ABSTRACT

Title of Dissertation: THE SENSITIVITY OF FIVE- TO TEN-YEAR-OLD CHILDREN TO VALUE, PROBABILITY, AND LOSS.

Ty W. Boyer, Doctor of Philosophy, 2005

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Classic and contemporary researchers have studied the child's abilities to discriminate quantitative values, understand probability, and appreciate risk and uncertainty. The current studies were designed to extend and methodologically integrate recent insights that have been made across these sub-areas. A computerized decision-making task, which allows manipulation of probability of success and quantitative outcome value, was developed. In the first study, this task was used to analyze the development of preference between options with systematically contrasted numerical outcome values. Contrary to recent research, this study revealed that participants, and particularly younger children (i.e., five- and six-year-olds), tend to neglect quantitative outcome value information, and seem to base choices primarily on probability information. In the second study, the task was used to assess the development of preference between options with systematically contrasted probabilities of success. Consistent with recent research, this study revealed that even young participants attend to differences in probability of success between decision alternatives; however, younger participants seemed less able to explicitly integrate decision outcomes, as assessed by more explicit measures of probability understanding. In the third study, probability of success was again manipulated, but wins were combined with losses. This study revealed, like Study 2, that children adjusted preference as a function of probability of success; however, consistent with Study 1, this study revealed that children tend to neglect outcome values. Cross-study analyses were conducted which further demonstrated that decision-making probabilities loom larger than outcome values. Collectively, these studies suggest that processing of probabilities developmentally precedes processing of quantitative outcome values, and that implicit processing developmentally precedes explicit decision integration. In the conclusion these findings and possible future directions are discussed.

THE SENSITIVITY OF FIVE- TO TEN-YEAR-OLD CHILDREN TO VALUE, PROBABILITY, AND LOSS.

By

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2005

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Acknowledgements

The author would like to thank the students, teachers, and administrators at the Center for Young Children at the University of Maryland, Friends Community School, Saint John’s Episcopal School, Norwood School, Henson Valley Montessori School, and Sandy Spring Friends School. Without their contribution the current studies would not have been possible. The author would also like to thank Michael Mengel and Sarah Knighton-Wisor, who assisted with data collection.

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Chapter 1: Introduction

Traditionally, cognitive developmental research has been conducted with an underlying assumption that younger children are less cognitively proficient than older children, adolescents, and adults. For instance, studies have demonstrated that with age come more sophisticated cognitive representations (Mandler, 1998), improved reasoning (DeLoache, Miller, & Pierroutsakos, 1998), more efficient strategies (Siegler, 1996), greater processing speed (Kail & Salthouse, 1994), increased working memory capacity, superior memory strategies (Ornstein, Haden, & Hedrick, 2004; Schneider & Bjorklund, 1998), and improved metacognition (Flavell, 1999; Flavell & Miller, 1998; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995). Each of these cognitive developments is likely related to the development of decision-making; however, quite recently the development of decision-making has emerged as a distinct area of study, with a unique set of empirical and theoretical issues (Byrnes, 1998; Furby & Beyth-Marom, 1992; Galotti, 2001; Klaczynski, Byrnes, & Jacobs, 2001).

In fact, many now argue that the abilities to interpret uncertain and potentially risky situations, and make wise decisions, are among the most important skills one develops (Beyth-Marom, Austin, Fischhoff, Palmgren, & Quadrel, 1993; Byrnes, 1998; Furby & Beyth-Marom, 1992; Garon & Moore, 2004; Halpern-Felsher & Cauffman, 2001; Irwin, 1993; Mann, Harmoni, & Power, 1989). It is also recognized from other perspectives (e.g., federal and educational policy making and naïve parenting) that the decisions children and adolescents make have the potential for significant consequences. Reciprocally, child and adolescent decision-making research has been implicated in debates on adolescent rights, health care, and criminal culpability (Cauffman & Steinberg, 2000a; 200b; Fried & Reppucci, 2001; Irwin, Igra, Eyre, & Millstein, 1997; Ozer, MacDonald, & Irwin, 2002; Steinberg & Scott, 2003; Wilcox, 1993). Unfortunately, however, relatively little is known of the development of the precise cognitive processes that underlie decision-making skills.

Developmental issues aside, the component processes people invoke when put in decision situations have been analyzed for centuries. Decision alternatives are oftentimes conceptualized as composed of potential positive and negative values (costs and benefits), and probabilities that either the positive or negative values will be realized if the alternative is chosen and implemented (Bernoulli, 1738/1954; Luce & Raiffa, 1957; Savage, 1954; von Neumann & Morgenstern, 1944). Using this behavioral decision theory perspective, individuals are assumed to estimate how desirable an alternative's benefits might be, how expensive the its costs might be, the probability of either occurring, and consequently, its expected value. In this sense, decision options have an *expected value*, which may be quantified as the sum of the products of the probabilities and values of potential outcomes. Contemporary cognitive decision-making research has moved well beyond analysis of individuals' use of expected values; however, many contemporary descriptive accounts, such as cumulative prospect theory and rank and sign dependent interpretations of axiomatic utility theory, explain decision-making in terms of subjective evaluations of outcome probabilities and values (Kahneman & Tversky, 1979; Luce, 1991; Luce & Fishburn, 1991; 1995; Tversky & Kahneman, 1992). Furthermore, in order to understand how basic decision-making abilities develop, one must consider how the most basic understanding of probability and outcome value information develop. Thus, the next sections of this paper will review the research that has considered the child's understanding of quantitative outcome value information and probability.

The Child's Understanding of Quantitative Outcome Values

As introduced, behavioral decision theory approaches generally propose that outcome values, the degree of satisfaction associated with potential outcomes, influence human choice. In traditional decision-making research, outcome values are typically quantified as money or a number of prizes or points that a research participant can garner through choices made or gambles taken. Unfortunately, very little previous research has analyzed the child's sensitivity to quantitative outcome values in decision situations. What little research there is on the topic suggests that from a relatively young age (i.e., five-years) children appreciate that outcomes that are associated with higher values (i.e., more points or prizes) are preferable to outcomes that are associated with lower values (Schlottmann, 2000; 2001; Schlottmann & Anderson, 1994). For instance, Schlottmann (2001) presented five- through 12-year-old participants with a series of gambles and asked them to rate the quality of each gamble. A controlled subset of these gambles differed in terms of the number of prizes that could be won. The results provide compelling evidence that even the youngest participants (five- to seven-year-olds) attend to quantitative differences in potential prizes, and adjust preferences accordingly. The results, however, also revealed significant differences between younger participants (i.e., five- to seven-year-olds) and older participants (i.e., eight- to 12-year-olds), in that older participants' preferences were slightly more consistent with normative expected value predictions, and older participants were more likely to attend to smaller quantitative differences.

Although only a limited number of studies have examined children's abilities to differentiate lower vs. higher outcome values in decision-making situations, a very rich literature has considered the development of more basic quantitative skills. Classic research proposed that children have limited quantitative understanding until the late preschool years. Piaget's number conservation experiments, for instance, demonstrated that preschoolers (i.e., three- to four-years) do not comprehend that altering the spatial arrangement of a number of objects (i.e., spreading several objects out vs. bunching them up together) actually has no bearing on the quantity of the objects (Piaget 1941/1965). Slightly older children (i.e., five- to seven-years), on the other hand, are able to conserve number after spatial manipulation. Piaget (1941/1965) therefore argued that quantitative competence is not achieved until number conservation is mastered.

More recent work, however, has challenged the notion that preschool children are quantitatively incompetent. Gelman and Gallistel (1978), for instance, documented several counting principles that children as young as two-and-a-half-years use. That is, although they do not yet understand the appropriate conventional labels to apply to a series of objects (they do not use "one" = 1, "two" = 2, etc.) by two-and-a-half -years children apply a unique label to every object in an array that is being counted (i.e., the one-one principle), they apply labels in the same order across counting episodes (i.e., the stable-order principle), and they differentiate the last label in a sequence from the previous labels as indicating the total count (i.e., the cardinality principle). Thus, use of these "how-to-count" principles is presented as evidence that preschool children have greater quantitative competence than previous research supposed (Gelman & Gallistel, 1978). Similarly, others have found that preschool-aged children (i.e., two-and-a-half- to four-year-olds) can successfully negotiate non-verbal calculation tasks with small numerical sets prior to mastering conventional mathematical skills (Huttenlocher, Jordan, & Levine, 1994; Levine, Jordan, & Huttenlocher, 1992; Mix, 1999). This is not to say that preschoolers' mastery of quantitative operations and principles is complete. On the contrary, several notable quantitative developments occur in the preschool period, between three- and five-years. These include a gradual increase in the accuracy with which children perform mathematical operations, an increase in the set sizes to which children can apply operations, and an increase in the degree to which children can abstract quantitative information and apply it to novel situations (Mix, Huttenlocher, & Levine, 2002). By four- or five-years, however, children typically have a repertoire of several strategies for performing mathematical operations (Siegler, 1996).

Others have gone a step further and have claimed that even infants have notable quantitative abilities. Using the habituation design, in which variability in participant looking time is used as a metric of cognitive discrimination, a number of studies have demonstrated that very young infants can differentiate small quantitative sets (Antell & Keating, 1983; Starkey & Cooper, 1980; Strauss & Curtis, 1981; Wynn, 1998). Antell and Keating (1983), for instance, habituated newborns to an array (i.e., either 2, 3, 4 or 6 dots on a card), then assessed looking time at an array of different numerosity (i.e., 3, 2, 6, or 4 dots at test). The results suggest that newborns can discriminate small numerical sets (i.e., they look longer during test when an array had changed from 2 to 3 dots, or from 3 to 2 dots), but have difficulty discriminating arrays that display larger quantities (i.e., looking times do not change from habituation to test when the array changed from 4 to 6 dots, or 6 to 4 dots). Starkey and Cooper (1980) found precisely the same results with slightly older children (i.e., four-month-olds), and Strauss and Curtis (1981) found similar results with richer visual arrays and even older children (i.e., 10- to 12-month-olds). Some even argue that infants are able to make simple calculations (i.e., they are perceptive of basic addition and subtraction operations). Wynn (1992; 1998), for example, showed five-month-olds an object (i.e., a doll), which was then hidden behind an opaque screen. While the initial object was hidden the infant saw the experimenter add another object (i.e., another doll) to the array. The screen was then lowered to reveal the quantitatively correct outcome (i.e., two dolls) or a quantitatively incorrect outcome (i.e., a single doll). The results revealed that participants looked significantly longer at the incorrect than the correct outcome, which is argued to be evidence that they had performed a basic addition calculation. These habituation findings, however, have not been without criticism; specifically, attempts at replication have been mixed (Langer, Gillette, & Arriaga, 2003; Wakeley, Rivera, & Langer, 2000a; 2000b), and some have argued that these studies confound numerical discrimination with more basic visual discrimination of spatial coverage (Clearfield & Mix, 1999; Mix, Huttenlocher, & Levine, 2002). These criticisms notwithstanding, studies of infant abilities have contributed to our understanding of early quantitative development, and are relevant for the development of sensitivity to quantitative outcome values.

The current studies were designed in part to extend what is known of the development of sensitivity to quantitative outcome values. Given the above reviewed research, it is predicted that the school-aged participants in the current studies will acknowledge differences in quantitative outcome values, and will adjust preferences accordingly. More specifically, it is predicted that participants in the current studies will consistently choose options with superior outcome values over those with inferior outcome values.

The Child's Understanding of Probability

A fair number of studies have considered the development of probability understanding. Early theory and research proposed that children are unable to understand probability until the later childhood years (Brainerd, 1981; Piaget & Inhelder, 1951/1975). Recent experimental studies, on the other hand, have found that relatively young children attend to probability, and even use probability to guide preference (e.g., Acredolo, O'Connor, Banks, & Horobin, 1989; Kuzmak & Gelman, 1986; Schlottmann & Anderson, 1994; Schlottmann, 2001). In what follows, the classic approaches, the contemporary approach, and potential methodological and theoretical sources of their differences are reviewed.

Classic Approaches Piaget and Inhelder (1951/1975) proposed that children do not understand probability until formal operational thought is achieved, around 12-years. To support this assertion, Piaget and Inhelder (1951/1975) used a number of experimental tasks (e.g., they asked children to make predictions of random draws from one location, random draws from two locations, and random vs. non-random mixture). Collectively, the results of these tasks supported Piaget's comprehensive theory of developmental stages: younger children (around five-years) erred dramatically and could not differentiate certain from random events; slightly older children (eight- to ten-years) succeeded in initial trials, but erred on subsequent trials; and older children (around 10-12 years) demonstrated understanding of chance.

A number of other experimental studies have found similar age trends, thus supporting the Piagetian theoretical explanation. For example, Hoemann and Ross (1971) presented children with circular disks that had systematically varied color portions, and asked child participants (four- to 13-year-olds) to pick the disk with the higher proportion of a color (proportion group), or to pick the disk, that if spun, would be more likely to result in a given color (probability group). The general findings were that younger children were less able than older children to pick the color with the higher probability, although all could perceive proportional color differences. Similarly, Kreitler and Kreitler (1986) tested child understanding of random mixture, random distribution, random drawing, and possible permutations. Consistent with Piaget, Kreitler and Kreitler (1986) found a domain-general increase in abilities with age.

As was the case across a number of cognitive developmental research areas, an information processing approach emerged as an alternative to the Piagetian account. Generally, those who adopted this perspective subdivided Piaget and colleagues' explanatory constructs into detailed processes (Bjorklund, 2000; Kerkman & Wright, 1988; Klahr & MacWhinney, 1998; Siegler & Alibali, 2005). Whereas Piaget attributed the failures of young children on experimental tasks to a vaguely defined lack of understanding, those adopting an information processing perspective proposed that other, more specific mechanisms develop (e.g., processing capacity, working memory, and strategies), thus enabling older children to succeed in instances where younger children fail. As Reyna and Brainerd (1994) note, the Piagetian and information processing approaches are not radically different; the latter simply adds details to the general propositions of the former.

Brainerd (1981), for instance, proposed that sufficient working memory capacity, which increases with age, is necessary for probability understanding. More specifically, Brainerd (1981) proposed that storage of initial frequencies, retrieval of previous responses and sampled items, and integration of initial frequencies and sampled items are necessary for processing probability. To test this Brainerd (1981) presented children with an experimental task that involved making a sequence of draws from containers that held varying ratios of items. The results supported the proposal. That is, although younger participants were able to recall initial frequencies, they could not maintain the information in working memory to make probability-based predictions, and were unable to adjust frequencies with subsequent draws.

Falk and Wilkening (1998) also adopted an information processing perspective, and designed a two-location drawing task to assess the strategies children use to process probability. In this task children (six- to 13-year-olds) were shown two transparent containers, the first containing some ratio of two different colored objects (e.g., 2 blue and 3 yellow beads), the second containing a different number of just one of the colored objects (e.g., 6 yellow beads). The child’s task was to add the excluded colored objects (e.g., blue beads) to the second container so as to preserve the ratio from the first container (e.g., to add 4 blue beads to the second container). Falk and

Wilkening (1998) emphasized probability (as opposed to mere proportions), by telling participants that they themselves would draw from one of the two containers, the experimenter would draw from the other, and whoever drew a winning color would win a prize. The findings were that the youngest participants (six- to eight-years) tended to use a less sophisticated one-dimensional strategy (i.e., they focused on a single pertinent variable, such as the number of winning beads in the initial container), somewhat older participants (eight- to 10-years) tended to use a more advanced difference strategy (i.e., they focused on the difference between win and lose beads in the initial container), and the oldest participants (10- to 13-years) tended to use the most sophisticated proportion strategy (i.e., they focused on the relative proportions of win and loss beads). Similarly, Dean and Mollaison (1986) found that older children are more likely to use more sophisticated calculation strategies than younger children. In total, the contribution of those using the information processing approach has been increased specification of the mechanisms by which probability understanding develops.

