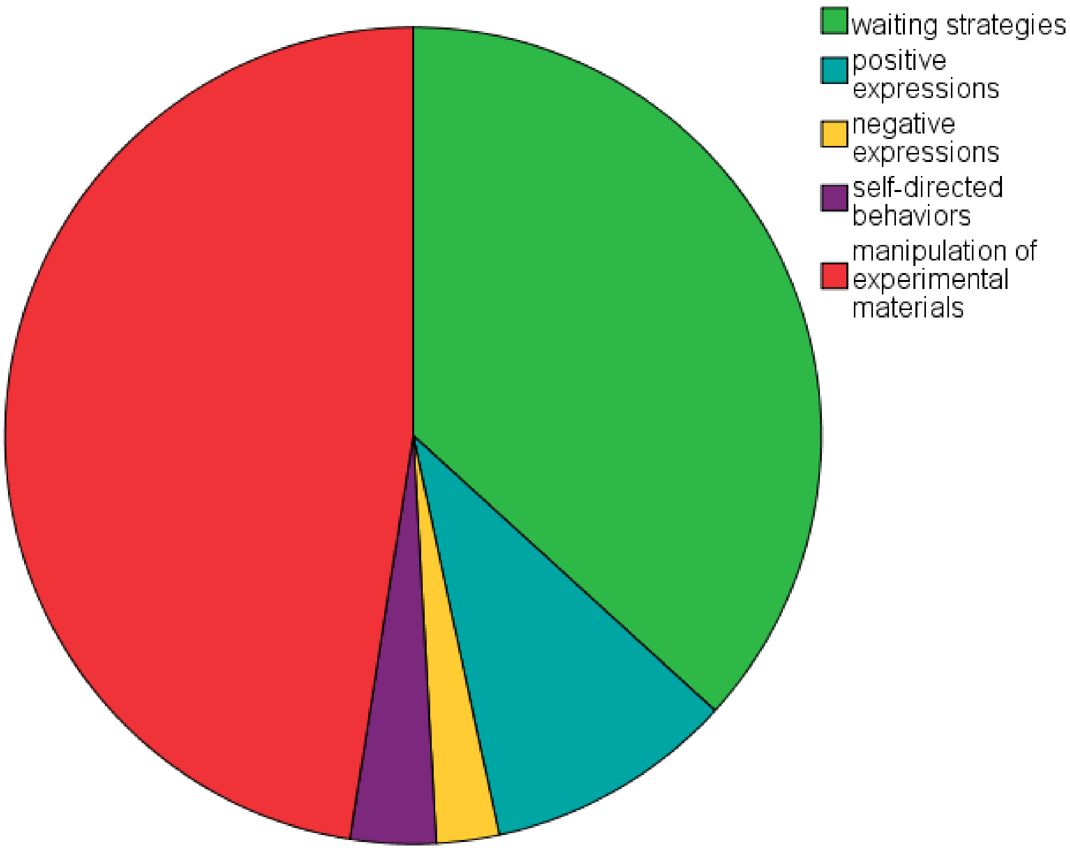

Figure 16. Probabilistic Choice Task: distribution of children's behaviors after choice

All of these behavioral categories were affected by the experimental condition: (i) children adopted waiting strategies less frequently in the Advantageous condition than in the Neutral and Disadvantageous conditions (Mann Whitney U test: Neutral vs. Advantageous: Z= -3.10, p= 0.002; Advantageous vs. Disadvantageous: Z= -2.44, p= 0.02); (ii) children showed positive expressions less frequently in the Disadvantageous condition than in the Neutral condition (Mann Whitney U test: Z= -2.29; p= 0.02); (iii) children showed more negative expressions in the Disadvantageous condition than in the Neutral condition (Mann Whitney U test: Z= -2.55, p= 0.01); (iv) children produced a lower number of self-directed behaviors in the Neutral condition than in the Advantageous and Disadvantageous conditions (Mann Whitney U test: Neutral vs. Advantageous: Z= -2.70, p= 0.007; Neutral vs. Disadvantageous: Z= -1.98, p= 0.05); (v) children manipulated the experimental materials more in the Advantageous condition than in the Neutral condition (Mann Whitney U test: Z= -2.69, p= 0.007), and more in the Disadvantageous condition than in the Advantageous condition (Mann Whitney U test: Z= -2.32, p= 0.02).

Finally, the waiting strategies were significant correlated with the outcome of children's choice (Spearman correlation: r_s= -0,089, N= 1112, p= 0,003): they employed these behaviors less when receiving seven rewards rather than one or four. Consistently, positive and negative expressions were correlated with the outcomes and the emotions indicated by children on the 5-point rating scale (Spearman correlation: positive expressions and outcome: r_s= 0.15, N= 1112, p< 0.01; positive expressions and emotion 1: r_s= 0.11, N= 1109, p< 0.01; negative expressions and outcome: r_s= -0.23, N= 1112, p< 0.01; negative expressions and emotion 1: r_s= -0.24, N= 1109, p< 001).

The role of previous outcome and emotional responses on children's subsequent choices

In order to evaluate the influence of the outcomes of previous choices on the subsequent decisions of children throughout the task, conditional fixed-effects logistic regression was performed.

In the Neutral condition, children chose the risky option more after choosing the safe option than after choosing a risky option regardless of the outcome (1 or 7) (outcome 1 vs. outcome 4: z= -9.25, p< 0.01, N= 79, number of observations= 703; outcome 7 vs. outcome 4: z= -11.06, p< 0.01, N= 79, number of observations= 703). Furthermore, they chose the risky option more after receiving outcome 1 than outcome 7 (outcome 7 vs. outcome 1: z= -2.93, p= 0.03, N= 79, number of observations= 703). In the Advantageous and Disadvantageous conditions, children chose the risky option more after choosing a safe option than after choosing a risky option, regardless of its outcome (1 or 7) (Advantageous condition: outcome 1 vs. outcome 4: z= -6.67, p< 0.01, N= 47, number of observations= 403; outcome 7 vs. outcome 4: $z= -8.12$, $p< 0.01$, $N= 47$, number of observations= 403; Disadvantageous condition: outcome 1 vs. outcome 4: $z= -6.54$, $p< 0.01$, $N= 50$, number of observations= 434; outcome 7 vs. outcome 4: $z= -4.67$, $p< 0.01$, $N= 50$, number of observations= 434). There was no significant difference between choices after receiving outcome 1 and outcome 7 (Advantageous condition: outcome 7 vs. outcome 1: $z= -0.46$, $p= 0.64$, $N= 47$, number of observations= 403; Disadvantageous condition: outcome 7 vs. outcome 1: $z= -0.40$, $p= 0.70$, $N= 50$, number of observations= 434).

In addition, it was analyzed whether the emotions indicated by children on the 5-point rating scale affected their subsequent decisions. In all conditions, children chose the risky option more when they felt sad about the outcome of their choice than when they declared to feel happy (Emotion 1: Neutral condition: very happy face vs. very sad face: $Z= -3.33$, $p= 0.001$, $N= 29$, number of observations= 255; happy face vs. very sad face: $Z= -3.23$, $p= 0.001$, $N= 29$, number of observations= 255; Advantageous condition: very happy face vs very sad face: $Z= -2.46$, $p= 0.02$, $N= 43$, number of observations= 377; happy face vs. very sad face: $Z= -4.22$, $p< 0.001$ $N= 43$, number of observations= 377; Disadvantageous condition: very happy face vs. very sad face: $Z= -3.57$, $p< 0.01$, $N= 45$, number of observations= 404; happy face vs. very sad face: $Z= -3.27$, $p= 0.001$, $N= 45$, number of observations= 404), whereas the emotions expressed after seeing the alternative option (emotion 2) did not affect the children's subsequent decisions.

3.6.2 The Children's Gambling Task

The Children's Gambling Task was administered to 111 children (22 four-year-olds, 33 5-year-olds, 50 six-seven-eight-year-olds; 51 males and 54 females); six of them did not select a minimum of 45 cards, therefore their data were excluded from statistical analysis.

For each block, the analysis of the distribution of data was performed using the Shapiro-Wilk Test. The data were not normally distributed (block 1: W = 0.93, p< 0.01; block 2: W = 0.92, p< 0.01; block 3: W = 0.95, p< 0.01; block4: W = 0.93, p< 0.01; block 5: W = 0.94, p< 0.01).

