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Neurobiological and Memory Models of Risky Decision Making in Adolescents Versus Young Adults

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Predictions of fuzzy-trace theory and neurobiological approaches are examined regarding risk taking in a classic decision-making task—the framing task—as well as in the context of real-life risk taking. We report the 1st study of framing effects in adolescents versus adults, varying risk and reward, and relate choices to individual differences, sexual behavior, and behavioral intentions. As predicted by fuzzy-trace theory, adolescents modulated risk taking according to risk and reward. Adults showed standard framing, reflecting greater emphasis on gist-based (qualitative) reasoning, but adolescents displayed reverse framing when potential gains for risk taking were high, reflecting greater emphasis on verbatim-based (quantitative) reasoning. Reverse framing signals a different way of thinking compared with standard framing (reverse framing also differs from simply choosing the risky option). Measures of verbatim- and gist-based reasoning about risk, sensation seeking, behavioral activation, and inhibition were used to extract dimensions of risk proneness: Sensation seeking increased and then decreased, whereas inhibition increased from early adolescence to young adulthood, predicted by neurobiological theories. Two additional dimensions, verbatim- and gist-based reasoning about risk, loaded separately and predicted unique variance in risk taking. Importantly, framing responses predicted real-life risk taking. Reasoning was the most consistent predictor of real-life risk taking: (a) Intentions to have sex, sexual behavior, and number of partners decreased when gist-based reasoning was triggered by retrieval cues in questions about perceived risk, whereas (b) intentions to have sex and number of partners increased when verbatim-based reasoning was triggered by different retrieval cues in questions about perceived risk.

Keywords: framing, behavioral inhibition, decision making, sensation seeking, fuzzy-trace theory

The topic of risky decision making in adolescence and young adulthood has become an increasing focus of research for both practical and theoretical reasons.[1] On the practical side, poor decisions about risk taking produce social, economic, and public health problems: Adolescents and young adults contribute disproportionately to crime, highway fatalities, and new cases of HIV–AIDS, and habits begun in youth—such as smoking, alcohol and drug use, and unhealthy eating—are major causes of adult morbidity and mortality (Romer, 2003). On the theoretical side, there is growing interest in understanding the basic decision processes underlying risk taking from adolescence to adulthood (for a recent overview of theories, see Reyna & Rivers, 2008). However, reported age differences in risk taking in the laboratory and the real world do not always follow the same age pattern (Figner, Mackinlay, Wilkening, & Weber, 2009). Critics of real-world statistics point out that opportunities to take risks increase from adolescence to young adulthood, and therefore these statistics cannot be taken at face value as reflecting increases in preferences for risk. Critics of laboratory tasks, in contrast, argue that laboratory tasks lack ecological validity and that risk preferences are better measured in terms of real-world behaviors.

In this study, we examine risk taking both in a classic laboratory task—the framing task—and in the context of real-life risk taking, such as initiation of sexual activity, in order to test predictions of

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[1] We distinguish adolescence from young or "emerging" adulthood, but we acknowledge that definitions differ. For example, the World Health Organization defines *adolescence* as the second decade of life (10–19 years of age).

fuzzy-trace theory. Risk taking is defined as choosing the gamble (as opposed to the sure option of equal expected value) in the laboratory task and in terms of engaging in real-life behaviors that expose young people to such risks as pregnancy and HIV–AIDS (although equal expected value is not assumed for real-world risks). Although correct and consistent condom use can mitigate real-world risks, these ideal practices are rarely achieved in this age group, and consequences such as failure to graduate from high school or college have greater impact for this age group. In other words, taking a risk by having sex as a 15-year-old does not mean that a bad consequence (e.g., premature pregnancy) will necessarily occur, only that such a consequence is more likely compared with not taking a risk. Both in the laboratory and in real life, risk taking involves choosing a course of action with greater uncertainty and the possibility of a negative outcome (a downside potential), relative to alternative courses of action. Whether laboratory tasks are actually related to real-life sexual behavior is one of the empirical questions that we investigate.

Theoretical Background

According to fuzzy-trace theory, risky decision making reflects developmental differences in knowledge, representation, retrieval, and processing (Reyna, 2008; Reyna & Adam, 2003). Specifically, as decision makers develop, they move from a reliance on more precise "verbatim" thinking toward fuzzier "gist" thinking about risk and reward. The distinction between verbatim and gist mental representations of decision options is drawn from research in psycholinguistics on representations of verbal information in which *verbatim* is defined as the surface form (or exact wording) and *gist* is defined as the substance (or essential meaning; Kintsch, 1974). Fuzzy-trace theory has extended the verbatim–gist distinction to representations of numbers, pictures, and events, as well as verbal materials (Reyna & Brainerd, 1995). On the basis of extensive evidence from both psycholinguistics and memory research, gist representations are elicited by vague questions (or retrieval cues) that reflect interpretations of reality (e.g., "false" memories or inferences that reflect attitudes and beliefs), whereas verbatim representations are elicited by specific cues that retrieve true memories of actual events (e.g., true memories of whether a person has practiced safe sex). Developmentally, from childhood to adulthood, the tendency to rely on gist representations over verbatim representations has been shown to increase in multiple tasks (see e.g., Brainerd, Reyna, & Ceci, 2008).[2]

The implication for risky decision making is that precise quantitative processing of risks and rewards is predicted to give way to qualitative processing that captures the gist (or bottom-line meaning) of decision options. Like many dual-process theories, fuzzy-trace theory assumes that both dual processes (verbatim-based and gist-based) are available in adulthood. However, extensive evidence supports the assumptions that verbatim and gist representations develop independently and that decision makers increasingly rely on gist-based thinking as a default as they develop (see e.g., Brainerd et al., 2008; Reyna & Lloyd, 2006). Thus, the preference for gist-based qualitative processing increases developmentally despite parallel increases in the competence to process information quantitatively (Haines & Moore, 2003; Kokis, Macpherson, Toplak, West, & Stanovich, 2002; Reyna & Brainerd, 1994; Stanovich, Toplak, & West, 2008).

Assessing Risky Decision Processes in the Framing Task

One of the earliest demonstrations of a developmental shift from verbatim to gist thinking was observed in a risky decision-making task, the framing task (Reyna & Ellis, 1994). In framing tasks, decision makers choose between a sure option and a gamble of equal or near-equal expected value (e.g., gaining $100 for sure vs. taking a 50% chance of gaining $200, otherwise gain nothing; Kühberger, Schulte-Mecklenbeck, & Perner, 1999). Framing effects occur when preferences change on the basis of superficial differences in the wording of options as gains or as losses. For example, a decision maker who is given $200 but must choose between losing $100 for sure or taking a 50% chance of losing $200, otherwise losing nothing, faces the same net consequences as described in the previous example involving gains. Adults change their preferences from risk aversion (choosing the sure thing) when "gains" are described to risk seeking (choosing the gamble) when "losses" are described, violating axioms of rationality (Tversky & Kahneman, 1986).