The Contemporary Approach A contemporary approach refutes the Piagetian and information processing findings that young children are unable to understand probability (Acredolo et al. 1989; Kuzmak & Gelman, 1986; Schlottmann & Anderson, 1994; Schlottmann, 2001). Kuzmak and Gelman (1986), for instance, challenged the Piagetian proposal that young children are unable to differentiate certain from possible events, which was tested with invention of a marble cage and marble tube task. The marble cage was a spherical wire cage containing marbles that could be spun to mix its contents (similar to a bingo hopper). The marble tube was a transparent plastic tube apparatus in which marbles lined up one by one. Each apparatus had a release mechanism that dispensed one of the marbles from the interior. Whereas dispensing from the spun marble cage was random, dispensing from the marble tube was certain. Kuzmak and Gelman (1986) presented young children (four- to seven-year-olds) with each apparatus and asked if they knew what color marble would be dispensed. The results were that children, independent of age, accurately responded that "yes," they did know what the next marble would be to exit the tube, and "no," they did not know the next marble that would exit the cage. Thus, Kuzmak and Gelman (1986) concluded that even 4-year-olds distinguish random from determined events, and therefore have some probabilistic sense.

Several other contemporary studies have used comparable experimental methods, have found similar results, and have drawn common conclusions (Acredolo et al. 1989; Schlottmann & Anderson, 1994; Schlottmann, 2001). With these studies participants were asked to generate an expected value, by rating a character's happiness on a non-numerical scale, when the character is faced with events of varying probability and value. Acredolo et al. (1989) presented two tasks to first- through fifth-grade participants. On the first task an experimenter showed the child bags of jellybean candies, one at a time, with various proportions of jellybean colors. The child was then asked to predict how happy another child, who liked a certain color of jellybean, would be to draw from each particular bag. On the second task, the child interacted with a computer game that displayed a bug character and several pots that the bug was attempting to jump into or avoid. The ratios of desirable to undesirable pots were manipulated, and the child was asked how happy the bug would be given various pot ratios. These tasks are comparable to the Piagetian single-location task in that a single ratio is presented and the child is asked to make a judgment. Contrary to Piaget, however, Acredolo et al. (1989) found that children between first- and fifth-grade could accurately and consistently attend to variations in the ratios of desired and total variables, could translate these probabilities into expected values, and therefore, demonstrated understanding of probability.

Schlottmann and Anderson (1994) and Schlottmann (2001) also asked children to derive probability-based expected values. In one task participants were shown circular disks that could be spun to win prizes, with systematically varied color portions. One of the colors was designated as the winning color, and children were to predict how happy a character would be to gamble with each disk. This method is structurally similar to that of Hoemann and Ross (1971) in that disks with variable color portions are used, and is conceptually similar to the Piagetian single location drawing task in that probability was considered from a sole target. In another task, Schlottmann (2001) presented children with a transparent tube, the back of which was lined with a strip of paper with systematically varied color portions (i.e., 4/5 blue, and 1/5 yellow). This tube contained a single marble. In each trial, each color at the back of the tube was paired with a prize value (e.g., the blue portions were associated with winning 8 prizes, the yellow were associated with winning 2 prizes). Participants were told that as the tube was shaken, and the marble came to rest in front of one of the colors, a character would win the prize associated with the color. Again, children were to predict how happy a character would be with the gamble given the proportions of color and prize values. As discussed above, children adjusted preferences as a function of the outcome value associated with the gamble, and more relevant to the current discussion, participants also adjusted preferences as a function of the probability of success associated with the gamble. “Overall, in contrast to the traditional view, the present results demonstrate functional understanding of probability and expected value in children as young as 5 or 6” (Schlottmann, 2001, p. 103). Collectively, these recent studies refute the classic approaches, and claim that very young children can demonstrate probabilistic competence.

There are three potential explanations for the difference between the classic and contemporary studies. First, a case might be made that contemporary theorists use simplified procedures, which enable the child to succeed. The key to this argument is that by introducing an expected value response mechanism, (e.g., having participant respond in terms of a character’s emotional state), the contemporary studies make the tasks more “real,” or intuitive, to the child. This argument, however, is flawed in two ways. First, and most basically, the traditional and contemporary methods are not radically different; in fact, each contemporary method is quite analogous to a traditional method. For instance, whereas Piaget and Inhelder (1951/1975) asked children which of two locations was more likely to produce a given object, Kuzmak and Gelman (1986) asked children to consider which of two apparatuses would produce a random or known outcome. Similarly, whereas Piaget and Inhelder (1951/1975) asked children which outcome was most likely given a single ratio gamble, Acredolo et al. (1989), Schlottmann and Anderson (1994), and Schlottmann (2001) asked children how happy a character would be with a single ratio gamble. These relatively analogous methods do not seem dissimilar enough to produce the vast disparity in the contemporary and traditional conclusions. Secondly, the contemporary studies actually require the child to process *more* than the classic studies (i.e., ratios, probabilities, ***and*** a character's probable emotional state). Of course, an increase in information implies greater complexity, and greater probability of error. Younger participants (e.g., five-year-olds), however, were more able to demonstrate systematic competence with the contemporary methodologies than the classic, due to, or perhaps despite of, the added information.

Another methodological explanation of the difference in findings, which is more difficult to dismiss, is that the contemporary methodologies simply obtain more information from the participant, which allows richer analysis of abilities. Whereas the classic studies presented the participant with a forced choice between options (i.e., what counter will be drawn, which spinner has a higher probability of success, how many counters are necessary to maintain equal probability), the contemporary studies present analysis of the degree of preference the child has of each option (i.e., how valuable is this spinner, tube, or ratio of objects). As such, the contemporary studies allow reflection on the participant's estimation of value of all options, rather than preference between options, and in this sense, provides a more sensitive assessment of the degree of the child's understanding.

The differences between the contemporary and classical findings, however, might also be explained theoretically. Furthermore, if it is conceded that the methods used in the contemporary and traditional research are not truly very different, a theoretical explanation may be more appropriate than a purely methodological one. Perhaps the key theoretical difference between the contemporary and traditional studies derives from incongruent definitions of probability "understanding." Whereas the contemporary studies assess intuitive and graded use of probability, the classic studies assess explicit and unequivocal probability understanding. In fact, whereas I have referred to these studies as the "contemporary" approach, Reyna and Brainerd (1994) label them as "the intuitive approach" and the Schlottmann (2001) paper is entitled, "Children's Probability Intuitions." Whereas Piaget and colleagues asked, "can the young child demonstrate an understanding of probability?" the contemporary theorists are asking, "can the young child use probabilistically structured information to guide intuitions?"

This difference in experimental investigation may actually soften the arguments the contemporary studies make against the classic studies, simply because those that used a classic approach acknowledged the young child's intuitive abilities:

> "Observing things superficially, we could have the impression that the young child, and even the baby, dissociate the possible from the necessary. When the nursing child hears a noise behind the door and expects, without being sure of it, to see his mother appear, we could say, in fact, that he considers this appearance as possible and not as certain, or even as probable to some degree. Such an interpretation would lead us to conceive of the judgment of probability as very primitive and even anterior to precise ideas about chance, or as related to *intuitive* notions of the uncertain or the unexpected" (Piaget and Inhelder, 1951/1975, p. 216-7).

Piaget and Inhelder move on to dismiss these "superficial" and "implicit" abilities as falsely indicative of probability "understanding," on the bases that young children also demonstrate pronounced inabilities. Contemporary theorists, on the other hand, propose that similar intuitive abilities are indicative of competence, and that Piaget failed to notice them with difficult tasks. If the notion of all-or-none competence is thrown out, or if a universal definition of competence is applied, however, the traditional and modern theories of probability understanding become indistinguishable. This is not to say that the contemporary methods and results do not differ from the traditional; rather, the methodological and empirical differences may originate from theoretically different definitions of probability understanding.

The methodology discussed below was designed in part to disentangle this argument. Rather than consider whether or not younger children are less competent than older children, the studies will attempt to determine, more intensively, the abilities and competencies of children of different ages. It is predicted, consistent with the contemporary approach, that intuitive probability understanding will emerge at a relatively young age; however, it is also predicted, consistent with the traditional approach, that explicit demonstration of probability understanding, as determined with a forced-choice measure, will emerge at a slightly later age.

The Child's Appreciation of Risk and Uncertainty

A number of experimental studies have attempted to plot the emergence of the child's understanding of risk and uncertainty. Risk-taking is a special condition of decision-making; specifically, risks are defined in the developmental literature as decisions in which one or more of the available alternatives have the potential to produce an undesirable outcome. Here, the specific probabilities are known. Uncertainty, in contrast, is the accepted term in the decision field for decision-making situations in which the associated alternative outcome probabilities are not available (Lopes, 1994; Tversky & Fox, 1995; Tversky & Kahneman, 1974). As with decision-making in the general sense, situations of risk and uncertainly are intrinsically related to probabilities and outcome values, and as such, the current discussion of the child's understanding of risk and uncertainty, and the above discussions of the child's understanding of outcome values and probabilities, are intrinsically related (although such relations have been very implicit thus far in the developmental literature). Furthermore, it is argued that the methods used to experimentally investigate the child's understanding of outcome values and probabilities might be manipulated to investigate the child's understanding of risk and uncertainty (or vice versa).

In perhaps the first study of risk-taking involving children, Slovic (1966) presented children, between the ages of six- and 16-years, with a series of choices, each of which resulted in either gain of a desirable prize or loss of all prizes. Slovic (1966) presented the participant with a row of 10 switches, nine of which were "safe," one of which was a risky "disaster" switch (initial .9 probability of gain, and .1 probability of loss). Participants were told that they could flip as many of the switches as they like, and for each safe switch they flipped they would receive a desirable prize; however, if they flipped the disaster switch they would lose all the prizes they had accumulated. Probabilistically, the most adaptive strategy in this task is to flip five of the switches (i.e., expected value = 2.5). Although very few participants elected to cease flipping switches prior to this point of maximum expected value, most participants did elect to stop and collect their prize after reaching this point, which suggests relative appreciation of the risk involved. Furthermore, although age was not analyzed as an independent variable, the results suggested an age X gender interaction; that is, boys, and particularly older boys, tended to be more risk-seeking (i.e., they tended to flip more switches than older girls).

One very recent study, Hoffrage, Hertwig, Weber, and Chase (2003), used this classic methodology, and found that five- and six-year-olds classified as risk-takers on the task (i.e., those that flipped a high number of switches) were far more likely to engage in actual risky behaviors than were those classified as risk-avoidant (i.e., risk-takers were more likely to attempt to cross a street when doing so was not safe). Another experimental task, Lejuez and colleagues' Balloon Analogue Risk Task (BART; Lejuez et al. 2002; 2003a; 2003b), makes use of a very similar structure (i.e., participants must choose whether or not to proceed through a series of events, with some probability of disaster). Recent studies conducted with the BART have revealed correlations between task performance and prototypical real-world risk behaviors (e.g., smoking cigarettes, drinking alcohol, and fighting). Hoffrage et al. (2003) and Lejuez et al. (2002; 2003a; 2003b) thus provide a degree of validation for the structure of Slovic's classic methodology with contemporary populations, and furthermore, suggest individual differences in risk appraisal.

Byrnes and colleagues' have also developed a decision-making task, referred to as "the decision game," which has introduced several interesting findings (Byrnes & McClenney, 1994; Byrnes, Miller, & Reynolds, 1999). In the decision game, participants are presented with a simple game board (similar to a traditional board game, as that used in Monopoly or Trivia Pursuit) that has a base area, an intermediate card area, a goal area, and three paths connecting each. At the intermediate area participants are required to flip a card, revealing either a trivia question or a “go back to base” command. The probability of success on each path varied through manipulation of question difficulty and rate of the “go back to base” command (i.e., one path had relatively more easy questions, making it relatively risk free, another more difficult questions, giving it moderate risk, and the third more “go back to base” commands, making it very risky). Therefore, the real decision on this task is which path to choose in pursuit of the goal area. Byrnes and McClenney (1994) found that adolescents and adults use similar strategies in evaluating the path options; however, adults made consistently better choices and were actually more optimistic in their abilities to succeed through risk (i.e., adults assumed greater confidence at reaching the goal area by answering difficult questions). Miller, Byrnes, and Reynolds (1999) extended this and incorporated feedback into the game by giving the participants more information about the questions that would be asked (in effect, making them less uncertain). Results showed that adult participants benefited from feedback more so than adolescents.

The “Iowa Gambling Task,” which has quite recently been applied to children and adolescents, is another experimental methodology that has become somewhat popular for assessing understanding of risk and uncertainty (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Damasio, & Lee, 1999; Bechara, Damasio, Damasio, & Tranel, 1994; Bechara, Damasio, Tranel, & Damasio, 1997; Damasio, 1994). Damasio and colleagues assume an affective decision-making perspective, and in effect argue that individuals do not necessarily need to explicitly understand the underlying probabilities of decision-makings situation to make rational decisions.

This *somatic marker hypothesis* posits that in cases of risk and uncertainty, emotional, rather than cognitive, acknowledgement of positive and negative consequences influences decision-making (Bechara et al. 2000; 1999; 1994; 1997; Damasio, 1994).

> "In short, somatic markers are a special instance of feelings generated from secondary emotions. Those emotions and feelings have been connected, by learning, to predicted future outcomes of certain scenarios. When a negative somatic marker is juxtaposed to a particular future outcome the combination functions as an alarm bell. When a positive somatic marker is juxtaposed instead, it becomes a beacon of incentive" (Damasio, 1994, p. 174).

This argument is quite congruent with the above argument that intuitive use of probability is sufficient for competence, and perhaps the timing and popularity of the two approaches is related.

Returning to the experimental design of the Iowa gambling task, participants are asked to draw cards from one of four decks, each of which has an unspecified schedule of gains and losses. The decks are manipulated so that two of the decks are comparatively risky (i.e., although they have generally larger payoffs, they lead to larger losses, ultimately resulting in net losses), and two of the decks are comparatively safe (i.e., they generally have smaller payoffs, but lead to smaller losses, ultimately resulting in net gains). Initially, participants show a preference for the risky decks; however, after about 30 trials healthy adults tend to gravitate towards the safer decks (Bechara et al., 1994; 1999; 2000b).

The gambling task has recently been adapted in attempts to assess the development of affective decision-making capacities. Each developmental adaptation of the task has involved several alterations to ensure comprehension by the younger samples, three of which are common across studies: 1) the prizes are items rather than monetary (e.g., children win candy), 2) wins and losses are represented by illustrated images (e.g., happy faces, bears, or apples represent wins, sad faces or tigers represent losses, rather than simple positive and negative numeric values), and 3) the prize values are relatively small (e.g., wins are one or two candies, losses are of similarly low value, rather than hundreds of dollars). Other manipulations have been less universal, and will be addressed individually.