The environment where the experiment was carried out did not affect children's choices (Kruskal Wallis ANOVA: block 1: H (2, N = 105) = 3.34, p = 0.19; block 2: H (2, N = 105) = 1.44, p = 0.49; block 3: H (2, N = 105) = 0.19, p = 0.91; block 4: H (2, N = 105) = 1.12, p = 0.57; block 5: H (2, N = 105) = 1.42, p = 049). Gender did not affect children's choices as well (Mann Whitney U test: block 1: Z = -0.07, N= 105, p = 0.94; block 2: Z = -1.12, N= 105, p = 0.27; block 3: Z = -0.31, N= 105, p = 0.75; block 4: Z = -0.24, N= 105, p = 0.81; block 5: Z = -0.73, N= 105, p = 0.47). Age affected children's performance, in that in the first block 5-year-old children selected more cards from the advantageous deck than 6-7-8-year-olds (Mann Whitney U test: N= 83, Z = -2.33, p = 0.02), whereas for the other blocks this effect was not significant.

Although there were significant correlations between all blocks (Table 4), there was a marginally significant difference in performance among blocks of trials (Friedman's ANOVA: Chi Sqr. (N = 105, df = 4) = 9.05, p = 0.06). Wilcoxon post-hoc tests highlighted a significant difference between block 2 and blocks 3 and 4: children selected more cards from the disadvantageous deck in block 2 than in blocks 3 and 4, as shown in Figure 17 (block 1 vs. block 2: N = 105, z = -1.07, p = 0.29; bock 1 vs. block 3: N = 105, z = -1.04, p = 0.30; block 1 vs. block 4: N = 105, z = -1.39, p = 0,17; block 1 vs. block 5: N = 105, z = -1.19, p = 0.23; block 2 vs. block 3: N = 105, z = -2.30, p = 0.02; block 2 vs. block 4: N = 105, z = -2.24, p = 0.02; block 2 vs. block 5: N = 105, z = -1.84, p =

0.07; block 3 vs. block 4: N = 105, z = -0.16, p = 0.87; block 3 vs. block 5: N= 105, z = 0.03, p = 0.98; block4 vs. block 5: N= 105, z = -0.48, p = 0.63).

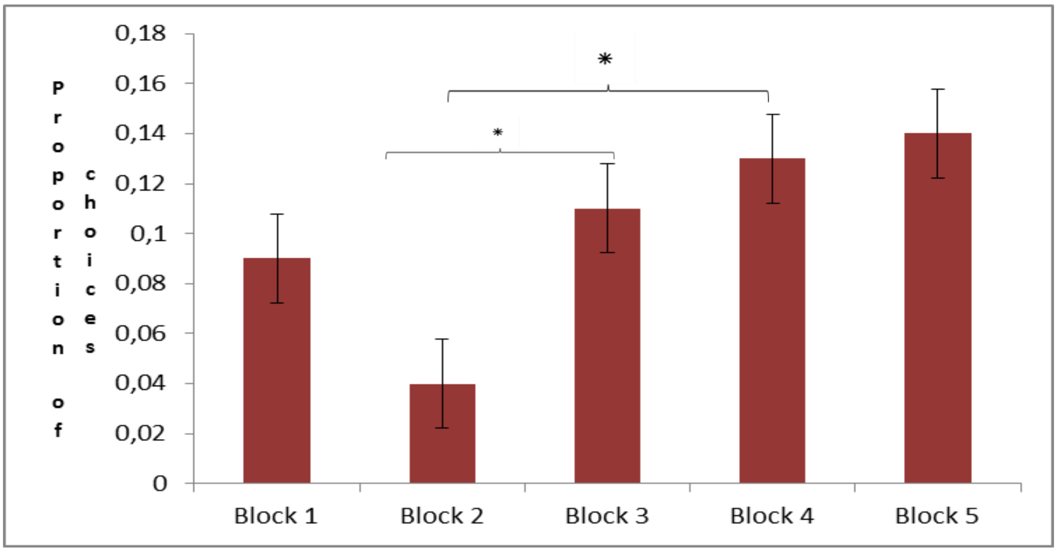

Figure 17. The Children's Gambling Task: Trend of choices throughout the Children's Gambling Task.

			Block 1	Block 2	Block 3	Block 4	Block 4
r_s Spearman	Block 1	Coefficient		.439**	401**	.492**	.376**
		Significance		0.000	0.000	0.000	0.000
		N		105	105	105	105
	Block 2	Coefficient	.439**		.749**	.672**	.424**
		Significance	0.000		0.000	0.000	0.000
		N	105		105	105	105
	Block 3	Coefficient	.401**	.749**		.735**	.504**
		Significance	0.000	0.000		0.000	0.000
		N	105	105		105	105
	Block 4	Coefficient	.492**	.672**	.735**		.564**
		Significance	0.000	0.000	0.000		0.000
		N	105	105	105		105
	Block 5	Coefficient	.376**	.424**	.504**	.564**	
		Significance	0.000	0.000	0.000	0.000	
		N	105	105	105	105	

**p= 0.01

Table 4. The Children's Gambling Task: Spearman correlations between blocks

3.6.3 The Bet Task

The Bet Task was administered to 127 children (33 four-year-olds, 40 five-year-olds, 54 six-seven-eight-year-olds, 62 males and 65 females).

Analysis of data distribution was carried out using the Shapiro-Wilk Test, which showed that data were not normally distributed ($W = 0.67$, $p < 0.01$). As for the other tasks, the environment in which the experiment was carried out and gender did not affect children's performance (Kruskal Wallis ANOVA: environment: H (2, N = 127) = 3.76, p = 0.15, Mann Whitney U test: block 1: Casa dei Bambini vs. Istituto Valente: Z= -1.77, N_1=41, N_2= 47, p= 0.08; Casa dei Bambini vs. laboratory: Z= -0.43, N_1=41, N_2= 17, p= 0.67; Istituto Valente vs. laboratory: Z= -0.99, N_1=47, N_2= 17, p= 0.32; block 2: Casa dei Bambini vs. Istituto Valente: Z= -0.55, N_1=41, N_2= 47, p= 0.56; Casa dei Bambini vs. laboratory: Z= -0.70, N_1=41, N_2= 17, p= 0.49; Istituto Valente vs. laboratory: Z= -1.23, N_1=47, N_2= 17, p= 0.22; block 3: Casa dei Bambini vs. Istituto Valente: Z= -0.35, N_1=41, N_2= 47, p= 0.72; Casa dei Bambini vs. laboratory: Z= -0.38, N_1=41, N_2= 17, p= 0.71; Istituto Valente vs. laboratory: Z= -0.08, N_1=47, N_2= 17, p= 0.93; block 4: Casa dei Bambini vs. Istituto Valente: Z= -0.07, N_1=41, N_2= 47, p= 0.94; Casa dei Bambini vs. laboratory: Z= -1.06, N_1=41, N_2= 17, p= 0.29; Istituto Valente vs. laboratory: Z= -0.90, N_1=47, N_2= 17, p= 0.37; block 5: Casa dei Bambini vs. Istituto Valente: Z= -0.30, N_1=41, N_2= 47, p= 0.76; Casa dei Bambini vs. laboratory: Z= -0.99, N_1=41, N_2= 17, p= 0.32; Istituto Valente vs. laboratory: Z= -1.14, N_1=47, N_2= 17, p= 0.25; Mann Whitney U test: gender: Z= -0,30, N= 127, p= 0,77), whereas there was a marginally significant effect of age on the percentage of tosses performed (Kruskal Wallis: H (2, N = 127) = 5.51, p = 0.06). The oldest group of children decided to bet more frequently than 5-year-olds, whereas there were no significant differences between the other age groups (Mann Whitney U test: 4-year-olds vs. 5-year-olds: Z= -0.07, N_1= 33, N_2= 40, p= 0.48; 4-year-olds vs. 6-7-8-year-olds: Z= -1.43, N_1= 33, N_2= 54, p= 0.15; 5-year-olds vs. 6-7-8-year-olds: Z= -2.32, N_1= 40, N_2= 54, p= 0.02; see Figure 18).

There was no significant correlation between the percentage of tosses performed and the winning frequency ($r_s = 0.08$, $N = 127$, $p = 0.40$).