Reyna and Ellis (1994) presented framing tasks to participants ranging in age from 4 to 11 years, but children chose, instead of money, from among different numbers of prizes to be won or lost. Spinners with different-sized colored sections (e.g., one third blue and two thirds red) were used to convey the probabilities of winning or losing prizes. Prior research has shown that even young children can judge outcome probabilities on the basis of contiguous colored areas of a spinner (Reyna & Brainerd, 1994; Schlottmann & Anderson, 1994). Prizes to be won with a given probability were placed in transparent bags directly on the corresponding colored section of the spinner. For example, in the gain frame, children might decide between winning one prize for sure versus a one-third chance to win three prizes if the spinner lands on blue (two-thirds chance to win nothing, represented by an empty transparent bag, if the spinner lands on red).

For loss frame problems, children were given an "endowment" of prizes (e.g., three prizes) and chose between such options as losing two prizes for sure versus a two-thirds chance of losing three prizes (one-third chance of losing nothing). (*Endowment* means that they were given an amount of toys in the "loss" frame from which different numbers of toys could be subtracted, so that net outcomes would be identical across frames.) Thus, the net numbers of prizes to be won were identical across gain and loss frames. Crucially, losses were acted out by removing smaller transparent bags of prizes from larger transparent bags so that net outcomes were displayed in front of the child (outcomes to be lost were also visible and were placed opposite the child, on the experimenter's side of the table). For each frame, three levels of reward (one, four, or 30 prizes) were combined with three levels of risk (one-third, two-thirds, and three-fourths chances to win noth-

[2] Fuzzy-trace theory does not predict that gist-based or heuristic performance always increases developmentally or that the ability to calculate goes down in childhood (on the contrary, quantitative competence improves from childhood to adulthood). Performance is a predicted function of developmental level but also depends on the requirements of the task (e.g., the precision of the response mode), the specificity of the retrieval cue, and the instructions, among other factors (see Reyna & Brainerd, 1995).

ing or to lose something). Two blocks of nine gain and nine loss decisions were presented within subjects in counterbalanced order. Similar framing tasks were used in the present study.

Note that participants did not experience outcomes (which produce carryover effects to subsequent trials), they did not have to subtract, and they did not have to remember numerical information within or across trials. Use of the spinner, which is common in children's board games and was demonstrated, ensured awareness that outcomes were random. Choices were "incentive compatible" because all participants were instructed that at the end of the game that they would win real prizes based on their choices in the game.

Developmental Differences in Framing Tasks

Adults show smaller framing differences when gain and loss problems are presented within subjects, and they take more risks overall in the context of games (see e.g., Boyer, 2006; Levin & Hart, 2003). Nevertheless, adults show a "standard" framing pattern: They are more risk seeking in the loss frame than in the gain frame. Reyna and Ellis (1994) found that, in contrast to adults, preschoolers treated the gain and loss frames equivalently. In other words, the youngest group of children did not show framing effects when net consequences were identical. However, they did not gamble all of the time; instead, they systematically modulated risk preferences according to the degree of risk and the amount of reward (see also Levin & Hart, 2003; Levin, Weller, Pederson, & Harshman, 2007; Reyna, 1996; Schlottmann, 2001; Schlottmann & Anderson, 1994). Their responses were roughly consistent with multiplicatively combining the quantitative dimensions of risk and of reward, as has been found in other studies of proportional reasoning (i.e., reasoning about quantitative dimensions that trade off, such as length and width in area judgment; Acredolo, O'Connor, Banks, & Horobin, 1989; Kerkman & Wright, 1988). Thus, the observed response pattern for preschoolers is consistent with their evaluating the options quantitatively in the framing task, taking both dimensions—risk and reward—into account.

The next-oldest group, second graders, exhibited the same pattern of equivalence across frames and judicious gambling depending on levels of risk and magnitudes of reward—except when differences between rewards in the sure thing and in the gamble were large (despite higher risk). In these situations, second graders preferred the larger gains (in the gamble) and preferred the smaller losses (in the sure thing). This response pattern is called "reverse framing" because it is the reverse of the adult framing pattern, namely, greater preference for gambling in the gain frame than in the loss frame. Thus, the responses of the middle age group were consistent with sometimes paying attention mainly to one rather than to two quantitative dimensions, the dimension of rewards. Reverse framing would occur if one paid more attention to differences in rewards, because more prizes could be won in the gamble in the gain frame and fewer prizes could be lost in the sure thing in the loss frame. (If one is thinking quantitatively, zero outcomes multiply out to zero and thus do not affect preferences; in both expected utility and prospect theory, any probability multiplied by a zero outcome is equal to zero expected value, and thus it literally does not count). Note that larger wins and larger losses are always found in the gamble in these problems because expected value (outcomes $\times$ probabilities) is constrained to be equal across the sure and gamble options ([1 prize $\times$ 1.0] probability = [3 prizes $\times$ 1/3 probability + 0 prizes $\times$ 2/3 probability]). Thus, reverse framing would be consistent with risk taking in the gain frame but with risk aversion in the loss frame.

The oldest group, fifth graders, also exhibited reverse framing effects (greater gambling in gain than loss frames) when differences between rewards were large. Note that although reward magnitude was manipulated, so that differences between outcomes in sure versus gamble options changed, the ratios of the outcomes were kept constant within each level of risk (see e.g., Furlong & Opfer, 2009; Peters, Slovic, Västfjäll, & Mertz, 2008). For example, when there is a one-third chance of winning, although the ratio of one to three prizes is the same as that of 30 to 90 prizes, the difference between outcomes is much larger in the latter than in the former. Because ratios are kept constant when reward magnitude is varied, the reverse framing pattern for large rewards indicates that rewards in the sure and gamble options are compared and that the size of this difference influences choices. Therefore, reverse framing is an important diagnostic pattern because it signals sensitivity to differences in rewards and processing of those differences quantitatively (i.e., that decision makers make distinctions between amounts of rewards). In short, the only dimension favoring the gamble in the gain frame, as shown in reverse framing, is greater rewards (and, conversely, for the loss frame, only fewer losses favor the sure thing; dimensions trade off in these problems by design). Adults rarely show this pattern of reverse framing (e.g., only two out of 102 participants in a study by Levin, Gaeth, Schreiber, & Lauriola, 2002). Reverse framing signals that decision makers are processing differences in reward magnitudes—a different way of thinking compared with that for standard framing (reverse framing is also distinct from simply choosing the risky option).