Kerr and Zelazo (2004) adopted a version of the gambling task, which was administered to three- and four-year-olds. For simplification purposes, two decks of cards (rather than four), and decreased prize values were used (i.e., the advantageous deck always had a win of one, and a loss of zero or one prizes, the disadvantageous deck always had a win of two, and losses of zero, four, five, or six prizes). These preselected values may be problematic, because they potentially confound the design; specifically, the disadvantageous deck's outcomes are more complex. This issue aside, Kerr and Zelazo (2004) revealed an age x trial block interaction; four-year-olds were more likely than three-year-olds to gravitate towards the advantageous deck in the latter trials of the task. Further analyses also revealed that four-year-olds selected from the advantageous deck at a rate significantly greater than chance, but three-year-olds selected from the disadvantageous deck at a rate significantly greater than chance. Although presented cautiously, there was also a gender difference; specifically, males were more likely to choose advantageously than females.

In another very recent study, Garon and Moore (2004) presented three-, four-, and six-year-olds with a fairly standard version of the Iowa gambling task. Children were shown four decks of cards (two of which were advantageous, two of which were disadvantageous), and were asked to draw cards from the decks to win and lose candy prizes. Unlike Kerr and Zelazo (2004), Garon and Moore (2004) found no main effect for trial block (i.e., no difference in deck preference between the first and second halves of the task), and no evidence of increased preference for the advantageous decks with age. The results, however, did reveal that six year-olds were more conceptually aware of the game structure than three- and four-year-olds. Finally, Garon and Moore (2004) found a gender X trial block interaction; however, again in contrast to Kerr and Zelazo (2004), females tended to choose from the advantageous decks more than males.

Crone and colleagues have administered another adaptation of the gambling task to slightly older children (six-year-olds through nine-year-olds), adolescents (12-13-year-olds and 15-16-year-olds), and young adults (Crone & van der Molen, 2004; Crone, Vendel, & van der Molen, 2003). This computerized version of the gambling task, which is referred to as "the hungry donkey task," presents the participant with four doors (instead of drawing cards from decks) and a hungry donkey character. The objective of the task is to open the doors so that the hungry donkey might get to apples that are on the other side. The task is otherwise structurally analogous to the original gambling task. The findings, across three studies, suggest development of decision-making abilities between childhood, adolescence, and young adulthood; that is, six-year-olds through twelve-year-olds did not gravitate towards advantageous doors as soon or as consistently as teenagers, who did not gravitate towards advantageous doors as soon or as consistently as adults (Crone & van der Molen, 2004; Crone et al. 2003). Also, older participants were more likely to gain explicit conceptual understanding of the task, and regarding individual differences, those identified as disinhibited were less likely to select advantageously.

In one final study, Ernst et al. (2003) administered a standard gambling task to adolescent and adult participants who had been classified as healthy or as having previously exhibited behavioral disorders. The general results were that healthy adolescents and adults did not significantly differ in task performance; however, adolescents with behavioral disorders demonstrated less improvement in task performance between administrations conducted a week apart than healthy participants. This, along with Crone and colleagues work, suggests an individual difference component to understanding risk and uncertainty.

Each of these experimental studies (the classic Slovic task, Byrnes and colleagues' decision-making game, and the Iowa gambling task) has informed what we know of children's decision-making tendencies in risky and uncertain situations. It is currently argued, however, that there is still much to be investigated, and what actually develops absolutely has not been determined! Byrnes and colleagues appeal to cognitive self-regulatory capacities that improve with the transition from adolescence to young adulthood (Byrnes, 1998; Byrnes & McClenney, 1994; Byrnes et al. 1999). Crone and van der Molen (2004) mention probability understanding as a potential cognitive mechanism of development, and further, empirically discount working memory capacity and inductive reasoning skills as sources of developmental change in risk-taking tendencies. Likewise, Garon and Moore (2004) mention the potential importance of win and loss frequency. Perhaps more intense manipulation of these types of tasks, with greater control over task variables, would lead to more precise understanding of the cognitive developments that underlie the child's appreciation of risk and uncertainty.

It is also argued that each of these uncertainty and risk-taking studies is quite conceptually and structurally similar to the above reviewed studies of child probability understanding. For instance, both the Iowa gambling task and Byrnes and colleagues' decision game use an experimental design and response mechanism that is quite similar to that of the traditional approach to probability understanding (i.e., both ask "what is your decision given the current situation?"). Similar to the contemporary studies of probability understanding, however, both the gambling task and decision game allow extremely rich analysis by using a sequence of choices as a metric for intuitive preference. This similarity might be made more explicit, and studies of the child's understanding of probability and studies of the child's understanding of risk and uncertainty might inform one another. Furthermore, these issues might be investigated with a common methodology. A methodology that attempts to accomplish just this is discussed below.

Chapter 2: The Current Studies

The current studies were designed to address the following questions:

(1) How sensitive are children to quantitative variations in outcome values in decision situations?

(2) How sensitive are children to probability of success in decision situations?

(3) How sensitive are children to loss, and can children differentiate more risky options from less risky options, in decision situations?

Although other researchers have asked these questions before, I have argued that methodological improvements might be made, and that these questions might be investigated more intensively. In addition, the literatures concerning each question have remained largely distinct; however, a common methodology might be adapted, which can extend and integrate the independent lines of research. In the current task participants were presented with a stream of choices between alternatives. This experimental procedure has several advantages over alternatives. First, the stimuli can be controlled (i.e., the probabilities of success and quantitative win and loss values can be manipulated), to address the roles of probability, outcome value, and risk in decision situations. Second, the various stimuli and contrasts that might be introduced will produce a rich data set, which should shed new light on the child's cognitive abilities. Finally, this format approximates probability as it is experienced in actual decision-making situations. As reviewed, studies of probability understanding tend to present the participant with a perceptually visible and static probabilistic structure (e.g., view this spinner, tube, or array of counters). Actual decisions, however, are composed of underlying, imperceptible, and time-variant probability structures, which the current task taps into.

The Expected Value Model

The design of the current task was governed by formally expressed probability and value structures. Decisions, at their most basic level, are composed of potential positive and negative values, and the probabilities that either the positive or negative values will be realized if an alternative is decided upon. In this sense, expected value can be a powerful research tool, particularly when investigating the development of the most basic processes. The classic normative expected value (EV) model states that the value of a decision alternative is the sum of the products of the probability (*P*) and value (*V*) of the potential outcomes associated with the alternative:

$$EV = \sum_{i=1}^{n} P_i V_i \qquad (1)$$

The foci of Studies 1 and 2 are the child's sensitivity to outcome value and the child's sensitivity to probability. In these studies task options involve two outcomes - one positive outcome, and one zero value outcome. Thus, for Studies 1 and 2, where $V > 0$ and P is the probability of winning V points, we can write equation (1) as

$$EV = PV \qquad (2)$$

Study 3, however, was designed to address appreciation of risk. Risk taking, by definition, involves both wins and losses. Therefore, a slightly more useful way of stating this task model, in which one outcome is positive and one is negative, represents both the potential gain and losses associated with the option:

$$EV = PV_1 + (1-P)\, V_2 \qquad (3)$$

Where $V_1 > 0$, $V_2 < 0$, and P is the probability of winning V_1. In this sense, an option might be considered risky when EV < 0 (i.e., when losses are more frequent or of higher quantitative value than gains). Furthermore, the gain V_1 and the loss V_2 were set equal to the same value, thus $V_1 = -V_2$. Using V instead of V_1, substituting into Equation (3) and rearranging terms yields:

$$EV = V\,(2P - 1) \qquad (4)$$

The PLUG Apparatus

Each of the current studies was conducted with a simple computerized task designed explicitly to analyze the development of sensitivity to quantitative outcome values, probabilities, and risk. Participants were asked to choose between two buttons on the computer screen, each of which was associated with a panel that did, or did not, light-up as a consequence of each button push. Whereas each button push that resulted in a lighted panel resulted in points gained, when the button failed to light the panel the child either gained no points (i.e., Study 1 and Study 2), or lost points (i.e., Study 3). The probability of success and the number of points associated with each button were manipulated, and the child's reactions to outcome values, probabilities, and losses could be analyzed over a considerable number of trials, within a standard methodology, hereafter referred to as the Probabilistic Light-Up Game (PLUG).

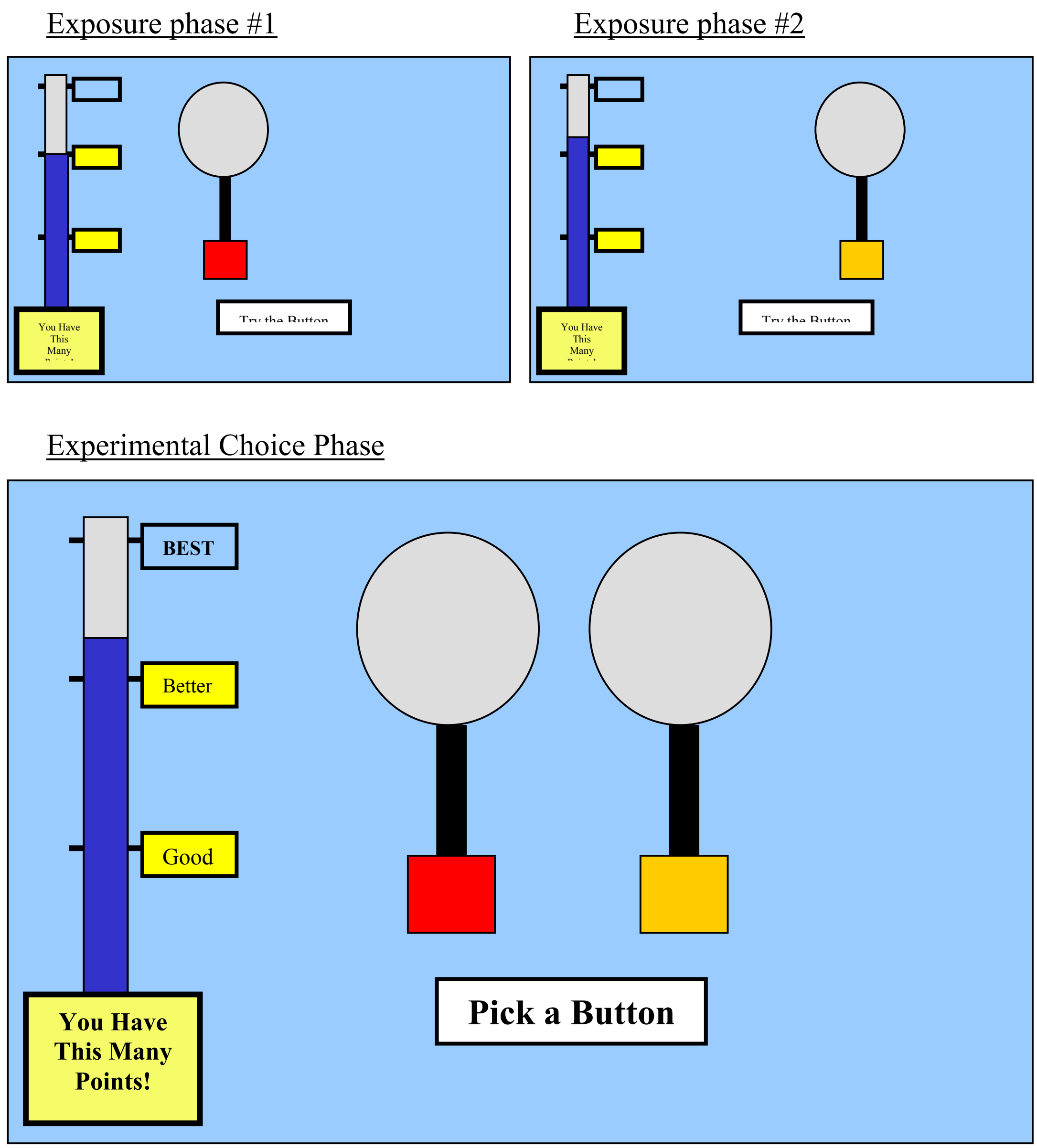
General Procedure

Each of the three studies followed the same format. After the participant's age and gender were gathered, the participant was read an assent script and was asked to verify that he/she wanted to participate. Basically, participants were told in child friendly terms that the game had been approved by an university Institutional Review

Board, that they could cease participation at any point in the task, and that they had the right to refuse to participate (See Appendix 1A for the entire assent script). Once the child agreed to participate, task instructions appeared and were read to the participant. Participants were told that they would get to push buttons to win and lose points, that when a button push resulted in a lighted bulb they would win points, when a button push resulted in an unlit bulb they would not win points (Studies 1 and 2) or would lose points (Study 3), and finally that they should try to win as many points as possible (See Appendix 1B for the entire instructions script). After receiving these instructions, participants were asked two multiple choice questions which were designed to verify that they understood the task. The first of these asked, “How do you play the light up game?” The response options were, “You move shapes,” “You push buttons,” or “You bounce balls.” Once the participant gave the correct reply (“You push buttons”), the second question appeared, which was, “What happens if you press a button and its light lights-up?” The available options were “You lose tokens,” “Nothing,” and “You win points.” Once the participant gave the correct response (“You win points”), a button labeled “Next” appeared. If the participant indicated that he/she did not understand the initial instructions, or if he/she responded incorrectly to either of the multiple-choice questions, he/she was taken to an alternate instructions screen, and the issue of confusion was readdressed more explicitly. Upon pressing the “Next” button, however, the participant proceeded to a session instructions screen, which stated that he/she would have the opportunity to try each button before beginning the choice aspect of the game, and that he/she would begin the task with 0 points.

Once the participant pressed a "Play the Game" button, he/she was taken to the *options exposure phase*. During this phase, the child saw a single button on the screen an inch either right or left of the center of the screen, and had ten trials of testing the lone option. On a probabilistically controlled percentage of these trials the button push resulted in a lighted panel, a window presenting a happy face, and the number of points won (e.g., V points, with probability P). If the button push did not light the panel, a window presented a sad face, and instead of winning the participant was informed that either no points had been won (e.g., Study 1 and Study 2, $V = 0$), or points had been lost (e.g., Study 3, V points, with probability $1 - P$). After ten exposure trials the first option disappeared, and the child was presented with a second button that was a different color than the first and appeared an inch from the center on the opposite side of the screen (whether the first button appeared right or left of the center of the screen was randomly selected by the program). After ten exposure trials with only the second option the child entered the *experimental choice phase*. In this phase the participant was shown both buttons simultaneously and was asked to make a series of 20 choices between the two (See Figure 1). As was the case in the exposure trials, the corresponding panels lit, and points were won, as governed by the probabilistic and outcome value control program inherent to each button. Across studies, the parameters for each button, and the contrasts between the buttons were strategically selected to assess the child's preference for higher value, more probable, and less risky options.