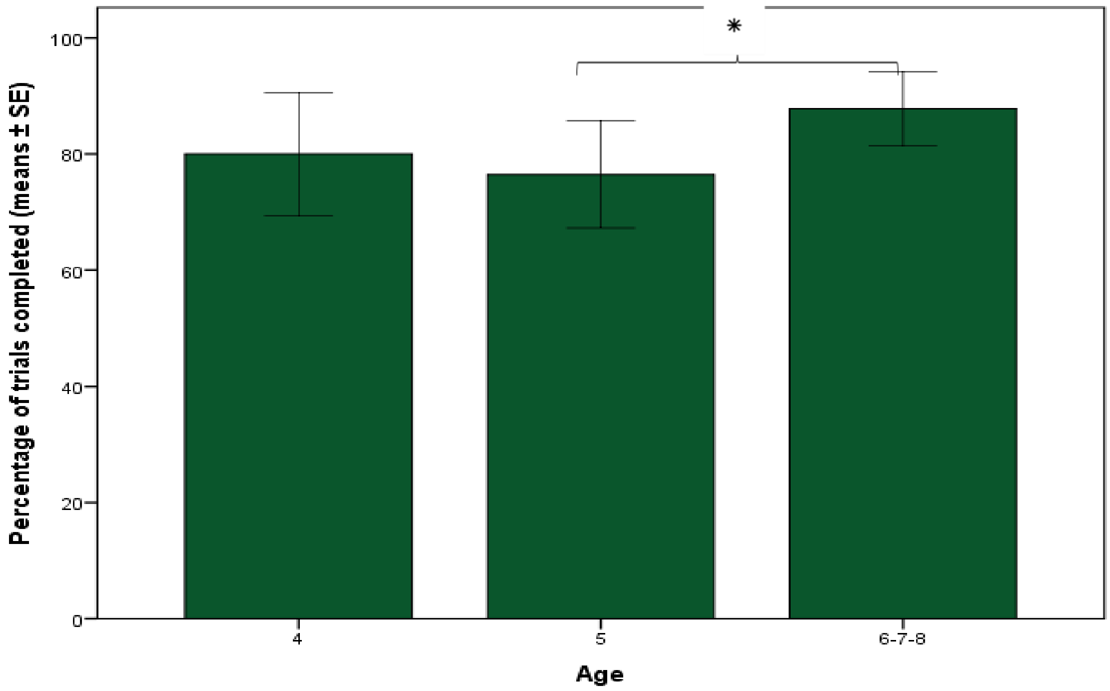

Figure 18. The Bet Task: Percentage of trials completed depending on age.

Evaluation of emotional correlates

The outcome of children's throws significantly affect the coherence of their responses to the 5-point rating scale (Friedman's ANOVA: Chi Sqr.= 183,19, p< 0,01). Specifically, children were more coherent when they won the bet compared to when they lost it (Figure 19).

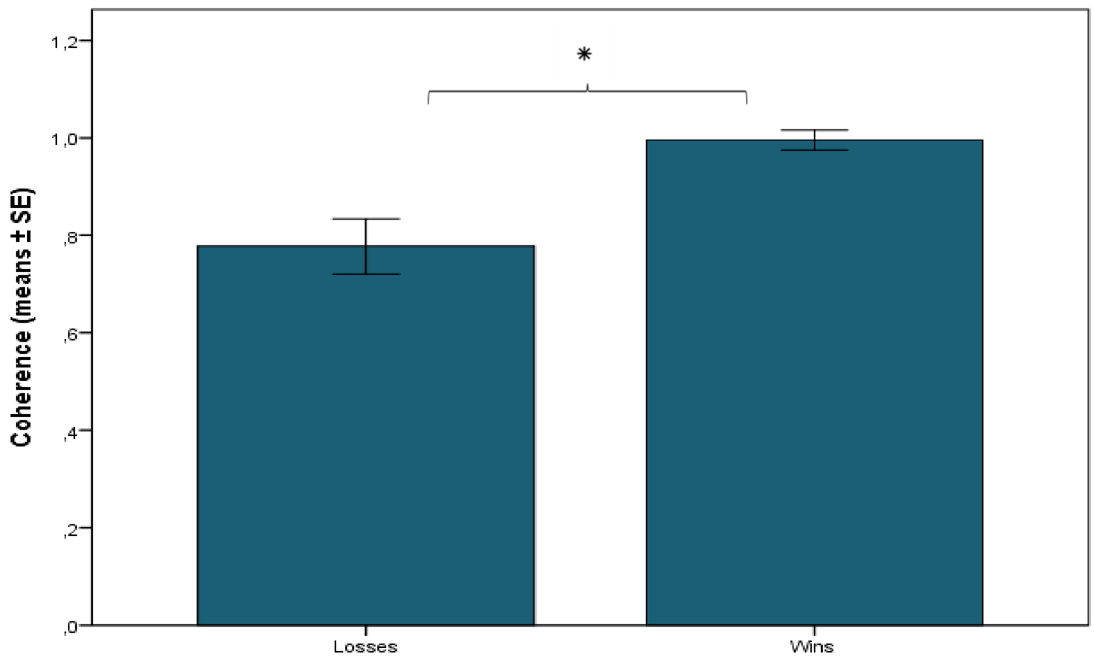

Figure 19. The Bet Task: Coherence of children responses to the 5-point rating scale according to the outcome of their bet

After the outcome of the coin toss, the same categories of behaviors scored in the Probabilistic Choice Task were identified (waiting strategies 39%, positive expressions 29%, negative expressions 12%, self-directed behaviors 3%, manipulation of experimental material 49%). When winning, children exhibited more waiting strategies, positive expressions and manipulation of experimental material than when losing (Mann Whitney U test: waiting strategies: Z= -4.61, p< 0.01; positive expressions: Z= -12.35; p< 0.01; manipulation of experimental material: Z= -3.75, p< 0.01).

3.6.4 Correlations between different tasks

The relation between performance in the Probabilistic Choice Task, the Children Gambling Task and the Bet Task was assessed. Specifically, I calculated the correlation between the proportion of choice of the risky option and the choices made by children in each CGT block, by controlling for age, BIN 4-6 battery total score, and Peabody Test standardized score in each condition of the Probabilistic Choice Task (see Tables 5, 6, 7).

	Advantageous	Neutral	Disadvantageous
Block 1	**r=0.41 p=0.01 N=37**	r=0.02 p=0.93 N=23	r=0.07 p=0.65 N=36
Block 2	r=0.26 p=0.11 N=37	r=-0.17 p=0.43 N=23	r=-0.14 p=0.39 N=36
Block 3	r=0.10 p=0.53 N=37	r=0.20 p=0.35 N=23	r=-0.18 p=0.29 N=36
Block 4	r=0.14 p=0.39 N=37	r=-0.03 p=0.89 N=23	r=-0.13 p=0.45 N=36
Block 5	r=0.13 p=0.45 N=37	r=-0.06 p=0.77 N=23	r=-0.26 p=0.11 N=36

Table 5. Partial correlation between the frequency of choice of the risky option and each block of the CGT by controlling for age. Significant correlations are indicated in bold type.

	Advantageous	Neutral	Disadvantageous
Block 1	**r=0.34 p=0.05 N=32**	r=0.23 p=0.31 N=20	r=-0.02 p=0.91 N=35
Block 2	r=0.31 p=0.08 N=32	r=-0.05 p=0.81 N=20	r=-0.15 p=0.39 N=35
Block 3	r=0.20 p=0.25 N=32	r=0.27 p=0.23 N=20	r=-0.28 p=0.09 N=35
Block 4	r=0.18 p=0.30 N=32	r=0.01 p=0.97 N=20	r=-0.18 p=0.29 N=35
Block 5	r=0.11 p=0.56 N=32	r=-0.01 p=0.98 N=20	r=-0.31 p=0.06 N=35

Table 6. Partial correlation between the frequency of choice of the risky option and each block of the CGT by checking for the total score obtained in the BIN 4-6 battery.

	Advantageous	Neutral	Disadvantageous
Block 1	**r=0.42 p=0.008 N=36**	r=0.19 p=0.37 N=22	r=0.05 p=0.79 N=36
Block 2	r=0.24 p=0.14 N=36	r=0.02 p=0.94 N=22	r=-0.13 p=0.45 N=36
Block 3	r=0.05 p=0.76 N=36	r=0.28 p=0.19 N=22	r=-0.25 p=0.13 N=36
Block 4	r=0.11 p=0.52 N=36	r=0.09 p=0.69 N=22	r=-0.17 p=0.32 N=36
Block 5	r=0.09 p=0.61 N=36	r=0.05 p=0.82 N=22	r=-0.29 p=0. 08 N=36

Table 7: Partial correlation between the frequency of choice of the risky option and each block of the CGT by checking for the total score obtained in the BIN 4-6 battery.

Moreover, the correlation between the proportion of choice of the risky option in each condition of the Probabilistic Choice Task and the percentage of tosses realized in the Bet Task was not significant (Neutral condition: r_s= 0.03, p= 0.87, N= 27; Disadvantageous condition: r_s= 0.21, p= 0.13, N= 51; Advantageous condition: r_s= 0.05, p= 0.71, N= 49). There relations were not significant even when controlling for age, total score obtained in the BIN 4-6 battery and the standardized score obtained in the Peabody Test (see Table 8).

	Age	BIN 4-6 battery	Peabody Test
Neutral	r=0.09 p=0.66 N=24	r=0.15 p=0.47 N=23	r=-0.03 p=0.91 N=21
Advantageous	r=0.08 p=0.57 N=46	r=0.07 p=0.66 N=45	r=0.03 p=0.85 N=39
Disadvantageous	r=0.15 p=0.30 N=48	r=0.14 p=0.32 N=48	r=0.22 p=0.13 N=47

Table 8: Partial correlations between the percentage of trials completed in the Bet Task and the proportion of choices of the risky option in each condition of the Probabilistic Choice Task by controlling for age, the total score obtained in the BIN 4-6 battery and the standardized score obtained at the Peabody Test.