It should be noted that not all developmental studies of "framing" effects have reported identical findings, although most have documented somewhat greater risk taking overall in older children than in adults (Boyer, 2006; Harbaugh, Krause, & Vesterlund, 2002; Levin & Hart, 2003; Levin, Hart, Weller, & Harshman, 2007; Levin, Weller, et al., 2007; Reyna & Ellis, 1994; Reyna & Mattson, 1994; Rice, 1995; Schlottmann, 2001; see Reyna, 1996; Reyna & Farley, 2006, Figures 6 and 7). When there are objective numerical differences between gains and losses (i.e., with no endowment), both children and adolescents respond differently to gains and losses and tend to show the standard framing pattern (see, e.g., the money problem in Chien, Lin, & Worthley, 1996; Reyna, 1996). Properly called reflection effects, these results are well accounted for by the psychophysical processing of numbers as described, for example, in prospect theory and as observed in children, animals, and adults when they process numbers (Brannon, 2006; Reyna, Nelson, Han, & Dieckmann, 2009; Tversky & Kahneman, 1986).

When differences between gains and losses are illusory (losses are really net gains), then responses to framing problems seem to reflect a relative focus on either quantitative dimensions (verbatim-based processing) or qualitative contrasts (gist-based processing), which varies developmentally. As discussed, the sharpest developmental differences are found between early childhood and early adolescence, but adolescents remain in transition. Thus, adolescents are predicted to be more likely to focus on quantitative differences in rewards manifested in reverse framing, but adults are predicted to be more likely to focus on qualitative

contrasts (e.g., between winning some money vs. maybe winning nothing) manifested in standard framing (Kühberger & Tanner, 2010; Reyna & Brainerd, 1991). Therefore, in the current study, we examine risk taking in the framing task for adolescents versus young adults—with a particular focus on response patterns such as reverse framing—to test fuzzy-trace theory's predictions.

Risk Taking in Real Life

Reyna and Farley (2006) argued that gist-based intuition would generally protect young people against taking unhealthy risks (see also Reyna, 2004; Reyna, Adam, Poirier, LeCroy, & Brainerd, 2005; Rivers, Reyna, & Mills, 2008). It is not that verbatim-based analysis of risk and reward is always risk promoting but rather that most adolescents are operating in a gain frame in which objective risks are often low (at least for single acts of risk taking) and benefits are often high, leading to a rational calculus of risk promotion (in the sense in which the word *rational* is used in economic theory; for alternative views of rationality, see Reyna & Farley, 2006; Reyna, Lloyd, & Brainerd, 2003). Phrases such as *it won't happen to me* are not entirely misleading for low-prevalence risks, such as exposure to HIV–AIDS in typical adolescent populations. Moreover, if thinking is quantitative, then even when risks are overestimated they can be compensated for by sufficiently high benefits.[3]

A review of the literature, in fact, revealed that in most studies in which perceptions of risk and benefits were assessed, these assessments predicted self-reported risk taking in adolescents (Reyna & Farley, 2006). In contrast, gist-based thinking is hypothesized to promote risk avoidance in mature decision makers because the magnitude of benefits does not offset the categorical possibility of catastrophic consequences (e.g., HIV–AIDS). Phrases such as *it only takes once* characterize this kind of noncompensatory (i.e., benefits do not compensate for risk) gist-based thinking (see e.g., Cohn, Macfarlane, Yanez, & Imai, 1995). Hence, adolescents who make the transition to gist-based intuition sooner than their peers do should be better able to avoid unhealthy risk taking. Findings from a sample of 596 high school students support this prediction: The more adolescents agreed with categorical statements such as *it only takes once to get HIV–AIDS*, the less likely they were to be sexually active and the lower their sexual intentions (Mills, Reyna, & Estrada, 2008). Although we have intentionally built on and integrated prior work (see e.g., Brewer, Weinstein, Cuite, & Herrington, 2004; Millstein & Halpern-Felsher, 2002), it should be noted that some theorists have made exactly the opposite prediction (that *it only takes once* is a faulty belief that promotes risk taking; Downs, Bruine de Bruin, Murray, & Fischhoff, 2004). In short, no other theory predicts that categorical thinking is more advanced or healthier than precise thinking.

It is important to note, however, that additional factors are likely to contribute to adolescent risk taking. Among the dimensions of neurobiology linked to real-life risk taking, *sensation seeking*, defined as a desire to experience new and exciting stimuli, has been found to vary developmentally as well as across individuals in adulthood (Romer, 2003; Zuckerman, 1994). High sensation seekers engage in risky and potentially dangerous behaviors as a means of achieving desired levels of arousal. This trait has been used as a predictor of problematic behaviors such as alcohol use, illicit drug use, dangerous driving, smoking, and sexual risk taking (Arnett, 1990a, 1990b; Hoyle, Fejfar, & Miller, 2000; Zuckerman, 1994). Sensation seeking is particularly high among adolescents, peaking around age 16 or so and declining thereafter (Arnett, 1992; Romer & Hennessy, 2007; Steinberg, 2008).

In classic work on this topic, Gray (1987, 1990) posited competing neurobiological systems of behavioral activation and inhibition, on the basis of neurological and behavioral evidence (see also Nawa, Nelson, Pine, & Ernst, 2008). The behavioral activation system is the appetitive motivational system—sensitive to rewarding stimuli—and is responsible for positive feelings such as hope, elation, and happiness. This system causes movement toward goals in response to rewarding environmental cues, as reflected in sensation seeking. The behavioral inhibition system is the aversive motivational system—sensitive to novel, punishing, or nonrewarding stimuli—and controls the experiences of anxiety, fear, sadness, and frustration. This system deters behavior that may lead to negative outcomes and inhibits movement toward goals. Carver and White (1994) developed self-report inventories to measure these motivational systems, called the behavioral activation scale (BAS) and behavioral inhibition scale (BIS).

Recent research on motivation and neurobiological development has also emphasized dual countervailing systems of reward sensitivity and behavioral inhibition. Steinberg (2008), for example, has argued that dopaminergic reward systems develop sooner than prefrontal cortical control systems, producing an imbalance that is most acute in adolescence and that drives risk taking. In this view, the increase in risk taking in adolescence is due primarily to increases in sensation seeking that are linked to changes in patterns of dopaminergic activity. Casey, Galvan, and associates have stressed the development of white matter connectivity between frontal areas of the brain and limbic reward systems, connections that ultimately serve to dampen risk taking in adulthood (Casey, Getz, & Galvan, 2008; Galvan, Hare, Voss, Glover, & Casey, 2007). Finally, Reyna and colleagues have emphasized pruning of brain connections during adolescence that facilitates rapid recruitment of simple gist, especially during heightened emotional arousal, and parallel development of behavioral inhibition in the prefrontal cortex that reduces impulsive responding (Reyna & Casillas, 2009; Reyna & Mills, 2007; Rivers et al., 2008; see also Figner, Mackinlay, Wilkening, & Weber, 2009).