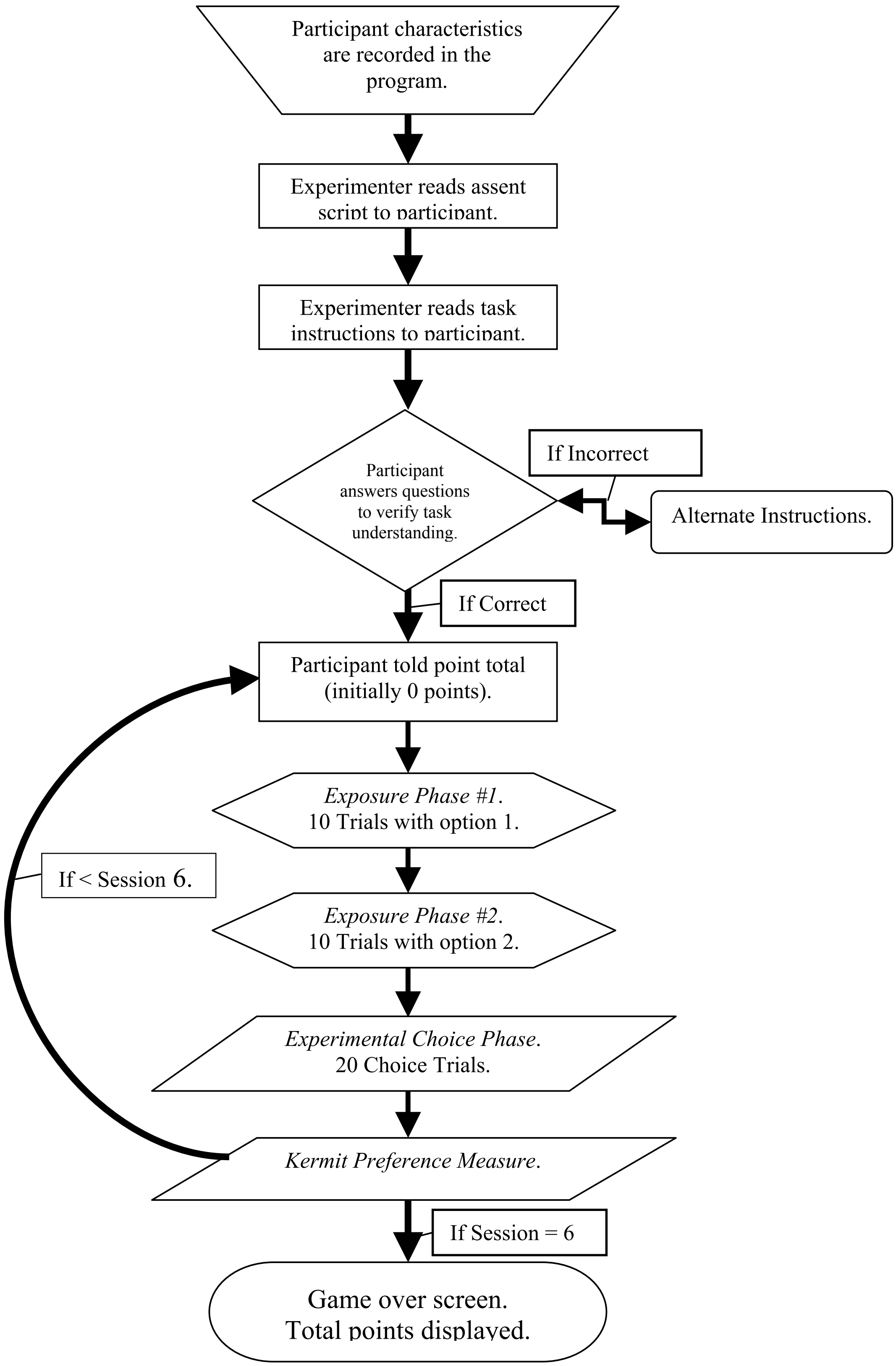
Figure 1. Visual representation of the PLUG task.



A final step was taken immediately after each series of 40-trials, which tested explicit understanding through forced choice. Participants were presented with a picture of Kermit the frog, they were told to imagine that Kermit also enjoys playing the game, and were asked which of the buttons that the they had experienced Kermit would prefer. Because this forced choice measure demands more explicit processing of the decision alternatives, and because children are believed to be capable of making intuitively guided choices before they explicitly realize the bases for their decisions, it was predicted that younger participants would be more likely to respond to the forced-choice question randomly (i.e., 50:50). Younger children, however, might not differ significantly from the older participants in intuitively guided preference across trials (i.e., button selection throughout the task).

After each child completed a series of exposure trials, choice trials, and the Kermit preference measure for a given contrast, he/she was told the current point total, and upon repressing the “Play the Game Button” a new set of 40 trials ensued marked by a modification of the appearance of the game (i.e., the buttons’ and background colors changed). All participants completed several sessions of the task in this manner, each of which involved contrasts drawn between new options with different probabilistic or outcome value structures (See Figure 2). It should also be noted that across studies a unique subset of contrasts were drawn against a centralized standard (i.e., in each study, across sessions, contrasts were drawn between four alternatives and a standard option that had $P = .5$, $V = 5$ points). Finally, for simplicity, the experiments incorporated whole number point values, and all point transactions throughout the task were recorded for the child to see in a point meter that appeared on the left side of the computer screen (as can also be seen in Figure 1).

Figure 2. Flowchart diagram of the steps of the PLUG experiment.



Chapter 3: Study 1 – The Child's Sensitivity to Quantitative Outcome Value

The few studies that have investigated the issue have generally found that relatively young children show appreciation of the benefits of higher over lower outcome values. Contemporary research has also revealed that children can attend to basic quantitative differences from a relatively young age (i.e., by 3-4 years). This, compounded with the fact that the outcome value associated with a give option is immediately perceptually available in the current task (i.e., participants are shown "You Won *V* Points!" every time they experience a win), led to the prediction that even the youngest participants in the current study will demonstrate sensitivity to outcome value. This study, however, was designed to more precisely assess how sensitive children are to quantitative outcome value.

Methods

Participants

The Institutional Review Board at the University of Maryland approved the current methodology for child participation (IRB/HSR Protocol Identification Number: 04-0498). Participants were 89 kindergartners, first-, second-, third-, and fourth-graders who were recruited from a kindergarten affiliated with the University of Maryland at College Park and suburban Maryland private elementary schools. (M_{age} = 7-years-10-months, SD_{age} = 1-year-6-months; 47 female, 42 male). For analytic purposes the participants were categorized into three age groups (32, 5-6-year-olds; 32, 7-8-year-olds; 25, 9-10-year-olds; See Table 1).

Table 1

Number of participants per age and gender category.

Gender	5-6 Years	7-8 Years	9-10 Years	Total
Female	14	17	16	**47**
Male	18	15	9	**42**
Total	**32**	**32**	**25**	**N = 89**

Materials

The intent of the current study is to examine the development of sensitivity to differences in quantitative outcome values between options in a basic decision-making situation; therefore, a unique subset of options and contrasts were selected. Each participant was asked to choose between two options (i.e., they were presented with two computerized buttons at a time) in each of six consecutive trial block sessions. Each trial block session involved 40 trials [i.e., 10 exposure trials to Option #1 + 10 exposure trials to Option #2 + 20 choice trials between Option #1 and Option #2). Thus, each participant experienced a total of 240 trials. Through the course of these six trial block sessions, participants were presented with five options that differed in value of success, but were constant in probability of success (P = 0.5):

$$V_1 = 3, V_2 = 4, V_3 = 5, V_4 = 6, V_5 = 7$$

These five options were incorporated into six different contrasts, two each at three levels of outcome value disparity ($V_x - V_y$ = 1, 2, or 3; See Table 2 for a summary of the values associated with each option, and the explicit contrasts that were drawn). For instance, in experimental contrast #5, with one option the participant won three

Table 2

Contrasts selected to assess the child's sensitivity to options with different value, holding probability of success constant, EV = PV.

Contrast[*]	V_x, V_y	P_x, P_y	$V_x - V_y$	$P_x - P_y$	$EV_x - EV_y$
1[b]	4 vs. 5	0.5 vs. 0.5	1	0.0	.5
2[b]	5 vs. 6	0.5 vs. 0.5	1	0.0	.5
3[b]	3 vs. 5	0.5 vs. 0.5	2	0.0	1.0
4[b]	5 vs. 7	0.5 vs. 0.5	2	0.0	1.0
5	3 vs. 6	0.5 vs. 0.5	3	0.0	1.5
6	4 vs. 7	0.5 vs. 0.5	3	0.0	1.5

[*] *Note*: The presentation of the contrasts followed a fixed random schedule, in the following order: Contrast 5, 1, 4, 6, 2, 3.
[b] *Note*: Contrast makes explicit use of a standard reference (V = 5, P = .5).

points on an average of half the trials, (and won no points on the remaining trials). With the other option the participant won six points on an average on half the trials (and won no points on the other half), thus producing a contrast disparity of three points (i.e., V_1 - V_2 = 3 points).

Procedure

Data collection took place during regular school or during after-school hours in familiar rooms adjacent to the participants' classrooms, in each of six data collection sites. Each participant was instructed and engaged the "Probabilistic Light-Up Game" as described above.

Results

Preliminary Analyses A series of preliminary analyses were conducted to assess the effects of potential confounding variables. These analyses revealed that option selection did not vary by data collection location (i.e., which of the six sites the data were collected at), by randomly assigned option characteristics (i.e., the color randomly assigned to each button by the computer program, and whether the first option appeared right or left of the computer screen center), and the total amount of time that children took to complete the experiment (M_{time} = 8-minutes, 10-seconds, SD_{time} = 3-minutes, 3 seconds). All subsequent analyses, therefore, were collapsed across these variables.

Experimental Choice Phase Analysis The experimental choice phase analyses considered participant rates of selection of the superior option in the experimental choice trials. Collapsing across age and gender groups and disparity conditions, participants selected the superior option (i.e., that with a superior outcome value) on just slightly over half of the total sessions (M = .518, SD = .203; See Table 3). The primary comparative analysis consisted of a 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 2 trial block (first or second block of ten experimental choice trials) X 3 contrast disparity condition (V_1 - V_2 = 1, 2, 3) mixed model Analysis of Variance (ANOVA), with age and gender analyzed between-subjects, and contrast disparity condition and trial block analyzed within-subjects. The dependent measure in this analysis was the number of times each participant chose the option with the superior outcome value, per ten trials, per disparity condition. This analysis revealed a significant main effect for age group, $F(2, 83) = 3.45$, $p = .036$, $1\text{-}\beta = .632$. Bonferroni controlled post hoc analyses indicated that the difference between the youngest (5- and 6-year-olds) and the middle (7- and 8-year-olds) age groups approached significance, $t\,(62) = 2.19$, $p = .060$. The ANOVA also revealed a

Table 3

Means and standard deviations of the proportion of trials participants selected the superior option in the experimental choice phase, per age group, gender, trial block, and disparity condition.

Age Group	
5-6-year-olds	.489 (.225)
7-8-year-olds	.540 (.183)
9-10-year-olds	.528 (.194)
Gender	
Female	.502 (.188)
Male	.536 (.218)
Trial Block	
Trial Block 1	.513 (.188)
Trial Block 2	.522 (.217)
Disparity Condition	
Disparity Condition1	.494 (.204)
Disparity Condition2	.524 (.210)
Disparity Condition3	.535 (.193)
Overall	**.518 (.203)**

Note: N = 89

significant main effect for gender, $F(1, 83) = 3.99$, $p = .049$, $1\text{-}\beta = .506$, with males selecting the superior option more frequently than females. The main effects for trial block and disparity condition were not significant.

Individual Selection Analyses Individual selection analyses were conducted in order to assess whether the performance of a few participants may be biasing the sample. The binomial theorem was used to determine whether each individual participant's selections throughout the entire task significantly differed from random response. It was determined that selecting either option (i.e., the superior or inferior button) on 72 of the total 120-trials was the significant difference criterion (assuming

$\alpha < .05$). This analysis revealed that the vast majority of participants did not select either the superior or inferior option more frequently than expected by chance. In fact, only 10 participants (11%) selected the superior option more frequently than expected by chance, and only four participants (4%) selected the inferior option more frequently than expected by chance. This finding suggests that participants tended to use a split judgment strategy, selecting either option with near equal frequency.

Forced-Choice Analysis The final series of analyses considered participant selection on the explicit forced-choice measure (i.e., whether or not the participant accurately predicted Kermit would prefer the superior option). Collapsing across age and gender groups and disparity conditions, participants responded that Kermit would prefer the superior option (i.e., the option with a superior outcome value) on just over half of the total sessions (*M* = .562, *SD* = .497; See Table 4).

Table 4

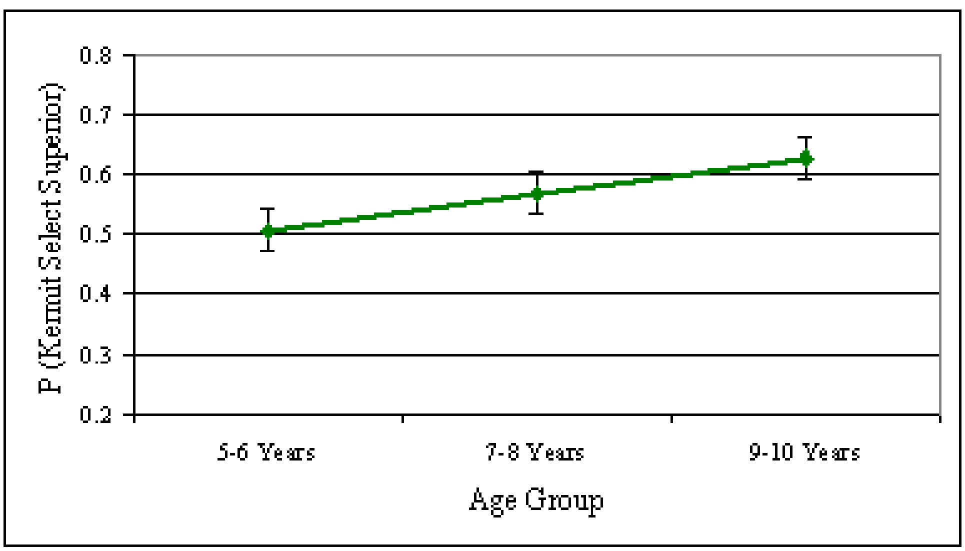
Mean proportion of accurate prediction on the forced-choice Kermit preference measure, per age group, gender, and disparity condition.

Age Group	
5-6-year-olds	.505
7-8-year-olds	.568
9-10-year-olds	.627
Gender	
Female	.567
Male	.556
Disparity Condition	
Disparity Condition1	.551
Disparity Condition2	.562
Disparity Condition3	.573
Overall	**.562**

Note: N = 89

Responses on the forced-choice measure were significantly, but only moderately, correlated with selection of the superior option in the experimental choice phase sessions, *R* (534) = .213, $p < .001$. A 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 3 contrast disparity condition (V_1 - V_2 = 1, 2, 3) mixed model ANOVA, with age and gender analyzed between-subjects, and contrast disparity condition analyzed within-subjects, was conducted. The dependent measure in this analysis was the number of times participants accurately predicted that Kermit would prefer the superior option. Although accuracy in predicting that Kermit would prefer the superior option did increase with age (See Figure 3), the analysis revealed that this main effect was non-significant, $F(2, 83) = 2.07$, $p = .132$, $1\text{-}\beta = .416$, as were all other main effects and interactions.

Figure 3. Accuracy in the forced-choice measure per age group.