Similarly, no significant correlation emerged between performance in each block of the Children's Gambling Task and the percentage of tosses performed in the Bet Task (see Table 9).

			Block 1	Block 2	Block 3	Block 4	Block 5	percentage of tosses performed
r_s Spearman Coefficient	Block 1	Coefficient		.439**	.401**	.492**	.376**	-0.072
		Significance		0.000	0.000	0,000	0,000	0.472
		N		105	105	105	105	103
	Block 2	Coefficient	.439**		.749**	.672**	.424**	0.106
		Significance	0.000		0.000	0.000	0.000	0.285
		N	105		105	105	105	103
	Block 3	Coefficient	.401**	.749**		.735**	.504**	0.013
		Significance	0.000	0.000		0.000	0.000	0.899
		N	105	105		105	105	103
	Block 4	Coefficient	.492**	.672**	.735**		.564**	-0.115
		Significance	0.000	0.000	0.000		0.000	0.246
		N	105	105	105		105	103
	Block 5	Coefficient	.376**	.424**	.504**	.564**		-0.071
		Significance	0.000	0.000	0.000	0.000		0,475
		N	105	105	105	105		103
	percentage of tosses performed	Coefficient	-0.072	0.106	0.013	-0.115	-0.071	
		Significance	0.472	0.285	0.899	0.246	0.475	
		N	103	103	103	103	103	

**. p= 0.01

Table 9. Correlations between the percentage of tosses performed in the Bet Task and children's performance in each block of the CGT.

The total score obtained in the BIN 4-6 battery was affected by age (Kruskal Wallis: H (2, N= 179)= 91.90, $p< 0.01$). In particular, 6-7-8 years old children performed better than 4- and 5-year-olds, and the 5-year-old children performed better than 4-year-olds (Mann Whitney U test: 4-year-olds vs. 5-year-olds: Z= -6.22, N_1= 58, N_2= 64, $p< 0.01$; 4-year-olds vs. 6-7-8-year-olds: Z= -8.45, N_1= 58, N_2= 57, $p< 0.01$; 5-year-olds vs. 6-7-8-year-olds Z= -5.67, N_1= 64, N_2= 57, $p< 0.01$).

When controlling for age, there were no significant correlations between children's performances in the Children's Gambling Task and in the Bet Task, respectively, and the scores obtained in the BIN 4-6 battery (partial correlation: CGT: block 1: r_s= 0.04, N= 93, p= 0.72; block 2: r_s= -0.10, N= 93, p= 0.32; block 3: r_s= -0.08, N= 93, p= 0.46; block 4: r_s= -0.06, N= 93, p= 0.55; block 5: r_s= -0.14, N= 93, p= 0.18. Bet Task: r_s= 0.02, N= 113, p= 0.82). In contrast, the proportion of choice of the risky option in each condition of the Probabilistic Choice Task was related with some areas of the BIN 4-6 battery, when controlling for age. In particular, in the Neutral condition the proportion of choice of the risky option was significant correlated with children's performance in the Lexical area (partial correlation: rs= 0.23, N= 73, p= 0.046), in the Advantageous condition it was correlated with children's performance in the Pre-syntactic area (partial correlation: rs= 0.38, N= 43, p= 0.01), and in the Disadvantageous condition it was correlated with children's performance in the Counting area (partial correlation: rs= 0.29, N= 47, p= 0.043). Furthermore, the two awareness questions were correlated with the scores obtained in the BIN 4-6 battery (see table 10).

	First awareness question*	Second awareness question *
Total score of the lexical area	0,44 **p< 0,01**	0,58 **p< 0,01**
Total score of the semantic area	0,43 **p< 0,01**	0,58 **p< 0,01**
Total score of the counting area	0,45 **p< 0,01**	0,62 **p< 0,01**
Total score of the pre-syntactical area	0,44 **p< 0,01**	0,63 **p< 0,01**
Total score of BIN battery	0,46 **p< 0,01**	0,63 **p< 0,01**

Table 10. Partial correlations between the two awareness questions and the scores obtained in the BIN 4-6 battery.

Conversely, children's performances in the three gambling tasks did not correlate with the standard score obtained in The Peabody Test (Probabilistic Choice Task: r_s= 0.04, N= 165, p= 0.59; CGT: block 1: r_s= -0.02, N= 96, p= 0.85; block 2: r_s= -0.11, N= 96, p= 0.27; block 3: r_s= -0.04, N= 96, p= 0.67; block 4: r_s= -0.07, N= 96, p= 0.50; block 5: r_s= -0.11, N= 96, p= 0.28; Bet Task: r_s= 0.001, N= 116, p= 0.99).

3.6.5 Thermal data results

The performance in the Probabilistic Choice Task of a sample of 15 children (4 five-year-olds, 6 six-year-olds, 2 seven-year-olds, 3 eight-year-olds; 7 males and 8 females) was recorded by using an infrared thermal camera. Eight children were tested in the Disadvantageous condition and 7 children were tested in the Advantageous condition.

To assess whether the slope of the thermal signal was affected by phase (phase 1, phase 2 and phase 3 which constituted the task, see paragraph 3.4.2), outcome (1, 4, 7), alternative option (1, 4, 7), and trial number a fixed-effects within-subject regression was performed. There were no significant interactions between outcome and phase (F(4, 396)= 0.37, p= 0.83) and between alternative option and phase (F(4, 396)= 0.33, p= 0.86). None of the variables of interest affected the slope of the thermal signal during the task (phase 1 vs. phase 2: t= 0.92, p= 0.36; phase 1 vs. phase 3: t= 0.04, p= 0.97; phase 2 vs. phase 3: t= -0.88, p= 0.38. Outcome 1 vs. outcome 4: t= -1.22, p= 0.23; outcome 1 vs. outcome 7: t= -0.35, p= 0.73; outcome 4 vs. outcome 7: t= 1.10, p= 0.27. Alternative option 1 vs. alternative option 4: t= -0.33, p= 0.74; alternative option 1 vs. alternative option 7: t= -0.16, p= 0.86; alternative option 4 vs. alternative option 7: t= 0.22, p= 0.82. Trial: t= -1.61, p= 0.10).

Chapter Four - Discussion

The aim of the present study was to assess preschool and school age children's preferences in the context of uncertainty and to evaluate their ability to make advantageous decisions in risky situations.

To this purpose, 183 children from age four to eight years were administered a battery of tasks, including three gambling tasks: the Probabilistic Choice Task, The Children's Gambling Task and the Bet Task. In the Probabilistic Choice Task, children faced a series of choices between a safe option, yielding always four rewards, and a risky option, yielding either one or seven rewards with different probabilities, according to the experimental condition. Overall, children preferred more the risky option in the Advantageous condition, in which the probability to get the larger reward was higher than in the other two conditions. Thus, it seems that children were able to make advantageous choices, by taking into account the probabilities of the different outcome of their decisions. This result is in line with previous findings which provided evidence in favor of a functional understanding of probability and expected value in young children (Schlottmann and Anderson 1994, Harbaugh et *al*. 2002). In this sample, five years old children significantly preferred the risky option in the Advantageous condition and significantly preferred the same option in the Disadvantageous condition, whereas the same did not hold true for four- and six-seven-eight-year-olds. These data are consistent with previous findings which highlighted an improvement with age in the ability to make advantageous choices in gambling tasks, also depending on the neural maturation, which gradually continues in the course of development (Crone et *al*., 2005, 2007; Bunch et *al*., 2007 Gao et *al*., 2009; Steelandt et *al*., 2013). However, surprisingly, in this sample older children did not utilize the same maximizing strategy as the five-year-olds. This result cannot be explained by a lack of comprehension of the task, since, six, seven and eight years old children gave more correct answers to both awareness questions compared to the youngest children. This difference was possibly due to other factors that characterized the two groups. Indeed, analyzing the level of education of their parents, a significant difference between the two groups emerged: the level of education of the parents of six-seven-eight-year-olds was lower than the one of the five years old children’s parents, and it is known that the level of education and the socio-economic origin are inversely proportional to the commitment to gambling activities (as reviewed in Serpelloni, 2013, and Bastiani et *al*., 2013). Another explanation of our result could be that older children were more involved in gambling activities during daily routines. While parents tend to monitor and prevent preschoolers from using tablets and smartphones, in the transition from preschool to elementary school children have more opportunities to be involved with their peers in these attractive activities, without the adults’ supervision. The advent of the internet and new digital technologies has undoubtedly made gambling activities more accessible, bringing them closer to a public generally far away from gaming rooms, such as children. In particular, online gambling offers extremely exciting and engaging graphics and messages, attracting a very young target: a survey conducted by Datanalysis and presented to the “International pediatric congress on environment, nutrition and skin diseases” in 2014, reports that about 400,000 children between seven and nine years old have already been introduced in the world of instant lotteries, sports betting and online gambling by parents, relatives or friends. Recently, the so-called "ticket redemption", the slot machine for children, is becoming increasingly popular. The game consists in inserting a coin, pushing a button, shooting at a target and trying to win a "ticket". More tickets are accumulated, more precious is the prize that can be withdrawn (e.g. Ipad, ultimate Mp3, cell phones, wristwatches, toy cars, dolls, necklaces and bracelets). Although they differ from adult gambling due to some features such as the lack of money-making (which makes these slot machines perfectly legal) and the implication of a certain degree of skill in acquiring tickets, the "ticket redemption" have remarkable similarities with classic slot machines for the game dynamics and for the presence of a prize; hence, it is likely to experience frustration when not receiving any reward, despite the commitment and the money paid, losing the playful aspect of the game. It is possible that the older children in the current study were more engaged and more familiar with the dynamics of gambling than the preschool children, as shown by the fact that in the Bet Task they decided to bet significantly more than five-year-olds. Moreover, older children were also less sensitive to disparities in the reward outcome: in particular, in the Neutral and Disadvantageous conditions, in which the probabilities to get only one reward were higher than in the Advantageous condition, children less sensitive to rewards chose significantly more the risky option than children with a high reward sensitivity index.