In sum, adolescent risk taking is likely to be a function of multiple factors, including how adolescents process risk and reward and how this processing changes with development. Here, framing tasks offer an advantage because risk and reward can be manipulated factorially, so that developmental differences in sensitivity to each can be measured. Response patterns such as reverse and standard framing, which reflect relative emphases on quanti-

[3] Verbatim processing could, in principle, produce high or low estimates of risk. One could imagine two adolescents who each engage in verbatim processing: One person might, after processing his risk in a specific, quantitative fashion, conclude that his precise risks are high, but another person could, after similar processing, conclude that his precise risks are low. The risk need not be low to favor risk taking; it simply has to be outweighed by the benefits. Risk takers perceive their risks as higher than those of nonrisk takers when asked verbatim questions (which cue memories of risky behaviors) but still perceive them as low relative to benefits (Reyna & Farley, 2006).

tative versus qualitative processing, can also be identified. We administered, in addition to measures from framing tasks, measures of sensation seeking, BAS, and BIS that have been used successfully with adolescents in order to examine neurobiological hypotheses about motivational factors underlying risk taking.

Our analyses proceeded as follows: First, we applied analyses of variance to compare risk taking of adolescents and that of adults in framing tasks using both choices and preference ratings as dependent measures. Second, we examined relations between a variety of other dimensions of risk taking (e.g., individual differences in sensation seeking and inhibition) and age. To confirm that these dimensions of risk taking group together in theoretically sensible ways, we then performed factor analyses, which included indices of risk behavior from the framing tasks (such as the extent of reverse as opposed to standard framing); other measures of verbatim and gist processing and risk perception, such as categorical thinking about risk; and measures of sensation seeking, BAS, and BIS for the same individuals. We extracted a small set of theoretically meaningful factor scores that represented separate dimensions of risk taking. Finally, we used these factors scores in regression analyses to predict self-reported risky behaviors and behavioral intentions, including early initiation of sexual behavior, behavioral intentions to engage in sex, and number of sexual partners.

Method

Participants

Participants were 153 students (102 young adults recruited from the participant pool at Cornell University and 51 adolescents recruited from local high schools and families of Cornell students). The young adults ranged in age from 18 to 22 ($M = 19.7$, $SD = 0.90$), and the adolescents ranged from 14 to 17 ($M = 15.5$, $SD = 1.1$). The majority in both age groups were female (76% and 61%, respectively). Among young adults, 58% identified as White (European descent); 5% as Hispanic; 1% as African American; 30% as Asian; and 6% as mixed/other. Among adolescents, 78% identified as White (European descent); 6% as Hispanic; 2% as African American; 10% as Asian; and 4% as mixed/other. Written parental permission and oral assent were obtained for minors; all others provided written consent, and the project was approved by the Cornell Institutional Review Board.[4]

Design

Problems were randomly presented within gain–loss blocks; three levels of risk were crossed with three levels of reward to produce nine problems in each block. Participants were randomly assigned to one of two groups: 76 received nine gain decisions first, followed by nine loss decisions; and 77 received nine loss decisions first, followed by nine gain decisions. An equal number of male and female (save one female) participants within each age group received each order of block presentation.

Materials and Procedure

The framing task involved making a choice between two spinners: one painted entirely red to represent a sure option and the other painted with varying proportions of blue and red to represent a gamble. Arrows were affixed to the center of each spinner. Risk levels were: one-half, two-thirds, and three-fourths chance of winning nothing in the gain frame and one-half, two-thirds, and three-fourths chance of losing something in the loss frame. Reward levels were low ($5), medium ($20), or high ($150). Money was placed on the spinners to convey hypothetical wins or losses. In loss problems, participants were given an endowment, from which losses were subtracted (net outcomes displayed for both frames were the same; procedures for problem presentation are summarized in Table 1). After each problem was presented, participants selected the sure or gamble option and then provided a rating indicating degree of preference. A 7-point smiley-face scale (similar to the ones used by Reyna & Ellis, 1994, and by Schlottmann & Tring, 2005) was used to elicit a rating of degree of preference for each choice.

After doing the framing task, participants completed a demographic survey, gist and verbatim measures, sexual history and intentions scale, a sensation-seeking scale, the BAS, and the BIS (for full scales, see Carver & White, 1994; Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002; the gist and verbatim scales were published in Mills et al., 2008, and in Reyna, 2008). (Although the framing task is an experiment, limitations inherent in correlational analyses of self-reported risk taking should be acknowledged; Bruine de Bruin, Downs, Murray, & Fischhoff, 2010).

Although we designed questions to tap gist versus verbatim processing, we also tested whether they grouped together as predicted by theory, which they did (see later). For gist and verbatim questions, participants were instructed that if they were not sexually active, they should report their perceptions of risks and benefits if they were to have sex. We also varied response formats and questions within each type of question, gist versus verbatim: Gist measures were designed to draw on global attitudes and less precise mental representations, whereas verbatim measures were designed to elicit more specific or quantitative judgments. The four gist measures included the Categorical Risk scale, the Gist Principles scale, a Global Risk question, and a Global Benefits question. The Categorical Risk scale consisted of nine items (e.g., "Even low risks happen to someone") rated on a 5-point scale ranging from *strongly disagree* to *strongly agree*, with ratings averaged ($\alpha = .718$). Strongly agreeing that "Even low risks happen to someone" or that "it only takes once" to get pregnant or get HIV–AIDS indicates higher perception of risk, relative to strongly disagreeing. The Gist Principles scale contained 15 simple principles (e.g., "Avoid risk," "Better safe than sorry," and "I have a responsibility to my partner to not put him/her at risk") that were either endorsed or not, and endorsements were summed ($\alpha = .744$). Again, higher agreement reflected greater perception of risks. The Global Risk question was "Overall, for you, which of the following best describes the risks of having sex?"; responses

[4] Although both adolescents and adults were drawn from Cornell families and were similar socioeconomically, it should be acknowledged that the populations were not identical: There were more Asians in the adult sample and correspondingly fewer White/Caucasians of European descent, compared with the adolescent sample, but similar percentages of Hispanics, African Americans, and mixed/other.

Table 1
Sample Procedure for Gain and Loss Framing Decisions

Gain decision
"You have a choice. If you pick this [the all-red spinner], you win $5 for sure. If you pick this [the half-red, half-blue spinner], you take a chance. If the spinner lands on red, you win $10, but if the spinner lands on blue, you win nothing." The experimenter then placed money on the correct spinner and spinner sections and asked, "What do you want to do: win $5 for sure [pointing to the sure option], or spin the spinner and maybe win $10 [pointing to the correct section of the gamble spinner] or maybe win $0 [pointing to the correct section of the gamble spinner]?"
Loss decision
"I am going to give you $10." The $10 was placed on the participant's side of the table. The experimenter then continued, "You have a choice. If you pick this [the all-red spinner] side, you lose $5 for sure. If you pick this [the half-red, half-blue] side, you take a chance. If the spinner lands on blue, you lose $10. If the spinner lands on red, you lose nothing." Acting out the "loss" by taking money away, the experimenter then placed the net gains on the correct spinner and spinner sections and asked, "What do you want to do: lose $5 for sure [pointing to the sure option], or spin the spinner and maybe lose $10 [pointing to the correct section of the gamble spinner] or maybe lose $0 [pointing to the correct section of the gamble spinner]?"

were *none, low, medium,* and *high.* The Global Benefits question was "Overall, for you, which of the following best describes the benefits of having sex?"; responses were *none, low, medium,* and *high.* Although both gist and verbatim judgments must draw on information about the self that is stored in long-term memory, gist questions were intentionally more fuzzy or vague than were verbatim questions in order to be a better retrieval cue for global, gist representations of sexual risk (consistent with research on retrieval cues; Brainerd & Reyna, 2005).