Discussion

The above results were unexpected. Whereas previous studies have demonstrated that relatively young children are able to use quantitative outcome values to guide preferences (Schlottmann, 2000; 2001; Schlottmann & Anderson, 1994), the obtained results revealed significant age differences in sensitivity to outcome value, and across dependent measures, the youngest participants selected the superior option on no more than half of the trials. Group differences aside, the individual performance results suggest that most participants, independent of age, had a tendency to employ a split-judgment strategy in the current task (i.e., they picked neither option more frequently than expected by chance). This is demonstrative of relative insensitivity to quantitative outcome values.

It appears that participants may have been using probability information, rather than outcome value information, to guide their selections. Recall, the probability of success for each alternative was controlled (i.e., $P = .5$ for both alternatives in each of the 40-trial sessions). Since each alternative in every decision pair had equal probability for success, if participants were using probability to guide their selections, the result would be near equal selection of each alternative. This was precisely what was found, despite the differences between each of the alternatives' quantitative outcome values. Essentially, participants, and particularly the younger participants, seem to have adopted a strategy of seeking wins instead of losses, independent of the quantitative point value associated with winning. Perhaps had the constancy of probability across alternatives been made more apparent, maybe participants would have demonstrated greater reliance upon outcome values. Implementing a condition in which probability is constant across the two options in a decision pair, but variable across sessions may be one way to do this, which is one direction future studies may go. Another manipulation that might shed some light on this issue would be to control the outcome value associated with each option and draw contrasts between options with varying probabilities of success. This was precisely what was done in Study 2.

One potential alternative explanation for the obtained results is that, despite being readily perceptually available, the presentation of quantitative outcome value was dependent upon conventional numerical representation (i.e., on every win trial the participant was shown, "You won *V* points," with outcome value represented as *V* = "3," "4," "5," "6," or "7"). In designing the study it was assumed that even the youngest participants (i.e., five-year-olds) would be familiar with the graphical presentation of each numeral (i.e., that they could identify "3" as "three," and comprehend that "3" is less than "4," etc.). No participants, in any of the age groups demonstrated any confusion whatsoever to this presentation strategy; however, it is possible that the results may have been slightly different had the outcome values associated with each alternative been presented differently. For instance, one alternative strategy would be to present each point won discretely (i.e., as "O, O, O" instead of "3"). Another alternative would be to present the points in a more tangible fashion (i.e., physically present the participant with *V* tokens per win). Either of these manipulations might make the quantitative outcome value associated with each alternative more salient, perhaps especially so for the younger participants, and should be taken into consideration in future studies.

Another related possibility is that the quantitative outcome values contrasted in the current experiment were not sufficiently disparate to motivate consistent selection of the superior alternative. The current study revealed only slight evidence that selection is related to outcome value disparity; however, perhaps participants would have been more attentive to quantitative outcome value and would have selected the superior option more frequently, had there been greater discrepancy between the contrasted pairs (e.g., had disparity been 3, 6, and 9 points, rather than 1, 2, and 3 points). This too is an issue that future work should consider.

Chapter 4: Study 2 – The Child's Sensitivity to Probability

The current study was designed to assess the child's sensitivity to probability in a decision-making situation. The findings of Study 1 suggested that children may attend to probability of success and neglect quantitative outcome values. In addition, recent research has found that children are able to use probability information to guide preferences. It was therefore predicted that even young children would be sensitive to probabilistic differences in outcomes, and would select the more probable alternative significantly more often than the less probable alternative. This, however, is the primary empirical question the current study was explicitly designed to answer. Another issue of central importance is whether or not there would be a difference between intuitively guided selection of options in the choice phases of the task and more explicit preference, as assessed by the forced-choice dependent measure (i.e., Kermit preference). Although even the youngest children in the current sample might intuitively select the more probable option more frequently than the less probable option, it was also predicted that there would be age differences in explicit preference (i.e., older children would be more accurate than younger children in surmising that a character would prefer the probabilistically superior option).

Methods

Participants

The Institutional Review Board at the University of Maryland approved the current methodology for child participation (IRB/HSR Protocol Identification Number: 04-0498). Participants were 80 kindergartners, first-, second-, third-, and fourth-graders who were recruited from a kindergarten affiliated with the University of Maryland at College Park and suburban Maryland private elementary schools (M_{age} = 7-years-10-months, SD_{age} = 1-year-7-months; 43 female, 37 male). For analytic purposes the participants were categorized into three age groups (28, 5-6-year-olds; 29, 7-8-year-olds; 23, 9-10-year-olds; See Table 5). All participants had parental permission and assented to participate.

Materials

Each participant was asked to choose between two options (i.e., they were presented with two computerized buttons at a time) in each of six consecutive trial block sessions of 40 trials, for a grand total of 240 trials [i.e., (10 exposure trials to Option 1 + 10 exposure trials to Option 2 + 20 choice trials between Option 1 and Option 2) X 6 experimental sessions = 240 total trials]. The choices were drawn from a set of five options that differed in probability of success, but were constant in value of success (V = 5 points):

$$P_1 = .3, P_2 = .4, P_3 = .5, P_4 = .6, P_5 = .7$$

Each trial block session included a different contrast, and the six contrasts represented two examples each of three levels of disparity in outcome probability ($P_x - P_y$ = .1, .2, or .3; See Table 6).

Table 5

Number of participants per age and gender category.

Gender	**5-6 Years**	**7-8 Years**	**9-10 Years**	**Total**
Female	12	18	13	**43**
Male	16	11	10	**37**
Total	**28**	**29**	**23**	**N = 80**

Table 6

Contrasts selected to assess the child's sensitivity to options with different probabilities of success, holding outcome value constant, EV = PV.

Contrast[*]	V_x, V_y	P_x, P_y	$V_x - V_y$	$P_x - P_y$	$EV_x - EV_y$
1[b]	5 vs. 5	0.4 vs. 0.5	0	0.1	.5
2[b]	5 vs. 5	0.5 vs. 0.6	0	0.1	.5
3[b]	5 vs. 5	0.3 vs. 0.5	0	0.2	1.0
4[b]	5 vs. 5	0.5 vs. 0.7	0	0.2	1.0
5	5 vs. 5	0.3 vs. 0.6	0	0.3	1.5
6	5 vs. 5	0.4 vs. 0.7	0	0.3	1.5

[*]*Note*: The presentation of the contrasts followed a fixed random schedule, in the following order: Contrast 5, 1, 4, 6, 2, 3.
[b] *Note*: Contrast makes explicit use of a standard reference (V = 5, P_w = .5).

For instance, in contrast #3, choice of one button yielded five points on an average of 3/10 of the trials (and no points in the other 7/10 of the trials) while the other button yielded five points on an average of 5/10 trials (and no points on the remaining 5/10 trials). Thus, the probabilities of winning differed by .2 (i.e., $P_1 - P_2 = .2$).

Procedure

Data collection took place during regular school or during after-school hours in familiar rooms adjacent to the participants' classrooms, in each of five data collection locations. The experimental protocol described above was used in this experiment.

Results

The same series of analyses that were conducted in Study 1 were used in the current study (i.e., preliminary analyses, experimental choice phase analyses, individual selection analyses, and forced-choice analyses). Again, preliminary analyses revealed that option selection did not vary by data collection location (i.e., where the data were collected), by randomly assigned option characteristics (i.e., the color randomly assigned to each button by the computer program, and whether the first option appeared right or left of the center of the computer screen), and the total amount of time that children took to complete the experiment (M_{time} = 8-minutes, 39-seconds, SD_{time} = 4-minutes, 5 seconds); therefore, all subsequent analyses were collapsed across these variables.

Collapsing across age and gender groups and disparity conditions, participants selected the superior option (i.e., that with a superior probability of success) on slightly over half of the total sessions (*M* = .577, *SD* = .197; See Table 7).

Table 7

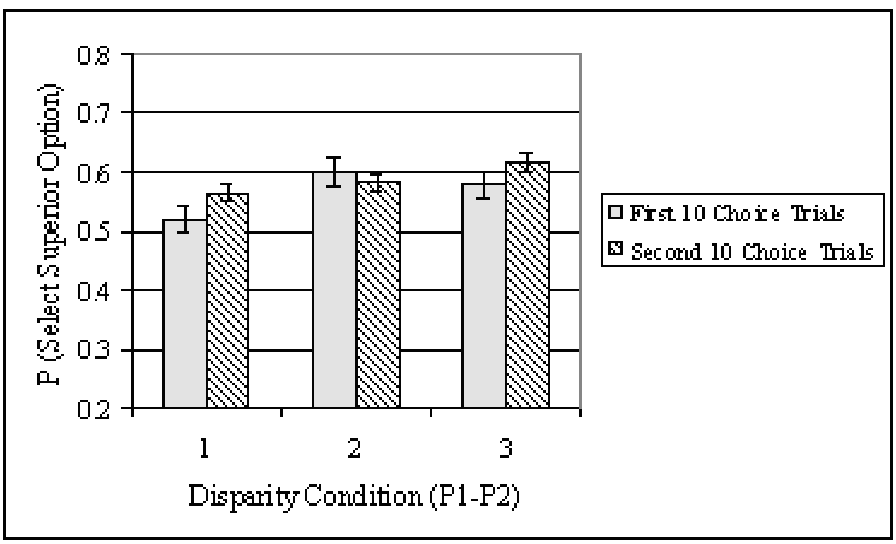
Means and standard deviations of the proportion of trials participants selected the superior option in the experimental choice phase, per age group,gender, trial block, and disparity condition.

Age Group	
5-6-year-olds	.595 (.228)
7-8-year-olds	.550 (.154)
9-10-year-olds	.589 (.202)
Gender	
Male	.577 (.188)
Female	.577(.207)
Trial Block	
Trial Block 1	.566 (.188)
Trial Block 2	.588 (.205)
Disparity Condition	
Disparity Condition1	.543 (.197)
Disparity Condition2	.591 (.198)
Disparity Condition3	.597 (.192)
Overall	**.577 (.197)**

Note: N = 80

The primary analysis was a 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 2 trial block (first or second block of ten experimental choice phase trials) X 3 contrast disparity condition (P_1 - P_2 = .1, .2, .3) mixed model ANOVA, with age and gender analyzed between-subjects, contrast disparity condition and trial block analyzed within-subjects, and button preference throughout the experimental choice phase sessions as the dependent measure (i.e., the number of times the participant chose the option with the superior probability of success, per ten trials, per disparity condition). This analysis revealed a significant main effect for trial block, $F(1, 74) = 5.24$, $p = .025$, $1-\beta = .618$; participants selected the superior option more frequently in the second than the first trial block. A significant main effect also emerged for disparity condition, $F(2, 148) = 5.16$, $p = .007$, $1-\beta = .820$, with a simple main effect between the first and second disparity conditions, $F(1, 74) = 9.33$, $p = .003$, $1-\beta =$ .854. There was also a significant interaction between disparity condition and trial block, $F(2, 148) = 3.81$, $p = .024$, $1-\beta = .686$ (See Figure 4).

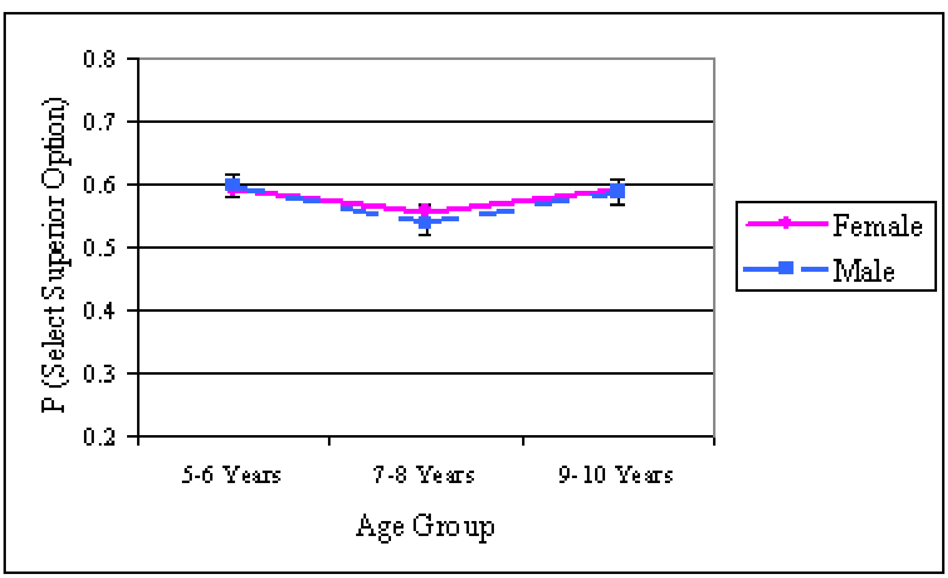
Figure 4. The mean frequency with which participants selected the superior option, per trial block and disparity condition.



In the highest and lowest disparity conditions (i.e., P_1 - P_2 = .1 and .3) performance improved across trial blocks (i.e., participants picked the superior over the inferior alternative more frequently in the second than the first trial block); however, surprisingly, this was not the case in the middle disparity condition (i.e., participants actually selected the superior over the inferior option more frequently in the first trial block in the P_1 - P_2 = .2 condition). The main effects and all potential interactions for age and gender, however, were non-significant (See Figure 5).

Analyses of each individual participant's selections were conducted to assess whether the above trends were consistent across participants. The binomial theorem determined that selecting either option on 72 of the 120 total trials was the significant difference criterion (assuming $\alpha < .05$). In contrast to the response patterns observed in Study 1, a fair number of participants (23 participants, 29%) selected the more probable option more frequently than expected by chance.

Figure 5. The mean frequency with which participants selected the superior option, per age group and gender.



Conversely, only one participant selected the less probable option more frequently than expected b y chance. This suggests that consistent selection of the superior option is not limited to just a few participants, and because the superior option was chosen more frequently than expected by chance by substantially more participants than the inferior option was, these results suggest relative sensitivity to probability.

The final analysis considered participant selection in the explicit forced-choice measure (i.e., which button Kermit would prefer). Collapsing across age groups, genders, and disparity conditions, participants responded that Kermit would prefer the superior option (i.e., that with a superior probability of success) on just over half of the total sessions (*M* = .560, *SD* = .497; See Table 8). Responses on this measure were significantly correlated with selection of the superior option in the experimental choice sessions; however, as was the case in Study 1, this correlation was only

Table 8

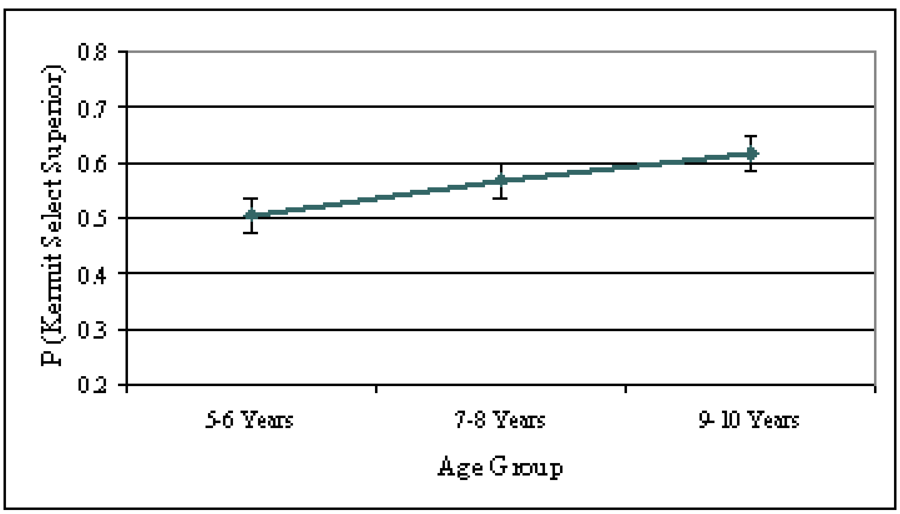
Mean proportion of accurate prediction on the forced-choice Kermit preference measure, per age group and disparity condition.