However, based on the optimal decisions made by five-year-olds, it might be hypothesized that their probabilistic reasoning skills were overestimated, relying on classical theories on the development of the concept of probability, which declared that young children do not understand the concept of chance and that they are not able to reason in probabilistic terms before the age of seven (Piaget & Inhelder, 1975). However, several studies showed that five years old children made optimal decisions in probabilistic tasks, in which they had to evaluate the chances of two alternatives (Reyna & Brainerd, 1994; Girotto, Fontanari, Gonzalez, Vallortigara & Blaye, 2016). Among factors that could explain conflicting evidences in the literature, Girotto et *al*. (2016) enumerate task complexity, limits in inhibitory control at different ages, implicit versus explicit understanding of probabilities and the idea that the development of probability understanding may not follow a linear trajectory. Thus, according to these more recent evidences, the difference found in the current study between five-year-olds and older children should be better investigated and further studies are needed to extensively investigate the emergence and the development of this important but neglected ability.

The lack of correlation between the proportion of choice of the risky option and the two awareness questions was probably due to the fact that the two dependent variables considered require two different types of processes: implicit understanding of the task when choosing between the two conflicting options and explicit understanding of it when answering to the two awareness questions. It may be expected that these two levels of understanding interact later in development, as a difficulty in metacognitive reasoning on the maladaptive choices has been documented in adult pathological gamblers (Brevers et *al.*, 2012).

As for the analysis of the emotional correlates using the Weisberg and Beck's (2011) 5-point rating scale, when considering the whole sample children reported their emotions coherently with the outcomes of their choices, confirming the reliability of this measure. Children's emotions were affected by choice outcomes and experimental conditions. Moreover, adopting waiting strategies seemed to help children to tolerate the frustration of unfavorable outcomes, since these behaviors occurred significantly more often when children won only one reward and in the Disadvantageous condition than in the Advantageous condition. As for adults and some non-human primates (Troisi, 2002), implementing this kind of activities could help children to cope with stressful situations, and these behaviors could also be the expression of a negative emotion, such as frustration, following an unfavorable outcome (Pecora, Addessi, Schino & Bellagamba, 2014).

Furthermore, in all three conditions, children chose significantly more the risky option after choosing a safe option, than after choosing a risky option. Only in the Neutral condition, children preferred to choose the risky option after receiving only one reward than when they won seven rewards. This result could be related to the characteristics of the condition itself, in which the two alternatives (one or seven rewards), linked to the choice of the risky option, had the same probability to occur. Even in this case, children might have reasoned in probabilistic terms by implementing a "loss-stay" strategy, expecting the larger reward after receiving an unfavorable outcome. Otherwise, this result could also be explained in terms of perseverative errors, in agreement with previous findings which showed that children are less able to shift their decision's strategy after a negative feedback than adolescents and adults (Crone, Somsen, Zanolie & van der Molen, 2006).

Emotional responses affected children’s subsequent choices. Children preferred to choose the risky option more when they reported to feel sad or very sad about the outcome of their previous choice. However, the emotions declared after seeing the unchosen option did not affect children’s subsequent decisions. Thus, it seems that children did not experience regret about their choices, focusing their attention only on what they have won and not on what they could have received. This may be due to the fact that this task did not imply losses that could cause a feeling of regret in children. This interpretation is also coherent with the thermal data analysis. The lack of a loss could have made this task not salient enough at the emotional level, since there was no variation in sympathetic activation following the outcomes of the choices made by the children during the task compared to the baseline.

In the Children’s Gambling Task, children appeared to adopt a choice’s strategy, that they maintained throughout the test, since the performance in the five blocks of trials were positively correlated with each other. Overall, the trend of choices throughout the blocks resulted advantageous. Once again, the five-year-olds, already from the first block, were able to select more cards from the advantageous deck than the older children.

In the Bet Task, as mentioned above, six-seven-eight-year-olds decided to bet more often than five years old children, and overall children’s will to bet was not affected by the frequency of winning. The coherence of emotional responses differed between the events of wins or losses. When winning, children gave more coherent responses than when loosing. It might be hypothesized that the lower coherence of responses following a loss was due to coping strategies that children used to conceal the presence of a negative feeling caused by the loss of their rewards, so that they hid their frustration declaring to feel happy anyway (Manstead, 1995; Cole, 1986); thus, in future studies, it would be interesting to analyze their emotional reactions also at a physiological level by means of infrared thermography.

In relation to linguistic and mathematical reasoning, our results show that children's performances in the three gambling task was not affected by their level of linguistic understanding; whereas some of their numerical skills were positively correlated with the proportion of choice of the risky option in the Probabilistic Choice Task. Interestingly, the answers to the two awareness questions were related with the scores obtained in the different areas investigated by the BIN 4-6 battery, highlighting the key role of numerical skills in the comprehension of the task. Children that gave more correct answers to these questions were also those that demonstrated better numerical reasoning skills. Although the abilities evaluated by this battery were not as sophisticated as probabilistic reasoning, they constituted an essential prerequisite for understanding and achieving success in the Probabilistic Choice Task.

Finally, the lack of correlation between the three different gambling tasks (with the only exception of the correlation between the first block of the CGT and the proportion of risky choices in the advantageous condition of the Probabilistic Choice Task) might suggest that these tasks investigate different aspects of risk propensity, confirming that it is a multi-faceted and multi-dimensional construct.

In future studies, it would be important to deepen the analysis of emotional responses through infrared thermography, by expanding the sample and by performing an individual analysis of children's performance in a choice task. In addition, in order to have a more complete picture of children's decision-making under risk, it would be recommended to integrate the experimental procedure with other tools, such as questionnaires to evaluate the emotional-adaptive functioning of children and of their parents.

The evidence provided by various authors in favor of an early development of risk propensity suggests important future clinical and educational applications. Further developmental research highlighting both cognitive and emotional mechanisms and processes involved in decision-making under risk may be helpful to identify strategies and biases in subjects prone to engaging in risky behaviors that may eventually lead to future behavioral disorders and diseases (as pathological gambling), thus allowing the development of early intervention programs. Given the premature involvement of children in gambling activities, prevention acquires a key role: selective prevention, especially aimed at children, is particularly effective, allowing early detection of vulnerability and potentially risky behaviors, permitting focused intervention programs (Serpelloni, 2013). To plan prevention actions, it will be crucial to fully understand factors and mechanisms underlying risk propensity. Thus, it is important to keep exploring this topic since early childhood, hopefully with a multidisciplinary approach that manages to combine different experimental methods in order to achieve solid results.

Bibliography

Aïte, A., Cassotti, M., Rossi, S., Poirel, N., Lubin, A., Houdé, O., Moutier, S. (2012). Is human decision making under ambiguity guided by loss frequency regardless of the costs? A developmental study using the Soochow Gambling Task. *Journal of Experimental Child Psychology* ,113, 286–294.

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing.

Andersen, Steffen, Harrison, Glenn W., Lau, Morten I., & Rutström, E. Elisabet (2006). Dual criteria decisions. Working Paper 06-11, Department of Economics, College of Business Administration, University of Central Florida.