Concerning verbatim measures, prior research has indicated that specific cues and precise response formats are more likely to elicit verbatim representations from memory, such as specific memories of behaviors that are relevant to the judgment (e.g., episodes of unprotected sex; Mills et al., 2008; Reyna & Brainerd, 1995). Verbatim measures included the Specific Risk scale and the Quantitative Risk scale. The Specific Risk scale consisted of five items (e.g., "I am likely to have HIV-AIDS in the next 6 months") rated on a 5-point scale ranging from *strongly disagree* to *strongly agree*, with ratings averaged ($\alpha = .826$). On the Quantitative Risk scale, participants were asked to rate on a 0%–100% scale the chances that they "have a sexually transmitted disease." Endpoints and midpoint were defined. Again, higher scores reflect higher perceptions of risk.

Gist and verbatim measures were designed to retrieve different kinds of memory traces and therefore to elicit different bases for risk judgments. When participants were asked a specific question (such as "Are you likely to get HIV-AIDS in the next six months?"), verbatim cues in the question (along with the response scale) elicited memories of relevant past behaviors (e.g., memories of unprotected sex for one person or of lonely Saturday nights for another person). Those exemplars of behaviors (true memories, such as the true memories shown to be elicited on the basis of the same kinds of verbatim cues in memory studies) are used to formulate an answer to the question about risk perception. If a person retrieves memories of many instances of unprotected sex, that person will judge his risk as higher than would someone who retrieves memories of many instances of lonely nights. Higher risk taking leads to higher judged perception of risks because cues in questions elicit verbatim memories of behaviors, not the other way around. Verbatim questions are answered on the basis of actual behavior, whereas gist measures rely more on one's overall views of sex (i.e., interpretations of events), regardless of one's actual behavior. Hence, gist and verbatim measures of risk perception are expected to be related in different ways to behavior and behavioral intentions because they tap different kinds of memory traces within the same individuals.

The Brief Sensation Seeking (SS) scale, adapted for use with adolescents, contained eight items (e.g., "I would love to have new and exciting experiences, even if they are illegal") rated on a 5-point scale ranging from *strongly disagree* to *strongly agree* ($\alpha = .714$). The BAS contained 13 items (e.g., "When I see an opportunity for something I like, I get excited right away"; $\alpha = .802$) rated on a 5-point scale ranging from *strongly disagree* to *strongly agree.* The BIS contained seven items (e.g., "Even if something bad is about to happen to me, I rarely experience fear or nervousness"; $\alpha = .709$) rated on a 5-point scale ranging from *strongly disagree* to *strongly agree.* For the SS, BAS, and BIS, mean ratings were input to analyses.

Scores derived from the preceding scales were related to three outcome measures. First, participants were asked a dichotomous ("yes"/"no") behavioral question, "Have you ever had sex?" Second, participants indicated the total number of sexual partners (male or female) in their lifetime. Third, they responded to five questions that measured behavioral intentions to have sex (e.g., "Do you think you will have sex (or have sex again) during the next year?"). Ratings were made on a 5-point scale ranging from *very unlikely* to *very likely* ($\alpha = .860$).

Results and Discussion

Analyses of Variance for Framing Tasks

Between-group factors were gender, age group (adolescent vs. young adult), and order of blocks (gain first vs. loss first); within-group factors were frame (gain vs. loss), risk (one half, two thirds, three fourths), and reward ($5, $20, and $150). Separate analyses using these factors were conducted on choice data and on preference ratings (ratings were signed according to whether participants chose the sure thing or the gamble); results were highly similar for both dependent measures. Significant effects ($p < .05$) are reported. For the choice analysis, there were significant main effects of frame, $F(1, 145) = 4.53$, $p < .05$, $\eta_p^2 = .03$; order, $F(1, 145) = 5.33$, $p < .05$, $\eta_p^2 = .04$; risk, $F(1, 145) = 19.05$, $p < .001$, $\eta_p^2 = .12$; and reward, $F(1, 145) = 34.97$, $p < .001$, $\eta_p^2 = .19$. As Figure 1 shows, both age groups were sensitive to levels of risk, choosing the gamble less often when the probability of the worse outcome in the gamble increased. Risk was also significant for preference ratings, $F(1, 145) = 6.33$, $p < .01$, $\eta_p^2 = .04$. Risk did not interact with age group, or any other factor, for either choice or preference ratings.

Reward was also significant for preference ratings, $F(1, 145) = 15.09$, $p < .001$, $\eta_p^2 = .09$. Thus, both choices and preference ratings for the gamble declined as the stakes increased (i.e., as

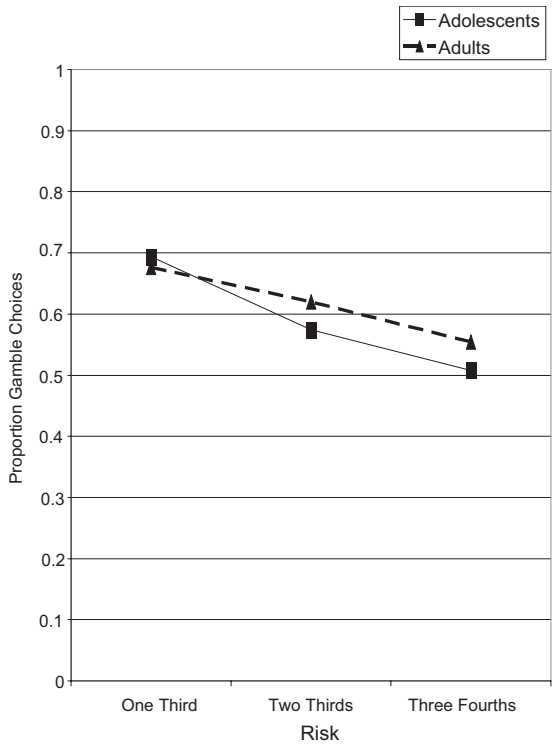

Figure 1. Effect of objective risk (probability of worse outcome) on adolescent and adult choice of the gamble in framing problems.

rewards or "losses" increased). However, the interpretation of differences in response to levels of reward is qualified by a series of two-way interactions and, ultimately, by a three-way interaction that encompasses all of the two-way interactions (these patterns are described later in the context of the three-way interaction). For choices, the two-way interactions included reward with age group, $F(1, 145) = 3.08$, $p < .05$, $\eta_p^2 = .02$, and reward with frame, $F(1, 145) = 9.78$, $p < .001$, $\eta_p^2 = .06$; reward and order missed significance, $F(1, 145) = 2.71$, $p = .069$, $\eta_p^2 = .02$. For preference ratings, the two-way interaction of reward with age group missed significance, $F(1, 145) = 2.83$, $p = .06$, $\eta_p^2 = .02$, but reward and frame, as well as reward and order, interacted significantly, $F(1, 145) = 9.59$, $p < .001$, $\eta_p^2 = .06$, and $F(1, 145) = 3.31$, $p < .05$, $\eta_p^2 = .02$, respectively.