Age Group	
5-6-year-olds	.506
7-8-year-olds	.569
9-10-year-olds	.616
Gender	
Female	.550
Male	.572
Disparity Condition	
Disparity Condition1	.531
Disparity Condition2	.569
Disparity Condition3	.581
Overall	**.560**

Note: N = 80

moderate, *R* (480) = .199, $p < .001$. A 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 3 contrast disparity condition ($P_1 - P_2 = .1, .2, .3$) mixed model ANOVA was conducted, with age and gender analyzed between-subjects, contrast disparity condition analyzed within-subjects, and the number of times participants predicted Kermit would prefer the superior option as the dependent variable. As Table 8 and Figure 6 illustrate, accuracy in predicting that Kermit would prefer the superior option improved with age; however, the analysis revealed that this effect was non-significant, $F(2, 74) = 2.12$, $p = .128$, $1-\beta = .421$, as were all other main effects and interactions.

Figure 6. Accuracy in forced-choice measure per age group.



Discussion

The current results are reasonably consistent with recent studies that have found that even relatively young children attend to, and adjust preferences based upon, probability (Acredolo et al. 1989; Kuzmak & Gelman, 1986; Schlottmann & Anderson, 1994; Schlottmann, 2001). Whereas previous studies tend to present participants with perceptually visible and static probabilistic gambles (e.g., "view this spinner, tube, or array of counters"), however, the current task revealed that children are relatively sensitive to underlying, imperceptible, and time-variant probabilities. Not only did participants select the more probable option more frequently than the less probable option, a fair number of participants selected the superior option at a rate greater than expected by chance.

Another interesting aspect of the results was that there were significant differences between disparity conditions (i.e., participants were more likely to select the more probable option over the less probable option when the two had a larger disparity in probability of success), and trial blocks (i.e., participants were more likely to select the more probable option over the less probable option in the second set of 10 choice trials). Each of these findings might be attributed to uncertainty. At the outset, participants were not informed that one button had a higher probability of success than the other. This, of course, is why it was predicted that more disparate conditions would require less sensitivity to probability than would less disparate conditions, and that selection would improve with prolonged trials, which the results supported.

Moving on, as mentioned in the introduction, contemporary studies have produced results that are not entirely consistent with classic studies, typically by revealing that children are able to process probability earlier in development than the classic approach presumed. However, contemporary studies of the development of probability understanding have differed from classic approaches both in terms of the response mechanism used to gauge "understanding," and in terms of what qualifies as "understanding." Regarding the former, it was proposed that perhaps some of the differences between the contemporary and classic studies might be attributed to the response mechanism that each employs. Whereas classic studies have largely relied on forced-choice response (i.e., what is the most likely outcome of the current gamble? which of two gambles do you prefer?) contemporary studies have relied on a far richer mechanism that asks the child to estimate a degree of preference with a given gamble. Regarding the latter, whereas classic studies have adopted a rigid theoretical perspective that requires explicit demonstration of probability understanding, contemporary studies have adopted a theoretical perspective that qualifies graded and implicit demonstration of probability use as "understanding." The current studies were designed to tease these issues apart by including both a forced-choice measure (i.e., which option would Kermit prefer?) and a metric for more intuitive preference (i.e., button selection throughout the choice phases of the task). There are three theoretically rooted patterns of data that could emerge with these dual measures: 1) Younger participants might fail on both measures (i.e., select the more and less probable options in each pair with equal frequency, and predict Kermit would prefer either option with equal frequency), 2) Younger participants might succeed on both measures (i.e., select the more probable option over the less probable option, and predict Kermit would prefer the more probable option over the less probable option), or 3) Younger participants might succeed on one measure (i.e., intuitively select the more probable option more frequently than the less probable option), and fail on the other (i.e., explicitly predict Kermit would prefer either option with equal frequency). If the pure classic approach provides the most accurate explanation, and children do not understand probability until later childhood, we would expect data pattern 1. If children are simply more competent than the classic approach presumed, we would expect data pattern 2. If, however, the argument that different measures lead to different results *and* variable theoretical interpretations is most accurate, we would expect data pattern 3. This third pattern is the best fit with the obtained data. Whereas there was minimal developmental variance in selection during the experimental choice phases (i.e., the youngest participants actually selected the more probable option slightly more frequently than the older participants), there was a linearly increasing developmental pattern in the forced-choice measure. Although this developmental effect on the forced-choice measure was non-significant, it was apparent that the youngest participants (i.e., five- to six-year-olds) selected the more probable option more frequently in the choice trials than they predicted Kermit would prefer the more probable option (i.e., 59.5% of trials vs. 50.6% of forced-choices). That said, the different measures do lead to different results. With a more intuitive measure younger children are more able to demonstrate sensitivity, and development appears to proceed from implicit to more explicit ability; however, which is more indicative of probability “understanding” is truly a theoretical issue.

In discussing Study 1 it was mentioned that children, and particularly younger children, seem to neglect the quantitative outcome value associated with a decision-making alternative, but attend to its probability of success. The current study further supports this conclusion; whereas there was a significant age effect in selection of the option with higher outcome value in Study 1, there was not a significant age effect in selection of the more probable option in the current study. Furthermore, across ages, participants selected the more probable option over the less probable option in the current study more frequently than those of Study 1 selected the higher outcome value option over the lower outcome value option. Future research could further exploit this issue by increasing the complexity of the task, and pit probability of success against outcome value (i.e., implement conditions in which options with higher probability of success are pitted against options with higher quantitative outcome values, options with moderate probability of success are pitted against options with moderate outcome values, and options with low probability of success are pitted against options with low outcome values). Another possibility would be to implement a condition that involves greater than one potential non-zero outcome. This was exactly the strategy used in the following study, in that wins were combined with losses, rather than zero value outcomes.

Chapter 5: Study 3 – The Child's Sensitivity to Loss

The current study, for most intents and purposes, is a replication of Study 2, with one added manipulation; it also considers the child's sensitivity to risk. As discussed in the introduction, risk-taking is defined as behavior that entails some probability of loss. In this sense, although Studies 1 and 2 were investigations of the child's sensitivity to uncertain elements in a decision-making task, neither study tapped the child's sensitivity in a risky situation, where choices could produce losses. The current study was explicitly designed to do just this because each button press that did not result in a win resulted in a loss of points. Furthermore, although Study 1 allowed analysis of quantitative outcome value differences, and Study 2 allowed analysis of probability of success, by supplementing wins with losses the current study allows analysis of probability of success with two non-zero outcome values.

Methods

Participants

The Institutional Review Board at the University of Maryland approved the current methodology for soliciting child participation (IRB/HSR Protocol Identification Number: 04-0498). All participants had parental permission and assented to participate. The sample consisted of 77 kindergartners, first-, second-, third-, and fourth-graders who were recruited from a kindergarten affiliated with the University of Maryland at College Park and suburban Maryland private elementary schools (M_{age} = 7-years-10-months, SD_{age} = 1-year-6-months; 44 female, 33 male). For analytic purposes the participants were categorized into three age groups (26, 5-6-year-olds; 28, 7-8-year-olds; 23, 9-10-year-olds; See Table 9).

Table 9

Number of participants per age and gender category.

Gender	5-6 Years	7-8 Years	9-10 Years	Total
Female	13	17	14	**44**
Male	13	11	9	**33**
Total	**26**	**28**	**23**	**N = 77**

Materials

Again, five options were paired to produce 6 different experimental contrasts (Outlined in Table 10). The contrasts that were drawn were identical to those in Study 2; however, wins were supplemented with losses rather than non-wins. The five options differed in probability of success, but all point transactions (e.g., wins and losses) had a common value (V_1 = 5 points, V_2 = -5 points):

$$P_1 = .3, P_2 = .4, P_3 = .5, P_4 = .6, P_5 = .7$$

Again, there were two contrasts where the probability of winning differed by .1, two contrasts differed by .2 and two contrasts differed by .3 (See Table 10). Unlike Study 2, two of the options (those with P = .3 and P = .4) are comparatively risky because losses are more probable than wins. In this sense, participants may not only prefer an option with a higher probability of success because it leads to more frequent wins, but also because the options with a higher probability of success have a lower probability of loss. Thus, while the probability disparities between contrasts in the current experiment are identical to those drawn in Study 2, there is a two-fold increase in the expected value disparity between the currently contrasted options. Therefore, it is expected that this manipulation will magnify the results obtained in Study 2, and that

Table 10

Contrasts selected to assess the child's sensitivity to options with different probabilities of success, holding outcome value constant, $EV = V\,(2P_w - 1)$.

Contrast*	V_x, V_y	P_x, P_y	$V_x - V_y$	$P_x - P_y$	$EV_x - EV_y$
1[b]	5 vs. 5	0.4 vs. 0.5	0	0.1	1.0
2[b]	5 vs. 5	0.5 vs. 0.6	0	0.1	1.0
3[b]	5 vs. 5	0.3 vs. 0.5	0	0.2	2.0
4[b]	5 vs. 5	0.5 vs. 0.7	0	0.2	2.0
5	5 vs. 5	0.3 vs. 0.6	0	0.3	3.0
6	5 vs. 5	0.4 vs. 0.7	0	0.3	3.0

**Note*: The presentation of the contrasts followed a fixed random schedule, in the following order: Contrast 5, 1, 4, 6, 2, 3.
[b] *Note*: Contrast makes explicit use of a standard reference ($V = 5$, $P = .5$).

participants will develop a preference for the more probable options, particularly when contrasts are more disparate, to even a greater degree than in Study 2. It was also predicted that even younger children would select the probabilistically superior option more frequently than the inferior option, but that older children might be more likely to form an explicit cumulative preference (as assessed by the forced-choice measure). In any event, it is proposed that the current study will more precisely reveal the development of children's decision-making abilities in situations of potential loss.

Procedure

Data collection took place during regular school or during after-school hours in familiar rooms adjacent to the participants' classrooms, in each of six data collection sites. The experimental protocol was the same as in the previous experiments.

Results

The same series of analyses that were conducted in Studies 1 and 2 were again used (i.e., preliminary analyses, experimental choice analyses, individual selection analyses, and forced-choice analyses). Preliminary analyses revealed that option selection did not vary by data collection location (i.e., where the data were collected), by randomly assigned option characteristics (i.e., the color randomly assigned to each button by the computer program, and whether the first option appeared right or left of the center of the computer screen), or the total amount of time that children took to complete the experiment (M_{time} = 8-minutes, 14-seconds, SD_{time} = 2-minutes, 44 seconds), and therefore all subsequent analyses were collapsed across these variables.

Collapsing across age and gender groups and disparity conditions, participants selected the superior option (i.e., that with a superior probability of success) on over half of the total sessions (M = .590, SD = .199; See Table 11). A 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 2 trial block (first or second block of ten experimental choice phase trials) X 3 contrast disparity condition (P_1 - P_2 = .1, .2, .3) mixed model ANOVA with age and gender analyzed between-subjects, contrast disparity condition and trial block were analyzed within-subjects, was conducted. The number of selections of the superior options, per trial block and disparity condition, throughout the experimental choice sessions was the dependent measure. This analysis revealed a significant main effect for trial block, $F(1, 71) = 9.76$, $p = .003$, $1-\beta = .869$; participants selected the superior option more frequently in the second than the first trial block. There was also a significant main effect for disparity condition, $F(2, 142) = 11.08$, $p < .001$, $1-\beta = .991$, with a simple main effect which

Table 11

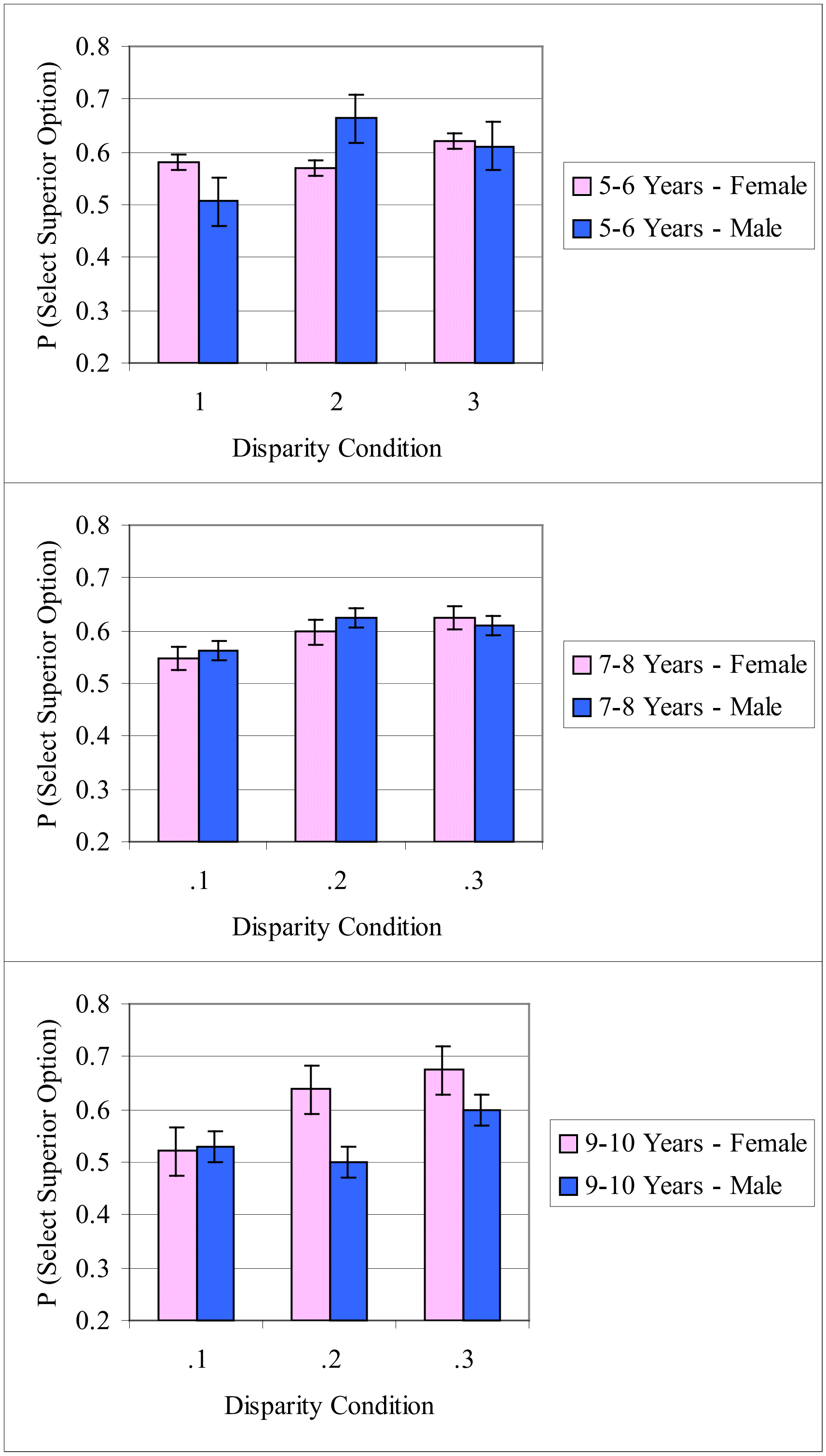
Means and standard deviations of the proportion of trials participants selected the superior option in the experimental choice phase, per age group and disparity condition.