Andersen, Steffen, Harrison, Glenn W., Lau, Morten I., & Rutström, E. Elisabet (2008b). Risk aversion in game shows. In J. C. Cox & G.W. Harrison (Eds.). *Risk aversion in experiments* (Vol. 12). Bingley, UK: Emerald, Research in Experimental Economics.

Andersen, S., Harrison, G.W., Lau, M.I., Rutstrom, E.E. (2010). Behavioral econometrics for psychologists. *Journal of Economic Psychology* 31. 553–576.

Andrews, G., & Moussaumai, J., (2015). Improving children's affective decision making in the Children's Gambling Task. *Journal of Experimental Child Psychology*, 139, 18–34.

Audusseau, J., & Juhel, J., (2015). Working Memory in Children Predicts Performance on a Gambling Task. *The Journal of Genetics Psychology*, 176 (1), 38-54.

Aureli T., Grazia A., Cardone D., Merla A. (2015). Behavioral and facial thermal variations in 3-to 4-month-old infants during the Still-Face Paradigm. Front. Psychol. 6:1586.

Bastiani, L., Gori, M., Colasante, E., Siciliano, V., Capitanucci, D., Jarre, P., & Molinaro, S. (2013). Complex factors and behaviors in the gambling population of Italy. Journal of Gambling Studies, 29(1), 1-13.

Bechara,A., Damasio, A., R., Damasio, H., Anderson, S.W., (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, Vol 50(1-3), pp. 7-15.

Bechara, A., Tranel, D., Damasio, H., Damasio, A.R., (1996). Failure to Respond Autonomically to Anticipated Future Outcomes Following Damage to Prefrontal Cortex. *Cerebral Cortex*, 6:215-225.

Beitz, K. M., Salthouse, T.A., Davis, H.P., (2014). Performance on the Iowa Gambling Task: From 5 to 89 Years of Age. *Journal of Experimental Psychology*: General, Vol. 143, No. 4, 1677–1689.

Bell, D. E. (1985). Disappointment in decision making under uncertainty. Operations Research, 33(1), 1-27.

Berkovitz B. Kirsch C. Moxham JB. Alusi G. Cheesman T. 3D Head and Neck Anatomy with Special Senses and Basic Neuroanatomy. United Kingdom: Primal Pictures; 2013.

Bernoulli, D. (1954). [1738] Exposition of a New Theory on the Measurement of Risk. Econometrica, 22, 23–36.

Boyer, Ty.W., (2006). The development of risk-taking: A multiperspective review. *Development review*, 26, 291-345.

Brevers, D., Cleeremans, A., Bechara, A., Greisen, M., Kornreich, C., Verbanck, P., Noe¨l, X. (2012). Impaired Self-Awareness in Pathological Gamblers. *J Gambl Stud*, 29:119–129

Bunch, K.M., Andrews, G., Halford G. S., (2007). Complexity effects on the children's gambling task. *Cognitive Development*, 22, 376-383.

Burnett, S., Bault, N., Coricelli, G., Blakemore, S., (2010). Adolescents' heightened risk-seeking in a probabilistic gambling task. *Cognitive Development* 25, 183–196.

Byrnes, J. P., Miller, D. C., & Schafer, W. D. (1999). Gender differences in risk taking: A meta-analysis. *Psychological Bulletin*, 125, 367.

Camille, N., Coricelli, G., Sallet, J., Pradat-Diehl, P., Duhamel, J. R., & Sirigu, A. (2004). The involvement of the orbitofrontal cortex in the experience of regret. Science, 304, 1167-1170.

Carlson, S.M., Zayas, V., Guthormsen, A., (2009). Neural Correlates of Decision Making on a Gambling Task. *Child Development*, 80, 4, 1076–1096.

Cauffman, E., & Steinberg, L. (2000). (Im)maturity of judgment in adolescence: Why adolescents might be less culpable than adults? *Behavioral Sciences and the Law, 18*, 741–760.

Cole, P. (1986). Children's Spontaneous Control of Facial Expression. *Child Development*. Vol. 57, No. 6, pp. 1309-1321

Cooper, M. L., Agocha, V. B., & Sheldon, M. S. (2000). A motivational perspective on risky behaviors: the role of personality and affect regulatory processes. *Journal of Personality, 68*, 1059–1088.

Cooper, M. L., Wood, P. K., Orcutt, H. K., & Albino, A. (2003). Personality and the predisposition to engage in risky or problem behaviors in adolescence. *Journal of Personality and Social Psychology, 84*, 390–410.

Coricelli, G., Dolan, R. J., & Sirigu, A. (2007). Brain, emotion and decision making: the paradigmatic example of regret. Trends in Cognitive Sciences, 11, 258-265.

Crone, E.A., Bunge, S.A., Latenstein, H., van der Molen, M.W., (2005). Characterization of children's decision making: sensititvity to punishment frequency, not task complexity. *Child Neuropsychology*, 11: 245–263.

Crone, E. A., Somsen, R. J. M., Zanolie, K., & van der Molen, M. W. (2006). A heart rate analysis of developmental change in feedback processing and rule shifting from childhood to early adulthood. Journal of Experimental Child Psychology, 95, 99–116.

Crone, E.A., & van der Molen, M.W., (2004). Developmental Changes in Real Life Decision Making: Performance on a Gambling Task Previously Shown to Depend on the Ventromedial Prefrontal Cortex. *Developmental Neuropsychology*, *25*(3), 251–279.

Crone, E.A., & van der Molen, M.W., (2007). Development of Decision Making in School-Aged Children and Adolescents: Evidence From Heart Rate and Skin Conductance Analysis. *Child Development*, 78, 4, 1288 – 1301.

Denison, S., & Xu, F., (2014). The origins of probabilistic inference in human infants. *Cognition*, 130, 335-347.

De Petrillo, F., Ventricelli, M., Ponsi, G., & Addessi, E. (2015). Do tufted capuchin monkeys play the odds? Flexible risk preferences in Sapajus spp. *Animal Cognition*, 18, 119-130.

De Petrillo, F., Tonachella, G., Addessi, E. (2017). Emotional correlates of probabilistic decision making in tufted capuchin monkeys (Sapajus spp.). *Animal Behaviour*, 129, 249-256

Derevensky, J.L., Gupta, R., Baboushkin, H.R., (2007). Underlying Cognitions in Children's Gambling Behavior: Can they be Modified? *International Gambling Studies*, Vol. 7, No. 3, 281–298.

Ebisch, S.J., Aureli, T., Bafunno, D., Cardone, D., Romani, G.L., Merla, A. (2012). Mother and child in synchrony: Thermal facial imprints of autonomic contagion. *Biological Psychology*, 89, pp. 123– 129

Eisenberg, N., Cumberland, A., Spinrad, T. L., Fabes, R. A., Shepard, S. A., Reiser, M., et al. (2001). The relations of regulation and emotionality to children's externalizing and internalizing problem behavior. *Child Development, 72*, 1112–1134.

Ellsberg, D., (1961). Risk, Ambiguity and the Savage Axioms. *The Quarterly Journal of Economics*, Vol. 75, No. 4, 643-669.

Engert, V., Merla, A., Grant, J.A., Cardone, D., Tusche, A., Singer, T. (2014). Exploring the Use of Thermal Infrared Imaging in Human Stress Research. *PLoS ONE* 9(3): e90782. doi:10.1371/journal.pone.0090782.

Esposito, G., Nakazawa, J., Ogawa, S., Stival, R., Putnick, D.L., Bornstein, M.H. (2015) Using infrared thermography to assess emotional responses to infants, Early Child Development and Care, 185:3, 438-447, DOI: 10.1080/03004430.2014.932153

Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S.L., & Keeney, R.L. (1981). *Acceptable risk*. New York, Cambridge University Press.

Gao, S., Wei, Y., Bai, J., Lin, C., Li, H., (2009). Young children's affective decision-making in a gambling task: Does difficulty in learning the gain/loss schedule matter*? Cognitive Development* 24, 183–191.

Garon N., & Moore, C., (2004). Complex decision-making in early childhood. *Brain and Cognition* 55, 158–170.

Garon, N., & Moore, C., (2007). Awareness and Symbol Use Improves Future-Oriented Decision Making in Preschoolers. *Developmental neuropsychology*, *31*(1), 39–59.

Garon, N., Moore, C., Waschbusch, D.A., (2006). Decision Making in Children With ADHD Only, ADHD Anxious/Depressed, and Control Children Using a Child Version of the Iowa Gambling Task. *Journal of Attention Disorders*.

Geurts, H.M., van der Oord, S., Crone, E.A., (2006). Hot and Cool Aspects of Cognitive Control in Children with ADHD: Decision-Making and Inhibition. *J Abnorm Child Psychol*, 34:813–824.

Gigerenzer, G., Todd, P.M. (1999). "Ecological rationality: the normative study of heuristics". In Gigerenzer, Gerd; Todd, Peter M.; The ABC Research Group. Ecological Rationality: Intelligence in the World. New York: Oxford University Press. pp. 487–497.