Gender interacted significantly with age group for choices, $F(1, 145) = 4.05$, $p < .05$, $\eta_p^2 = .03$, but missed significance for preference ratings, $F(1, 145) = 3.20$, $p = .076$, $\eta_p^2 = .02$. For choices, male adults were more likely than female adults to take risks (gender differences were smaller and in the opposite direction for adolescents). Gender also interacted with frame for both choices and preference ratings, $F(1, 145) = 4.23$, $p < .05$, $\eta_p^2 = .03$, and, $F(1, 145) = 4.01$ $p < .05$, $\eta_p^2 = .03$, respectively: Male participants were more likely to show framing effects than were female participants. Frame also interacted with order for choices, $F(1, 145) = 5.52$, $p < .05$, $\eta_p^2 = .04$, and missed significance for preference ratings, $F(1, 145) = 3.49$, $p = .06$, $\eta_p^2 = .02$. When the loss frame was presented first, participants were more likely to take risks in the gain frame (mimicking behavior in the first block of loss decisions), attenuating framing effects. Loss decisions were not affected by order. Order effects for this within-subjects manipulation of framing are not surprising if some participants recognized equivalence across gain–loss blocks (LeBoeuf & Shafir, 2003).

The remaining significant effect was a three-way interaction of frame, reward, and age group for both choices and preferences ratings, $F(1, 145) = 3.48$, $p < .05$, $\eta_p^2 = .02$, and $F(1, 145) = 4.02$, $p < .05$, $\eta_p^2 = .03$, respectively. As Figure 2 shows, adolescents and adults chose the gamble more often in the loss frame than in the gain frame—the standard framing pattern—when rewards were low or intermediate. However, when rewards were highest (and differences between outcomes were greatest), adolescents displayed a reverse-framing effect: They chose the gamble more often in the gain frame than in the loss frame. Young adults did not show this reversal of framing at the highest level of reward, but standard framing diminished. This three-way interaction was not affected by order (i.e., the four-way interaction with order was not significant). (Similar response patterns were observed when comparing choices for gains, only in the gains-first condition, and when comparing those choices with choices for losses only in the losses-first condition, separately by age group: a between-subjects' comparison of gains vs. losses. Framing effects, however, were larger, as expected.) Note that this interaction cannot be interpreted as "responding at a gist level to large rewards," because

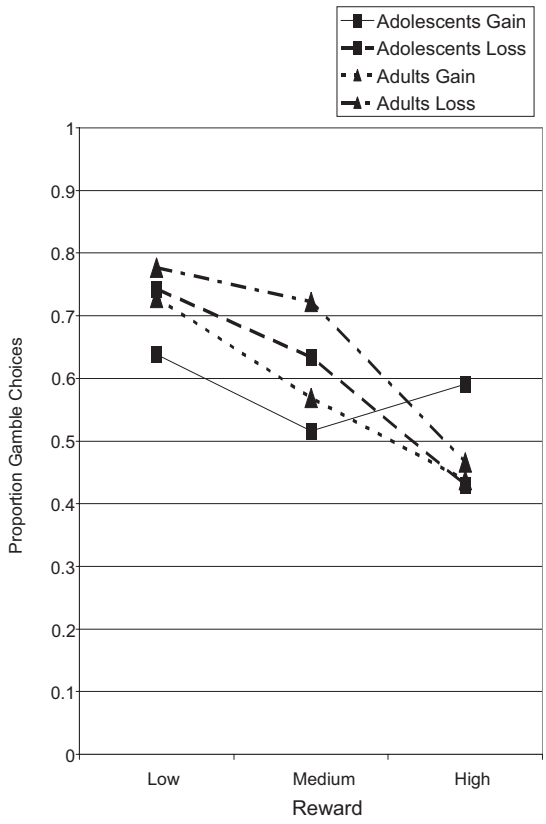

Figure 2. Effect of magnitude of reward on adolescent and adult choice of the gamble in gain and loss framing problems. Low = $5 expected value; Medium = $20 expected value; High = $150 expected value.

responding at a gist level is defined as assimilating different-sized rewards in contrast to responding at a verbatim level by making distinctions on the basis of the sizes of rewards. Adolescents showed the full reverse-framing pattern for large rewards, that is, risk seeking for gains but risk aversion for losses (the latter because smaller losses are found in the sure option). Although reward sensitivity is incorporated into the fuzzy-trace theory account (magnitudes of both rewards and risks matter in verbatim processing), these results for reverse framing and those for sensation seeking and reward sensitivity reported later are not accurately summarized by saying that adolescents are simply more sensitive to potential gains (rewards) and less sensitive to potential losses (punishments). Multivariate results that control for age follow simpler analyses relating dimensions of risk taking and age, for comparison with prior research.

Dimensions of Risk Taking and Age

As seen in Figure 3, dimensions of sensation seeking and BIS (sensitivity to negative consequences or punishment) were related to age as expected by theory and observed in prior studies (see e.g., Steinberg, 2008; Steinberg et al., 2008). (Age 22 is omitted in the graphs because there was only one participant at that age.) For sensation seeking, there was a significant deviation from linearity across age, $F(7, 143) = 2.23$, $p < .05$, $\eta_p^2 = .12$. The curvilinear pattern peaked between ages 17 and 18 and declined thereafter. BIS increased linearly with age, $F(1, 143) = 17.65$, $p < .001$, $\eta_p^2 = .14$. BAS (sensitivity to positive consequences or reward) did not vary significantly across age, although it correlated significantly with sensation seeking ($r_s = .386$, $p < .001$). As further evidence of convergent (and divergent) validity, sensation seeking correlated significantly with perceived benefits of sex ($r_s = .165$, $p < .05$) but not with perceived risks, whereas BIS correlated significantly with perceived risks ($r_s = .185$, $p < .05$) but not with perceived benefits. (Relations among all measures were evaluated using factor analyses; see later.)