Age Group	
5-6-year-olds	.592 (.204)
7-8-year-olds	.597 (.187)
9-10-year-olds	.585 (.209)
Gender	
Female	.597 (.195)
Male	.582 (.204)
Trial Block	
Trial Block 1	.574 (.190)
Trial Block 2	.609 (.207)
Disparity Condition	
Disparity Condition1	.543 (.204)
Disparity Condition2	.606 (.195)
Disparity Condition3	.626 (.190)
Overall	**.592 (.199)**

Note: N = 77

demonstrated greater selection of the superior option in the third than the first disparity condition, $F(1, 71) = 19.65$, $p < .001$, $1\text{-}\beta = .992$. The main effects for age and gender were non-significant; however, a significant interaction emerged between disparity condition, age group, and gender, $F(4, 142) = 3.23$, $p = .014$, $1\text{-}\beta = .820$ (See Figure 7). Although this interaction was quite unsystematic, it appears that although 7-8-year-old males and females selected similarly across disparity conditions, 5-6-year-old males selected the superior option more frequently than 5-6-year-old female in the middle disparity condition, and 9-10-year-old females selected the superior option more frequently than 9-10-year-old males in the same disparity condition.

Figure 7. Age X Gender X Disparity Condition interaction in option selection.



Analyses of each individual participant's selections were conducted to assess cross-participant consistency. The binomial theorem determined that selecting either option on 72 or more of the total 120 trials was the significant difference criterion (assuming $\alpha < .05$). A substantial number of the participants in the current study (31 participants, 40%) selected the more probable option significantly more frequently than chance, whereas no participants selected the less probable option more often than expected by chance. These results suggest that consistent selection of the superior option is not limited to a small subsection of the current sample, and that participants were relatively sensitive to probability in a decision situation with loss.

The final analysis considered selection in the explicit forced-choice measure (i.e., which button Kermit would like more). Collapsing across age and gender groups and disparity conditions, participants responded that Kermit would prefer the superior option on over half of the total sessions ($M = .580$, $SD = .494$; See Table 12). Responses on this measure were significantly, but only moderately, correlated with selection of the superior option in the experimental choice sessions, $R\ (462) = .180$, $p < .001$. Another 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 3 contrast disparity condition ($P_{w1} - P_{w2} = .1, .2, .3$) mixed model ANOVA was conducted, with age and gender analyzed between-subjects, contrast disparity condition analyzed within-subjects, and the number of times participants accurately predicted that Kermit would prefer the superior option as the dependent variable. As was the case in Studies 1 and 2, the analysis revealed no significant main effects; however, a significant interaction between disparity condition and age group

Table 12

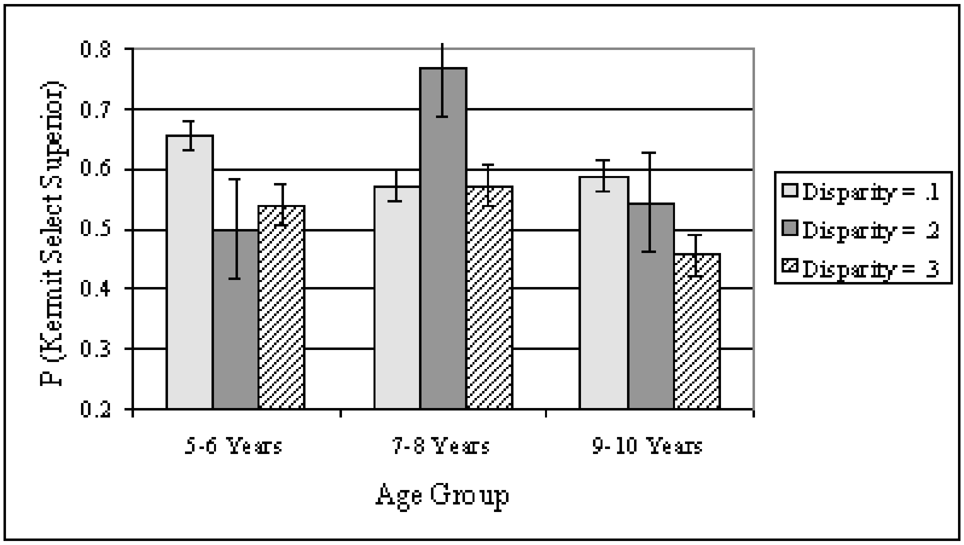
Mean proportion of accurate prediction on the forced-choice Kermit preference measure, per age group and disparity condition.

Age Group	
5-6-year-olds	.564
7-8-year-olds	.637
9-10-year-olds	.529
Gender	
Female	.595
Male	.561
Disparity Condition	
Disparity Condition1	.604
Disparity Condition2	.610
Disparity Condition3	.526
Overall	**.580**

Note: N = 77

emerged, $F(4, 142) = 2.94$, $p = .023$, $1\text{-}\beta = .778$. Surprisingly, as Figure 8 illustrates, participants in the youngest and oldest age groups were more accurate in predicting Kermit would prefer the superior option in the condition of minimal disparity than the other disparity conditions, and 7-8-year-olds demonstrated a highest degree of accuracy in the .2 disparity condition.

Figure 8. Age X disparity condition interaction on Kermit preference measure.



Discussion

The results of the current study were largely consistent with those of Study 2. Across ages, participants selected the options with greater probability of success more frequently than those with lesser probability of success. Further, participants were more likely to select the option with greater probability of success in instances of greater probability disparity, and in the later trial block. What is most surprising, however, is that the current results did not magnify those of Study 2. Supplementing wins with losses rather than non-wins produced a two-fold increase in the expected value discrepancy between the options contrasted in the current study over those contrasted in Studies 1 and 2. This led to the prediction that participants would select the more probable options substantially more frequently in the current study than in Study 2; however, this prediction seems to have not been met. Collapsing across age groups, participants did select the more probable option slightly more frequently in the current study than was the case in Study 2 (i.e., 59.0 % of trials vs. 57.7% of trials); however, this difference was not nearly as substantial as was expected. Interestingly, because the implementation of loss trials increases the number of quantitative outcome values involved, drawing comparisons between Study 2 and the current study further supports the argument that children tend to neglect quantitative outcome values, as was found in Study 1.

Also surprisingly, the current study failed to replicate the finding in Study 2 that different dependent measures produce different results. Whereas Study 2 revealed a linear developmental increase in selection of the more probable option on the forced-choice measure, the current study found no such evidence. In fact, the oldest participants in the current study appear to be the least accurate in predicting that Kermit would prefer the more probable option when asked to make a forced-choice. Furthermore, participants were surprisingly poor in predicting that Kermit would prefer the more probable option in the condition of maximum disparity (i.e., when the probability of success in the more probable option was .3 greater than that in the less probable option). Perhaps even more surprising, the oldest participants appeared to have had the most trouble with the condition of greatest disparity (i.e., the 9-10-year-olds predicted Kermit would prefer the more probable option in less than half of the .3 disparity condition sessions). Given the inconsistencies between Study 2 and the current study, performance on forced-choice vs. sequential selection measures must be explored further.

Chapter 6: Cross-Study Analyses

The results reported above were not entirely consistent with what was predicted. Contrary to the predictions made, it seems that processing of probability information may developmentally precede processing of quantitative outcome value information. That is, although there were age-based improvements in selecting a quantitatively higher valued option over a lower valued option (i.e., Study 1), there were really no age trends in selection of a more probable option over a less probable option (i.e., Studies 2 and 3; See Table 13). In this sense, participants in the current studies seem to have adopted a strategy of neglecting outcome values in favor for attending to probability of success, particularly the youngest participants (e.g., 5-6-year-olds).

A series of cross-study analyses were conducted to further probe these results. As introduced, each study made explicit use of a centralized standard alternative; specifically, in each study, four contrasts were drawn against an option that was

Table 13

Cross-study means and standard deviations of the proportion of trials participants selected the superior option in the experimental choice phase, per age group and disparity condition.

	Study 1[a] Outcome Value	**Study 2[b] Probability**	**Study 3[c] Probability w/ Loss**
Age Group			
5-6-year-olds	.489 (.225)	.595 (.228)	.592 (.204)
7-8-year-olds	.540 (.183)	.550 (.154)	.597 (.187)
9-10-year-olds	.528 (.194)	.589 (.202)	.585 (.209)
Overall	**.518 (.203)**	**.577 (.197)**	**.592 (.199)**

[a] *Note*: N = 89
[b] *Note*: N = 80
[c] *Note*: N = 77

associated with .5 probability of success and a quantitative outcome value of 5 points per win. For instance, in Study 1, an alternative that resulted in 3 points per win was contrasted against the standard that resulted in 5 points per win, each with .5 probability of success. Similarly, in Study 2 an alternative with .3 probability of success was contrasted against the standard with .5 probability of success, each of which resulted in 5 points per win. In expected value terms, these examples are equivalent contrasts, and this structural similarity might be exploited to perform cross-study comparisons.

The adopted strategy involved an analysis of the rate at which each participant selected each alternative option over the centralized standard (V = 5, P = .5). These selection rates were plotted against the alternative characteristic (i.e., if the alternative involved 3, 4, 6, or 7 points, or .3, .4, .6, or .7 probability of success). Lines-of-best-fit were then plotted through these alternative X selection rates plots, and the slope of these lines were used as a summary of each participant's selection (See Figure 9 for a graphical example of this plotting strategy, and See Figure 10 for the mean alternative vs. standard selection data). With this plotting strategy, a positive slope, which emerges when participants select the standard over the lower alternatives (i.e., select 5 over 3 and 4) and select the higher alternatives over the standard (i.e., select 6 and 7 over 5), is indicative of adaptive selection, whereas a zero or negative slope is indicative of no preference or maladaptive selection, respectively.

These cross-study slopes data were analyzed with a 3 age group (5-6 years, 7-8 years, 9-10 years) X 2 gender X 2 trial block (first or second block of ten experimental choice phase trials) X 3 experiment (Study 1, Study 2, Study 3) mixed model ANOVA, with age, gender, and experiment analyzed between-subjects, and trial block analyzed within-subjects. The dependent measure was each participant's slope of the alternative vs. standard line-of-best-fit. The analysis revealed a significant main effect for experiment, $F(2, 228) = 9.99$, $p < .001$, $1\text{-}\beta = .984$ ($M_{study\ 1} = .009$, $SD_{study\ 1} = .068$; $M_{study\ 2} = .045$, $SD_{study\ 2} = .067$; $M_{study\ 3} = .051$, $SD_{study\ 3} = .056$).

Figure 9. Graphical example of cross-study slope plotting analyses.

Example: Study 2, Participant Number 10, 2nd Block of 10 choice trials

Selected (.3, 5) over (.5, 5) on 3 of 10 trials -

Selected (.4, 5) over (.5, 5) on 5 of 10 trials -

Selected (.6, 5) over (.5, 5) on 10 of 10 trials -

Selected (.7, 5) over (.5, 5) on 7 of 10 trials -

Line-of-best-fit, Slope = .13

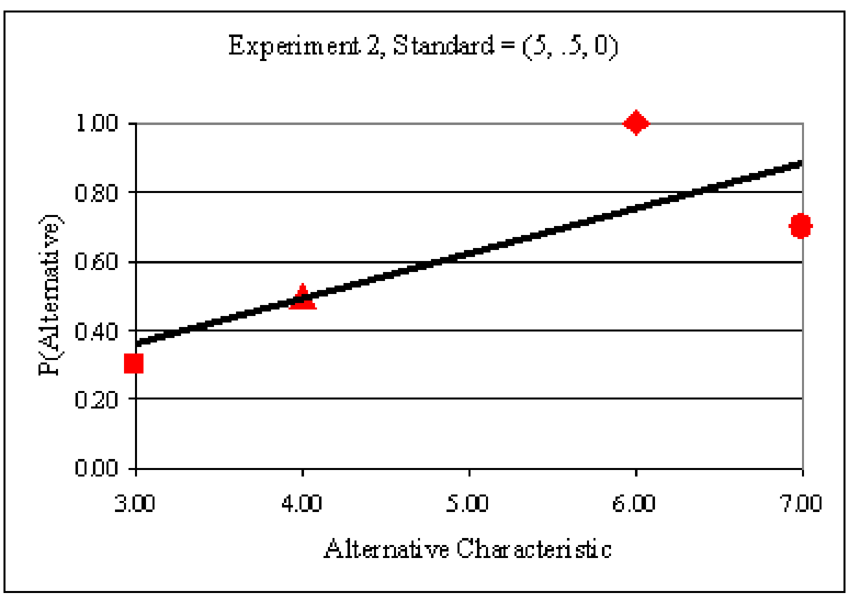
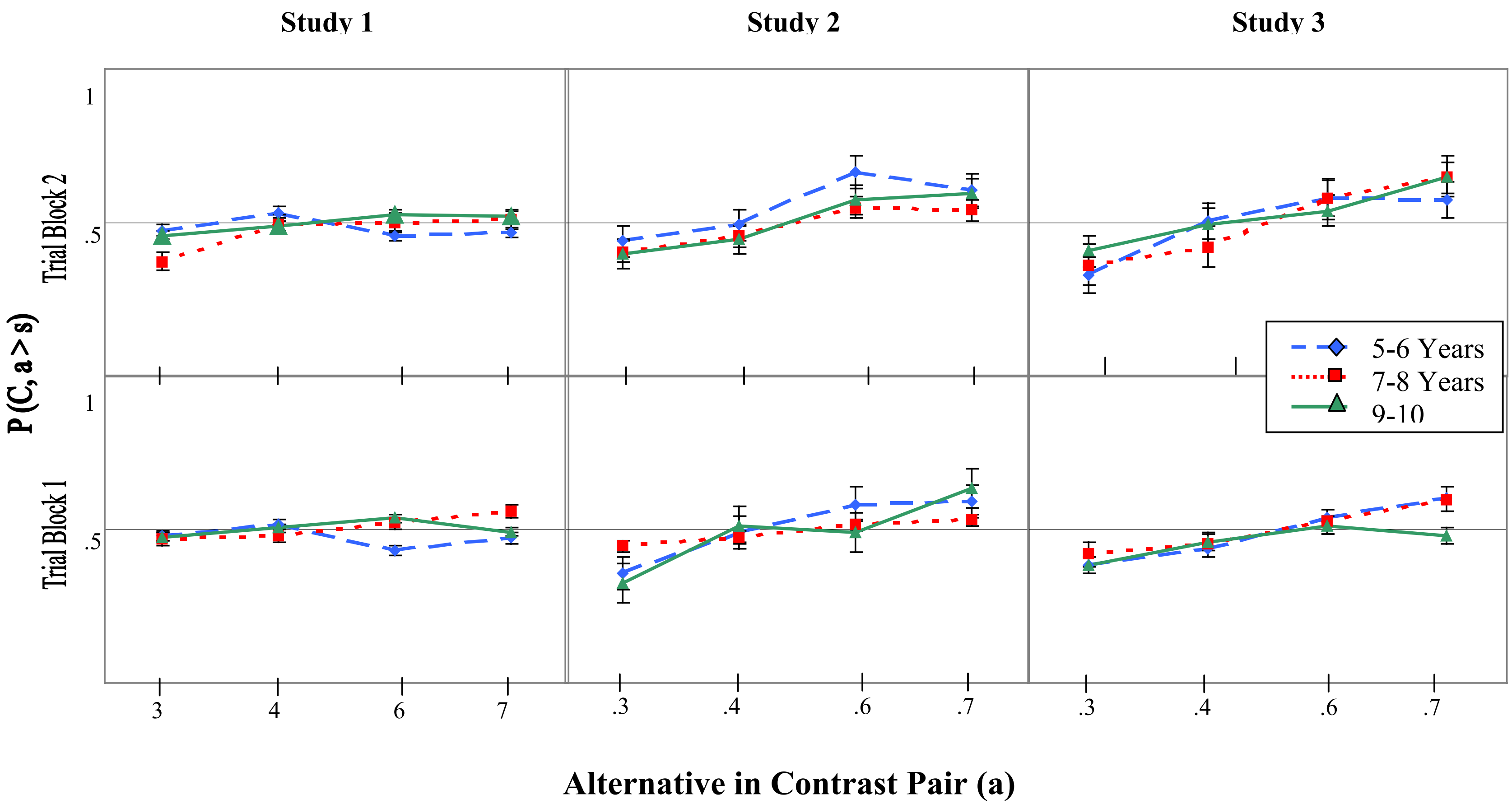
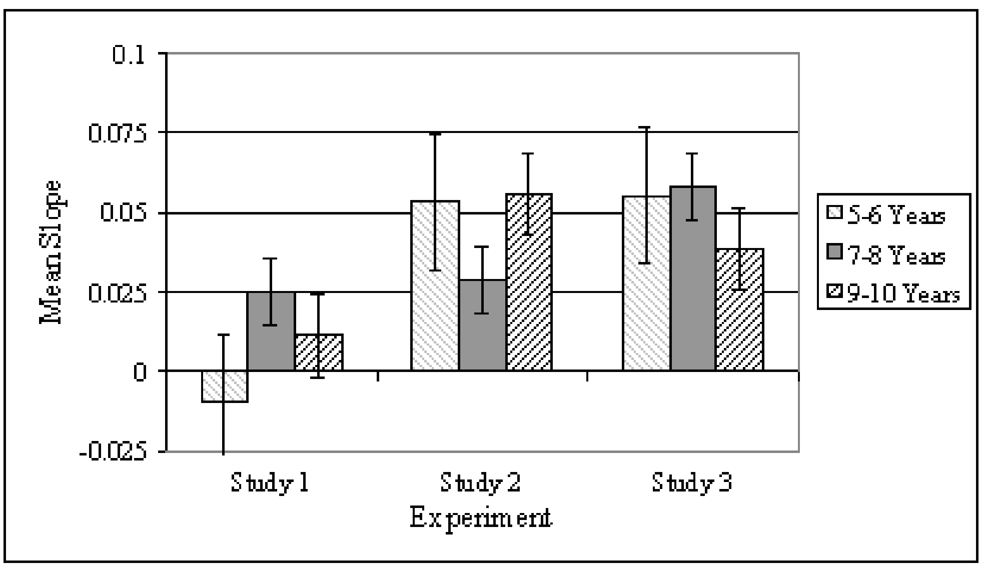