Gigerenzer, G., Czerlinski, J., & Martignon, L. (1999). How good are fast and frugal heuristics?. In Decision Science and Technology (pp. 81-103). Springer US.

Girotto, V., Fontanari, L., Gonzalez, M., Vallortigara, G., Blaye, A. (2016). Young children do not succeed in choice tasks that imply evaluating chances. *Cognition*, 152, pp. 32-39.

Gong, J., Yuan, J., Wang, S., Shi, L., Cui, X., Luo, X., (2014). Feedback-Related Negativity in Children with Two Subtypes of Attention Deficit Hyperactivity Disorder. *Plos One*, Vol. 9, Issue 6.

Guttentag, R., & Ferrel, J., (2008). Children's understanding of anticipatory regret and disappointment. *Cognition and emotion*, 22 (5), 815-832.

Harbaugh, W.T., Krause, K., Vesterlund, L., (2002). Risk Attitudes of Children and Adults: Choices Over Small and Large Probability Gains and Losses. *Experimental Economics*, 5:53–84.

Harms, M.B., Zayas, V., Meltzoff, A.N., Carlson, S.M., (2014). Stability of executive function and predictions to adaptive behavior from middle childhood to pre-adolescence. *Frontiers in psychology*, Volume 5, Article 331.

Harrison, G.W., & Rutström, E. E., (2009). Expected utility and prospect theory: One wedding and a decent funeral. *Experimental Economics*, 12(2), 133–158.

Heilbronner, S.H., Rosati, A.G., Stevens, J.R., Hare, B., Hauser, M. (2008). A fruit in the hand or two in the bush? Divergent risk preferences in chimpanzees and bonobos. Biology Letters 4: 246–249.

Heilman, R.M., Miu, A.C., Benga, O., (2009). Developmental and sex-related differences in preschoolers' affective decision making. *Child Neuropsychology*, 15: 73–84.

Hoffrage, U., Weber, A., Hertwig, R., & Chase, V. M. (2003). How to keep children safe in traffic: find the daredevils early. *Journal of Experimental Psychology: Applied*, *9*(4), 249.

Huettel, S.A., Stowe, C.J., Gordon, E.M., Warner, B.T., Platt, M.L., (2006). Neural Signatures of Economic Preferences for Risk and Ambiguity. *Neuron* 49, 765-775.

Hongwanishkul, D., Happaney, K.R., Lee W.S.C., Zelazo, P.D., (2005). Assessment of Hot and Cool Executive Function in Young Children: Age-Related Changes and Individual Differences. *Developmental Neuropsychology*, 28(2), 617–644.

Ioannou, S., Ebisch, S., Aureli, T., Bafunno, D., Ioannides, H.A., Cardone, D., Manini, B., Romani G.L., Gallese, V., Merla, A. (2013) The Autonomic Signature of Guilt in Children: A Thermal Infrared Imaging Study. PLoS ONE 8(11): e79440.

Ioannou, S., Gallese, V., Merla, A. (2014). Thermal infrared imaging in psychophysiology: Potentialities and limits. *Psychophisiology*. DOI: 10.1111/psyp.12243.

Ioannou, S., Morris, P., Mercer, H., Baker, M., Gallese, V., Reddy, V. (2014). Proximity and gaze influences facial temperature: a thermal infrared imaging study. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2014.00845.

Kacelnik, A., & Bateson, M. (1996). Risky theories—the effects of variance on foraging decisions. *American Zoologist*, 36, 402-434.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica: Journal of the Econometric Society*, 263-291.

Kerr, A., & Zelazo, P., (2004). Development of ‘‘hot’’ executive function: The children’s gambling task. *Brain and Cognition* 55, 148–157.

Knight, F. H. (1921). Risk, uncertainty and profit. *New York: Hart, Schaffner and Marx.*

Ladouceur, R., Dugas, M.J., Freeston, M.H., Leger, E., Gagnon, F., Thibodeau, N. (2000). Efficacy of a Cognitive—Behavioral Treatment for Generalized Anxiety Disorder. *Journal of Consulting and Clinical Psychology Evaluation in a Controlled Clinical Trial*, Vol. 68, No. 6, 957-964.

Levin, I.P., & Hart, S.S., (2003). Risk Preferences in Young Children: Early Evidence of Individual Differences in Reaction to Potential Gains and Losses. *Journal of Behavioral Decision Making*, 16: 397–413.

Levin, I.P., Hart, S.S., Weller, J.A., Harshman, L.A., (2007). Stability of Choices in a Risky Decision-Making Task: A 3-Year Longitudinal Study With Children and Adults. *Journal of Behavioral Decision Making*, 20: 241–252.

Levin, I.P., Weller, J.A., Pederson, A.A., Harshman, L.A., (2007). Age-related differences in adaptive decision making: Sensitivity to expected value in risky choice. *Judgment and Decision Making*, Vol. 2, No. 4, pp. 225-233.

Loomes, G., & Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. The Economic Journal, 805-824.

Lopes, L.L. (1983). Some thoughts on the psychological concept of risk. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 137-144.

Luman, M., Oosterlaan, J., Knol, D.L., Sergeant, J.A., (2008). Decision-making in ADHD: sensitive to frequency but blind to the magnitude of penalty? *Journal of Child Psychology and Psychiatry* 49:7, pp 712–722.

Luna, B., & Sweeney, J.A., (2001). Studies of Brain and Cognitive Maturation Through Childhood and Adolescence: A Strategy for Testing Neurodevelopmental Hypotheses. *Schizophrenia Bulletin*, Vol. 27, No. 3.

Manini, B., Cardone, D., Ebisch, S.J.H., Bafunno, D., Aureli, T., Merla, A. (2013). Mom feels what her child feels: thermal signatures of vicarious autonomic response while watching children in a stressful situation. *Frontiers in Human Neuroscience*. Vol.7. doi: 10.3389/fnhum.2013.00299

Manstead A.S.R. (1995) Children's Understanding of Emotion. In: Russell J.A., Fernández-Dols JM., Manstead A.S.R., Wellenkamp J.C. (eds) Everyday Conceptions of Emotion. NATO ASI Series (Series D: Behavioural and Social Sciences), vol 81. Springer, Dordrecht

Masunami, T., Okazaki, S., Maekawa, H., (2009). Decision-making patterns and sensitivity to reward and punishment in children with attention-deficit hyperactivity disorder. *International Journal of Psychophysiology* 72, 283–288.

Mata, F., Sallum, I., Miranda, D.M., Bechara, A., Malloy-Diniz, L.F., (2013). Do general intellectual functioning and socioeconomic status account for performance on the Children's Gambling Task? *Frontiers in Neuroscience*, Volume 7, Article 68.

Mazur, J.E., & Kahlbaugh, P.E., (2012). Choice Behavior of Pigeons (*Columba livia*), College Students, and Preschool Children (*Homo sapiens*) in the Monty Hall Dilemma. *Journal of Comparative Psychology*, Vol. 126, No. 4, 407–420.

McCormack, T., & Feeney, A., (2014). The development of the experience and anticipation of regret. *Cognition and emotion*, Vol. 29, No. 2, 266–280.

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review, 106*, 3-19.

Miller, D.C., & Byrnes, J.P., (1997). The Role of Contextual and Personal Factors in Children's Risk Taking. *Developmental Psychology*, Vol. 33. No. 5, 814-823.

Mischel, H. N., & Mischel, W. (1983). The development of children's knowledge of self-control strategies. Child Development, 54, 603–619.

Mischel, W., Shoda, Y., & Peake, P. K. (1988). The nature of adolescent competencies predicted by preschool delay of gratification. Journal of Personality and Social Psychology, 54, 687–696.

Mischel, W., Shoda, Y., & Rodriguez, M. L. (1989). Delay of gratification in children. Science, 244, 933–938.

Nakanishi, R., Imai-Matsumura, K. (2008). Facial skin temperature decreases in infants with joyful expression. *Infant Behavior & Development*, 31, pp.137–144.

O'Connor, E., McCormack, T., Feeney, A., (2012). The development of regret. *Journal of Experimental Child Psychology* 111, 120–127.

O'Connor, E., McCormack, T., Feeney, A., (2014). Do Children Who Experience Regret Make Better Decisions? A Developmental Study of the Behavioral Consequences of Regret. *Child Development*, Vol.85, No.5, Pages 1995–2010.

O'Connor, E., McCormack, T., Beck, S.R., Feeney, A., (2015). Regret and adaptive decision making in young children. *Journal of Experimental Child Psychology* 135, 86–92.

O'Keeffe, K. Philippines makes play as a gambling mecca. The Wall Street Journal, April 18, 2012. Retrieved from: http://online.wsj.com/article/SB10001424052702303624004577341330278436226.html.