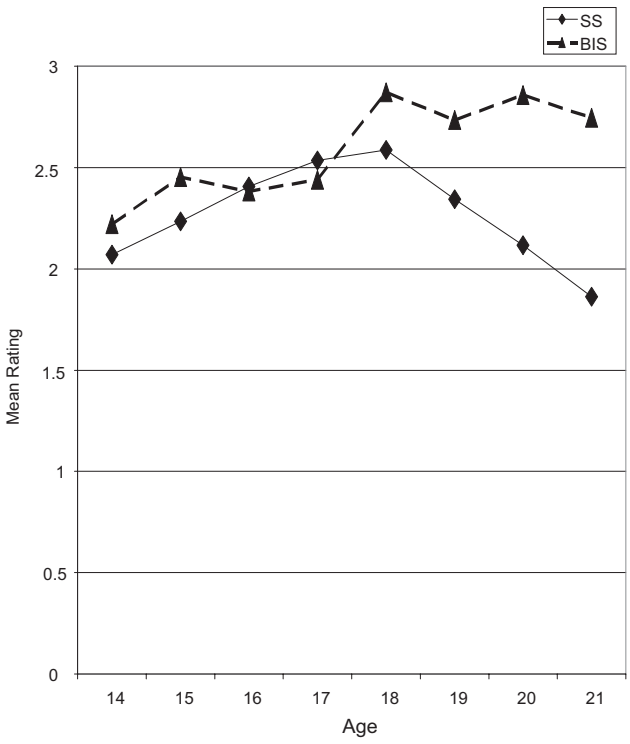

Figure 3. Mean ratings across age for the Brief Sensation Seeking (SS) scale and Behavioral Inhibition Scale (BIS).

As shown in Figures 4, 5, and 6, the three outcome measures varied linearly with age: initiation of sex, $F(1, 139) = 32.75$, $p < .001$, $\eta_p^2 = .22$; intentions to have sex, $F(1, 142) = 8.85$, $p < .01$, $\eta_p^2 = .09$; and number of sexual partners, $F(1, 134) = 10.20$, $p < .01$, $\eta_p^2 = .10$, all increased with age. However, despite associations with age, the neurobiological and motivational variables were not consistently associated with the three outcome variables. Correlations between sensation seeking, BAS, and BIS hovered near zero for initiation of sex and number of partners (although sensation seeking was significantly correlated with gambling in the framing task ($r_s = .179$, $p < .05$). Both sensation seeking and behavioral activation were correlated with intentions to have sex ($r_s = .173$, $p < .05$, and $r_s = .194$, $p < .05$, respectively), although BIS was not.

Correlations Between Gist and Verbatim Measures of Risk Perception and Risk Taking

According to fuzzy-trace theory, gist and verbatim measures of risk perceptions are expected to be related in opposite ways to risky behavior. Drawing on research on retrieval cues in memory, the theory predicts that specific questions act as cues to different mental representations and associated modes of processing (Reyna, 1995; Reyna & Brainerd, 1995). For example, the Gist Principles scale contains items such as "Avoid risk" and "Better safe than sorry." Such items would be expected to elicit global attitudes and perceptions that are negatively correlated with risk taking. Similarly, agreement with other gist measures such as categorical thinking (e.g., "It just takes once to get HIV/AIDS") or global perceptions of higher risk would also be expected to protect against risk taking, all other factors being equal. (Unlike other theories that predict a negative correlation between risk perception and risk taking, however, gist measures are global and simple, rather than precisely contextualized; cf. Fischhoff, 2008; Fishbein, 2008).

In contrast to retrieving global attitudes and perceptions, more specific questions about predictions of future behavior are likely to draw on memories of past behavior (Mills et al., 2008; Schacter & Addis, 2007; Szpunar & McDermott, 2008). That is, when a participant is asked to judge the likelihood of contracting a sexually transmitted infection in the next 6 months, that determination is based at least in part on retrieving episodes of past behavior (e.g., of unprotected sex) from memory and judging whether the remembered behavior is risky (and then projecting that judgment onto the future). Verbatim, or true, memories reflect to some degree whether the remembered behavior is risky (gist memories are colored by inferences, attitudes, and stereotypes and are associated with false memories; Brainerd & Reyna, 2005). Therefore, these more verbatim judgments are expected to be positively correlated with risk-taking

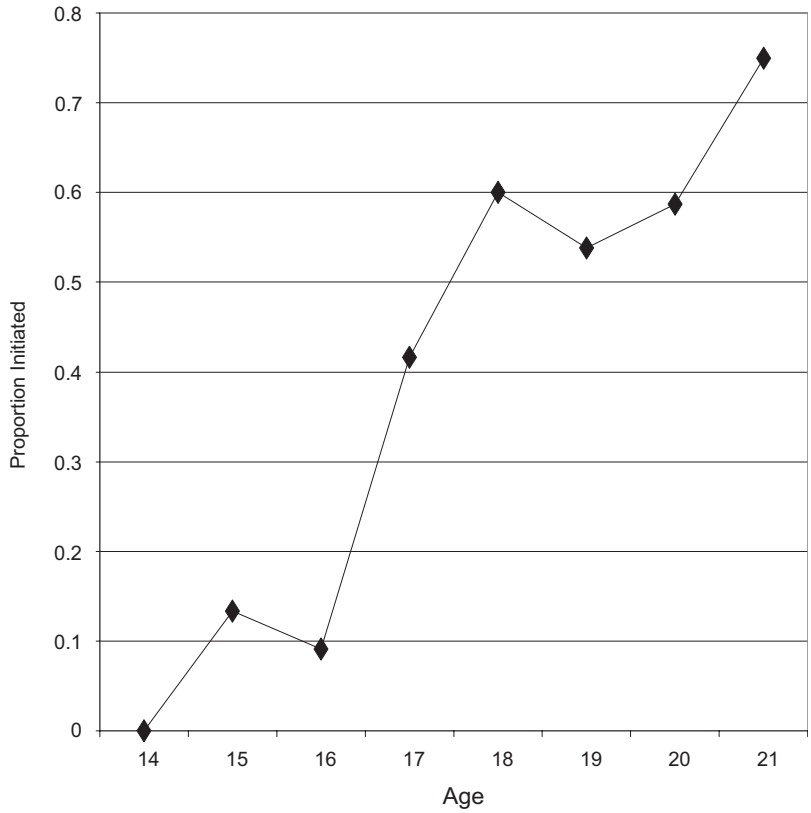

Figure 4. Proportion of participants at each age who have initiated sex.

behavior[5] (see Mills et al., 2008, for additional arguments and data). Note that all questions asked for assessments of personal risk. For example, the Global Risk (gist) question began, "For YOU . . ." Prior researchers have explained findings by noting that some risk perceptions retrieve realistic assessments of behavior on the basis of experience, and we have subsumed those explanations into the verbatim side of processing. However, none has predicted that oppositely signed correlations are produced by asking different risk-perception questions about the same target behaviors.

Moreover, fuzzy-trace theory predicts which kinds of questions will produce which direction of correlation. Verbatim questions are more specific than gist questions in two ways: (a) Their content is more specific (the relation between packed and unpacked probability statements; e.g., the risk of STDs or pregnancy related to having sex vs. the overall risk of having sex), which has been shown to be more likely to cue verbatim memories (Brainerd, Reyna, & Aydin, 2010; Reyna & Adam, 2003), and (b) their response scale is more precise (e.g., whether personal risk falls between 0 and 100 vs. whether personal risk falls into ordinal categories: *none, low, medium,* and *high*), which has also been shown to be more likely to cue verbatim memories (see Reyna & Brainerd, 1995).