Figure 10. Alternative vs. standard means, per study, age group, and trial block.



Bonferroni controlled post-hoc analyses revealed significant differences between Study 1 and Study 2, t (167)= -3.48, p = .001, and Study 1 and Study 3, t(164) = -4.36, p < .001; the slopes were significantly greater, and thus selection more adaptive, in Studies 2 and 3 than in Study 1. There was also an experiment X age group interaction, F(4, 228) = 2.64, p = .035, $1\text{-}\beta$ = .733 (See Figure 11). The youngest participants under performed the other age groups in Study 1, the middle age group participants lagged behind the other age groups in Study 2, and the oldest participants were below the younger age groups in Study 3. All other main effects and interactions were non-significant.

Figure 11. Mean slopes of alternative vs. standard lines-of-best-fit, per study and age group.



Chapter 7: General Discussion

Based largely on tenets of classic behavioral decision theory, the current studies analyzed age differences in sensitivity to quantitative outcome values and probabilities of success in a basic decision-making situation. Several contemporary studies have demonstrated that young children (i.e., five- to seven-year-olds) are relatively sensitive to quantitative outcome values (Schlottmann, 2000; 2001; Schlottmann & Anderson, 1994), and can intuitively use probability information to form preferences (Acredolo et al. 1989; Kuzmak & Gelman, 1986; Schlottmann, 2001; Schlottmann & Anderson, 1994). Recent studies have also demonstrated that appreciation of risk and uncertainty improves from the preschool years (i.e., three-years), into early childhood (i.e., 5-6-years), through adolescence, and into adulthood (Byrnes et al. 1999; Byrnes & McClenney, 1994; Crone & van der Molen, 2004; Crone et al. 2003; Ernst et al. 2003; Garon & Moore, 2004; Kerr & Zelazo, 2004).

Child performance on the current task did not dramatically depart from child performance in comparable sequential choice tasks (e.g., Crone & van der Molen, 2004; Garon & Moore, 2004; Kerr & Zelazo, 2004). For instance, whereas Garon and Moore (2004) found that six-year-old participants selected an advantageous option in an adapted version of the Iowa gambling task on an average of 52% of total trials, five- and six-year-old participants across the current studies selected the higher value or more probable option on an average of 56% of trials. Similarly, although they did not report exact means, Crone and van der Molen (2004) found that six- through twelve-year-olds selected the advantageous options on 50-60% of all trials in their adaptation of the Iowa gambling task. There are, however, notable differences between the design of the current studies and even these most comparable sequential decision tasks; most importantly, whereas these previous studies are relatively complex (i.e., outcome values and probabilities of success were allowed to covary), the current studies allow disentanglement of sensitivity to quantitative outcome values, sensitivity to probability, and sensitivity to risk.

In this regard, the current studies revealed that although even young children are sensitive to probability of success, they have a tendency to neglect quantitative outcome values, and in a similar vein, do not substantially increase sensitivity to the probabilities involved with a decision with an increase in risk. There are four primary findings that support the conclusion that participants were using a probability-over-outcome value strategy. First, in Study 1, which directly analyzed sensitivity to quantitative outcome values, participants tended to select either option with near equal frequency, and few participants selected the option with a higher quantitative outcome value more frequently than expected by chance. Second, participants in Studies 2 and 3 selected the more probable option more frequently than the less probable option, and furthermore, a substantial number of participants selected the option with higher probability more frequently than expected by chance. Third, the cross-study slope analyses revealed that participants were significantly more likely to select the superior alternative in Studies 2 and 3, where superiority was a function of probability of success, than in Study 1, where superiority was a function of quantitative outcome value. Fourth, there were no significant differences between Study 2 and Study 3, which involved similar manipulations of probability, but with different outcome value control.

These findings are actually quite consistent with some adult behavioral decision research. Tversky, Sattath, and Slovic (1988), for instance, argued that people tend to abide by a compatibility principle, with which probability holds prominence over other attributes in choice situations, and in essence, probability looms larger than monetary gains. In neglecting outcome values, and attending to probability of success, the children in the current studies, and particularly those in the youngest age group, seem to have used this very strategy. One direction future studies might go would be to plot the relative increment in probability that is equivalent to a given change in outcome value. This could be accomplished with the above used methodology by drawing comparisons between alternatives that have either greater quantitative outcome value contrast disparity or lesser probability of success contrast disparity than used above. In this sense, future studies might determine precisely the degree to which probability looms larger than quantitative outcome values.

Given the obtained pattern of results, it is important to contemplate possible explanations, and ask why participants, and particularly younger participants, were sensitive to probability of success, but largely neglected quantitative outcome value? One possibility is that younger populations (i.e., 5-6-year-olds) have accumulated greater general experience processing probability than quantitative outcome values in their everyday lives. As is standard for behavioral decision research, the current study conceptualized outcome values quantitatively, in terms of the number of points participants could win by selecting an alternative in a decision pair. Such a design is reliant on the assumption that participants are familiar with numeric figures (e.g., "3," "4," and "5"), and can make quantitative distinctions (e.g., "5" < "6" < "7"). As reviewed, previous research has found that preschoolers (i.e., two-and-a-half- to five-years) are capable of drawing quantitative comparisons, making basic non-verbal calculations, and enacting various numerical principles (Gelman & Gallistel, 1978; Huttenlocher et al. 1994; Levine et al. 1992; Mix, 1999; Mix et al. 2002). Some even propose that infants are capable of making small set quantitative comparisons and can perform very basic quantitative calculations (Antell & Keating, 1983; Starkey & Cooper, 1980; Strauss & Curtis, 1981; Wynn, 1992; 1998). In contrast, the current results revealed that even five- and six- year olds have some difficulty attending to quantitative differences in outcome values in a probabilistic decision-making task. Perhaps these results emerged because children simply are not as familiar with quantitative outcome values as they are with probability. Clearly, future studies should more explicitly explore the relationship between sensitivity to quantitative outcome values in decision-making situations (as analyzed in Study 1), and the development of more basic quantitative skills. Furthermore, future research should attempt to reconcile these differences, perhaps by making quantitative decision outcomes more salient, or by analyzing discrimination of quantitative outcome values in decision situations in the context of more advanced quantitative skills. Future studies may also consider the effects of individual differences in basic quantitative developments, and examine effects on sensitivity to quantitative outcome values in probabilistic decision situations.

Another potential explanation for the current results also implicates experience; however, this explanation shifts focus from experience with general processing of probability and value information to processing probability and value information on the current task. The current task was designed to sequentially expose children to probability of success, and it was argued that this design is preferable over alternatives because it captures the fact that actual decision probabilities are not immediately perceptible, are time-variant, and underlie experiences. In this sense, perhaps participants succeeded on the task when probability was manipulated because said manipulation captured probabilistic variability as children regularly experience it, thus enabling familiar processes. Conversely, the task presented participants with perceptually visible and static outcome values (i.e., "You won *V* points!"). Outcome values that are experienced as the result of actual decisions, however, are perhaps as time-variant, imperceptible, and underlying as are the probabilities of success associated with actual decisions. Thus, the results may reflect the fact that probabilities in the current task are relatively synonymous with actual decision probabilities, as children have experienced them, but outcome values in the current task are a bit different from true outcome values that children have experienced.

Another related potential explanation for the obtained results also deals with the task design. Perhaps control of probabilities in the sensitivity to outcome value experiment is nonequivalent to control of outcome values in the sensitivity to probability experiments. That is, whereas it was very obvious in Study 2 that outcome values were being held constant (i.e., every time a participant experienced a win they were shown "You won 5 points!"), it was far less obvious in Study 1 that probability of success was being held constant. In this sense, to choose effectively from trial to trial in Studies 2 and 3, participants only really needed to attend to probability of success, by virtue of the fact that outcome value was obvious. In order to choose effectively in Study 1, however, participants actually needed to attend to both the quantitative outcome value and probability of success associated with each alternative, because the constancy of probability of success was less obvious. In other words, Study 1 may have actually involved an assessment of sensitivity to probability of success ***and*** sensitivity to outcome value, whereas Study 2 may have, as planned, amounted to an assessment of sensitivity to probability. As a result of this issue, these findings might be better taken as evidence that although even young children are sensitive to probability, there is development of an ability to integrate sensitivity to probability and sensitivity to outcome value.

A key line of evidence, which strongly supports this proposal, is the forced-choice preference measure (i.e., the Kermit preference measure). The forced-choice measure was included to provide a more explicit assessment of probability and outcome value understanding. As discussed specifically above, Study 2 revealed that whereas there were no developmental differences in preference across the selection trials, there were slight developmental differences in response on the forced-choice measure. Interestingly, the developmental pattern in forced-choice response in Study 2 is nearly identical to that of Study 1 (See Tables 4 & 8, and Figures 3 & 6). In this sense, although selection on the experimental choice phases of Study 1 and Study 2 may have elicited slightly different processes, selection on the forced-choice measure appears congruent across studies (i.e., it required more explicit integration of probabilities and outcome values in each case). The fact that the correlations between experimental choice phase selection and forced-choice selection were similarly moderate across studies (i.e., $R \approx .20$) further supports the argument that there is something of a transition from implicit processing of probability information, as assessed by experimental choice phase selection, towards more cumulative and explicit integration of probability and outcome value information, as assessed by the forced-choice selection. In the very least, these findings collectively demonstrate that it is imperative that future studies take into account *both* dependent measures that tap into strictly controlled decision-making components, *and* the cumulative and explicit integration of those components.

Finally, the findings described are most certainly tentative, and it is necessary that future studies replicate and further explore the issues addressed prior to drawing firm conclusions. One major issue is that the participants in the current studies were predominantly socio-economically privileged (i.e., all were students at private elementary schools). Studies have, however, revealed that lower socioeconomic status (SES) groups tend to attain lower scores on standardized mathematics exams (Crane, 1996; Reyes & Stanic, 1988). Due to the fact that mathematic operations and the current decision-making processes involve similar processing requirements, the performance of the current upper SES sample may not be representative of all SES groups. Therefore, this is an issue future research should most certainly address. Also, the studies presented were entirely cross-sectional, and ideally, the developmental trends should be explored longitudinally. It would be exceptionally interesting to monitor whether or not sensitivity to probability is as stable, as well as whether or not sensitivity to quantitative outcome values developmentally increases, throughout the childhood years as the current studies suppose.

Appendix 1 – Experimental Procedural Protocol

Appendix 1A – Assent Script

The following script appeared after participant characteristics were entered, in order to verify the child was willing to participate.

- Today, if you want to, we're going to play a game.
- The University of Maryland likes this game.
- The game takes a few minutes to play, but you can stop playing the game whenever you want.
- You don't have to play the game if you don't want to.
    - Do you want to play the game?
        - Yes – Leads to participant characteristics screen.
        - No – Leads to program exit screen.

Appendix 1B – Instructions

The following instructions appeared on the screen, and were read to participants.

- We're going to play a game today called the "Light up Game." In this game you can push buttons to win and lose points.
- When you push one of the buttons, the light the button is connected to might Light-UP.
- If you push a button and its light turns on, you win points.
    - Study 1 & 2: But if you push a button and its light doesn't turn on, you don't win points.
    - Study 3: But if you push a button and its light doesn't turn on, you lose points.
- So you need to try really, really hard to win as many points as you can.
    - The Participant was then be asked, "Do you understand?"
        - Yes, he proceeded to the control questions screen
        - No, he proceeded to the alternate instructions screen.

Appendix 1C – Alternate Instructions

The following instructions appeared if the child indicated he did not understand the general instructions, or if either of the control questions was responded to incorrectly.

- Okay, when the Light-Up game starts, you are going to see buttons, and each button will be connected to a light.
- The whole game is for you to choose which button you want to press.
    - Study 1 & 2: If you push a button and its light turns on, you win points. If you push a button and its light doesn't turn on, you don't win points.
    - Study 3: If you push a button and its light turns on, you win points. If you push a button and its light doesn't turn on, you lose points.
    - So try really, really hard to win as many points as you can.

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