Paulsen, D.J., Platt, M.L., Huettel, S.A., Brannon, E.M., (2011). Decision-making under risk in children, adolescents, and young adults. *Frontiers in Psychology*, Volume 2, Article 72.

Paulsen, D.J., McKell Carter, R., Platt, M., Huettel, S.A., Brannon, E.M., (2012). Neurocognitive development of risk aversion from early childhood to adulthood, *Frontiers in human neuroscience*, Volume 5, Article 178.

Paulsen, D.J., Platt, M.L., Huettel, S.A., Branno, E.M., (2012). From risk-seeking to risk-averse: the development of economic risk preference from childhood to adulthood. *Frontiers in psychology,* Volume 3, Article 313.

Payne, J.W., Bettman, J.R., Coupey, E., and Johnson, E.J. (1992). A Constructive Process View of Decision Making: Multiple Strategies in Judgment and Choice. Acta Psychologica, 80, 107-141.

Pecora G., Addessi E., Schino G., Bellagamba F. (2014). Do displacement activities help preschool children to inhibit a forbidden action? Journal of Experimental Child Psychology (126), 80-90.

Petrides, M, & Milner, B., (1982). Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. Neuropsychologia, Vol 20(3), pp. 249-262.

Piaget, J. & Inhelder, B. (1975) The Origin of the Idea of Chance in Children. London: Routledge & Kegan Paul. (Original work published 1951).

Platt, M.L., & Huettel, S.A., (2008). Risky business: the neuroeconomics of decision making under uncertainty. *Nature Neuroscience*, Vol. 11, No 4.

Proctor, D., Williamson, R. A., Latzman, R. D., de Waal, F. B., & Brosnan, S. F. (2014). Gambling primates: reactions to a modified Iowa Gambling Task in humans, chimpanzees and capuchin monkeys. Animal Cognition, 17, 983-995.

Rakow T., Rahim S. B. (2010). Developmental insights into experience-based decision making. *Journal of Behavioral Decision Making* 23, 69–82.

Rothbart, M. K., & Bates, J. E. (1998). Temperament. In N. Eisenberg (Ed.), *Handbook of child psychology*: Social,emotional, and personality development. New York, NY, US: Wiley.

Quiggin, John (1982). A theory of anticipated utility. *Journal of Economic Behavior and Organization*, 3(4), 323–343.

Reyna, V.F., & Brainerd, C.J. (1994). The origins of probability judgement: A review of data and theories. In G. Wright & P. Ayton (Eds), *Subjective probability*, pp.239-272.

Reyna VF & Ellis SC. (1994). Fuzzy-Trace Theory and framing effects in children's risky decision making. *Psychological Science*, 5:275–279.

Rosati, A., & Hare, B., (2013).Chimpanzees and Bonobos Exhibit Emotional Responses to Decision Outcomes. PLoS ONE 8(5): e63058

Savage, L. (1954). The Foundation of Statistics. *Dover Publication, INC. New York* .

Schwarz, N. (2000). Emotion, cognition, and decision making. *Cognition and Emotion*, 14, 433–440.

Schlottmann, A., & Anderson, N.H., (1994). Children's Judgments of Expected Value. *Developmental Psychology,* Vol. 30, No. 1,56-66.

Schlottmann, A., (2001). Children’s Probability Intuitions: Understanding the Expected Value of Complex Gambles. *Child Development*, Vol. 72, No1, 103–122.

Serpelloni G. (2013), Gioco d’azzardo problematico e patologico: inquadramento generale, meccanismi fisiopatologici, vulnerabilità, evidenze scientifiche per la prevenzione, cura e riabilitazione, Manuale per i Dipartimenti delle Dipendenze, Dipartimento Politiche Antidroga, http://www.dronet.org/monografia.php?monografie=98

Sethi, A., Mischel, W., Aber, J. L., Shoda, Y., & Rodriguez, M. L. (2000). The role of strategic attention deployment in development of self-regulation: predicting preschoolers’ delay of gratification from mother-toddler interactions. Developmental Psychology, 36, 767–777.

Silk, J. S., Steinberg, L., & Morris, A. S. (2003). Adolescents’ emotion regulation in daily life: links to depressive symptoms and problem behavior. *Child Development, 74,* 1869–1880.

Simon, H. A. (1990). Invariants of human behavior. Annual Review of Psychology, 41, 1-20.

Sitkin, S.B., & Pablo, A.L. (1992). Reconceptualizing the determinants of risk behavior. *The Academy of Management Review, 17,* 9–38.

Slovic, P., (1966). Risk-taking in children: age and sex differences. Child Development, 37(1), 1966 pp. 169-176.

Smith, D.G., Xiao, L., Bechara, A., (2012). Decision Making in Children and Adolescents: Impaired Iowa Gambling Task Performance in Early Adolescence. *Developmental Psychology*, Vol. 48, No. 4, 1180–1187.

Steelandt, S., Broihanne, M.H., Romain, A., Thierry, B., Dufour, V., (2013). Decision-Making under Risk of Loss in Children. *Plos One*, Volume 8, Issue 1.

Steinberg, L., & Scott, E. S. (2003). Less guilty by reason of adolescence: developmental immaturity, diminished responsibility, and the juvenile death penalty. American Psychologist, 58, 1009–1018.

Steinberg, L. D. (2004). Risk taking in adolescence: What changes, and why? Annals of the New York Academy of Sciences, 1021, 51–58.

Stevens, J. R. (2010). Rational decision making in primates: the bounded and the ecological. Primate Neuroethology, 96-116.

Surowik, D. (2002). Leonard Savage's mathematical theory of decision. *Studies in logic, grammar and rhetoric,* 5 (18).

Suzuki, Y., Kobayashi, M., Kuwabara, K., Kawabe, M., Kikuchi, C., Fukuda, M. (2013). Skin temperature responses to cold stress in patients with severe motor and intellectual disabilities. *Brain & Development*, 35, pp. 265–269.

Troisi, A. (2002). Displacement activities as a behavioral measure of stress in nonhuman primates and human subjects. Stress, 5, 47–54.

Tversky, A., Kahneman, D., (1992). Advances in prospect theory: Cumulative representations of uncertainty. *Journal of Risk and Uncertainty*, 5, 297–323.

Van Duijvenvoorde, A.C.K., Jansen, B.R..J., Bredman, J.C., Huizenga, H.M., (2012). Age-Related Changes in Decision Making: Comparing Informed and Noninformed Situations. *Developmental Psychology* Association, Vol. 48, No. 1, 192–203.

van Duijvenvoorde, A.C.K., Huizenga, H.M., Somerville, L.H., Delgado, M.R., Powers, A., Weeda, W.D., Casey, B.J., Weber, E.U., Figner, B., (2015). Neural Correlates of Expected

Risks and Returns in Risky Choice across Development. *The Journal of Neuroscience*, 35(4):1549 –1560.

van Leijenhorst, L., Crone, E.A., Bunge, S.A., (2006). Neural correlates of developmental differences in risk estimation and feedback processing. *Neuropsychologia* 44, 2158–2170.

van Leijenhorst, L., Moor, B.G., Op de Macks, Z.A., Rombouts, S.A.R.B, Westenberg, P.M., Crone, E.A., (2010). Adolescent risky decision-making: Neurocognitive development of reward and control regions. *NeuroImage* 51, 345–355.

Vitaro, F., & Wanner, B., (2011). Predicting Early Gambling in Children. *Psychology of Addictive Behaviors*, Vol. 25, No. 1, 118–126.

Vlek, C., & Stallen, P.J. (1981). Rational and personal aspects of risk. *Acta Psychologica, 45,* 273-300

Von Neumann, J. V., Morgenstern, O., (1944). *The Theory of Games and Economic Behavior*.

Von Winterfeld, D., Edwards, W., (1986). Decision Analysis and Behavioral Research. Cambridge, England. Cambrige University Press.

Weber, E. U. (2010). Risk attitude and preference. Wiley Interdisciplinary Reviews: Cognitive Science, 1, 79-88.

Weber, E. U., & Johnson, E. J. (2008). Decisions under uncertainty: Psychological, economic, and neuroeconomic explanations of risk preference. Neuroeconomics: Decision Making and The Brain, 127-144.

Weisberg, D.P., & Beck, S.R., (2011). The development of children's regret and relief, *Cognition & Emotion*, DOI:10.1080/02699931.2011.

Weller, J.A., Levin, I.P., Denburg, N.L., (2011). Trajectory of Risky Decision Making for Potential Gains and Losses From Ages 5 to 85. *Journal of Behavioral Decision Making*, 24: 331–344.

Yaari, Menahem E. (1987). The dual theory of choice under risk. *Econometrica*, 55(1), 95–115.

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