Taken together, our predictions for gist and verbatim measures of risk perception lead to the kind of contradiction that is a hallmark of opponent-process models such as fuzzy-trace theory, namely, oppositely signed correlations for superficially similar questions. So, when participants are asked about the likelihood of pregnancy or a sexually transmitted infection in the next 6 months, risk perception should be positively correlated with risk taking; however, when asked whether the risk of sex is low, medium, or high, the same people's responses should be negatively correlated

[5] Note that although verbatim risk perception measures are expected to be related to past behavior, they are not measures of past behavior, as the data show: Correlations among the three measures of past behavior were .704, .731, and .924 for SS, BAS, and BIS, respectively. In contrast, the correlations between "rate the likelihood that you have a STD," for example, and the three behavioral measures were .221, .255, and .320. Also, the framing decision-making task does not ask about sexual behavior, and yet, in all principal component analyses, reverse framing loaded highly on the same factor as did the other two verbatim measures. This hypothesis was also directly tested by inputting the verbatim measures and the behavioral measures into a factor analysis (more precisely, principal components analysis) to see whether they all loaded significantly on a single factor (i.e., whether they were all related to past behaviors). Naturally, this analysis also tests the hypothesis of whether some (but not all) of the verbatim measures load with (i.e., are related to) past behaviors. Both orthogonal and oblique rotations were performed. The three verbatim measures are Quantitative Risk, Specific Risk, and Reverse Framing. The dichotomous (ever had sex) measure of behavior was excluded because of the requirements of the analysis (when included, it loaded with the other two behavioral measures but not with the verbatim measures). The conclusions were identical for all analyses: There were two factors, and the behavioral measures loaded highly on the first factor, and the verbatim measures loaded highly on the second factor. Factor loadings were as follows for the orthogonal solution: .83 and .88 for the behavioral measures on Factor 1

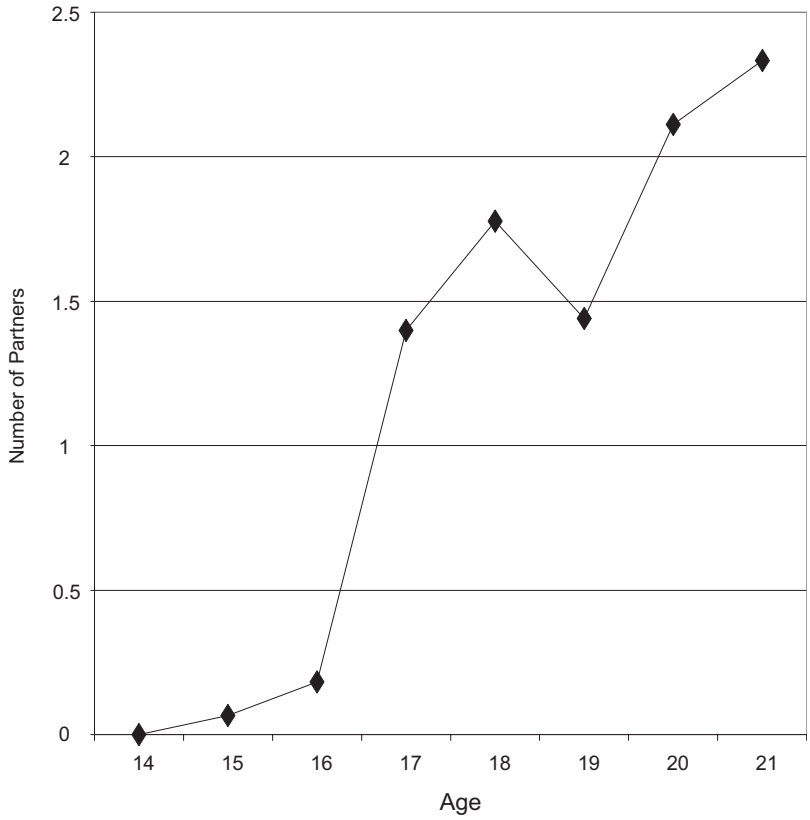

Figure 5. Mean number of sexual partners across age. One outlier is omitted at age 18.

with risk taking. For example, a risk-avoidant person might judge her global risk to be high if she had sex (based on global attitudes) but her probability of pregnancy or a sexually transmitted disease to be low (based on recollection of specific actual behaviors; see also Brewer et al., 2004). As shown in Figure 7, this kind of reversal (positive correlations for verbatim measures but negative correlations for gist measures) was observed for the current sample of participants, replicating earlier findings for a different sample of adolescents (Mills et al., 2008) and extending these predictions to a new dependent measure, number of sexual partners. (Global Benefits is not shown in Figure 7 because it is not a measure of risk perception.) Although one might introduce ad hoc arguments to explain away some of the correlations, it is more parsimonious to explain them all by distinguishing between gist and verbatim measures, and furthermore, this distinction was confirmed by factors analyses (reported later).

Although verbatim measures correlated with sexual behavior and risk taking—and such behavior increases with age as shown in Figures 4, 5, and 6—the verbatim measures were not correlated with age. Gist measures, although they, too, were associated with risk taking, were also not clearly associated with age. (Indeed, it could be argued that many of these gist judgments pertain to sexual initiation and would ultimately be displaced at a later age by categorical gist attitudes about, for example, having protected sex.) As discussed earlier, adolescence and emerging adulthood is a period of transition without sharp delineations between gist and verbatim thinking about risk (see Reyna et al., 2005; Rivers et al., 2008). Nevertheless, it is intriguing that measures of individual differences were associated with age but not risk taking, whereas measures of gist and verbatim thinking were associated with risk taking but not age.

As these results suggest, predictors of risk taking are correlated with each other and related in complex ways to behavior and behavioral intentions. Therefore, we now turn to an approach aimed at reducing this complexity in order to extract the shared components of potential predictors of risk taking and to confirm that they group together in theoretically predicted ways. This approach also avoids problems with interpreting intercorrelated predictors of risk taking by extracting orthogonal factors.

Factor Analyses: Dimensions of Risk Taking

Potential predictors of risk-taking behavior were input to a principal components analysis with orthogonal rotation (factor solutions were similar with and without rotation, and for oblique

versus .65, .66, and –.67 (reverse framing) for the verbatim measures on Factor 2. The oblique solution was highly similar: .82 and .89 for the behavioral measures on Factor 1 versus .65, .66, and –.68 (reverse framing) for the verbatim measures on Factor 2. (Verbatim measures did not load on Factor 1, and behavioral measures did not load on Factor 2.) Therefore, neither some nor all of the verbatim measures are measures of past behavior.

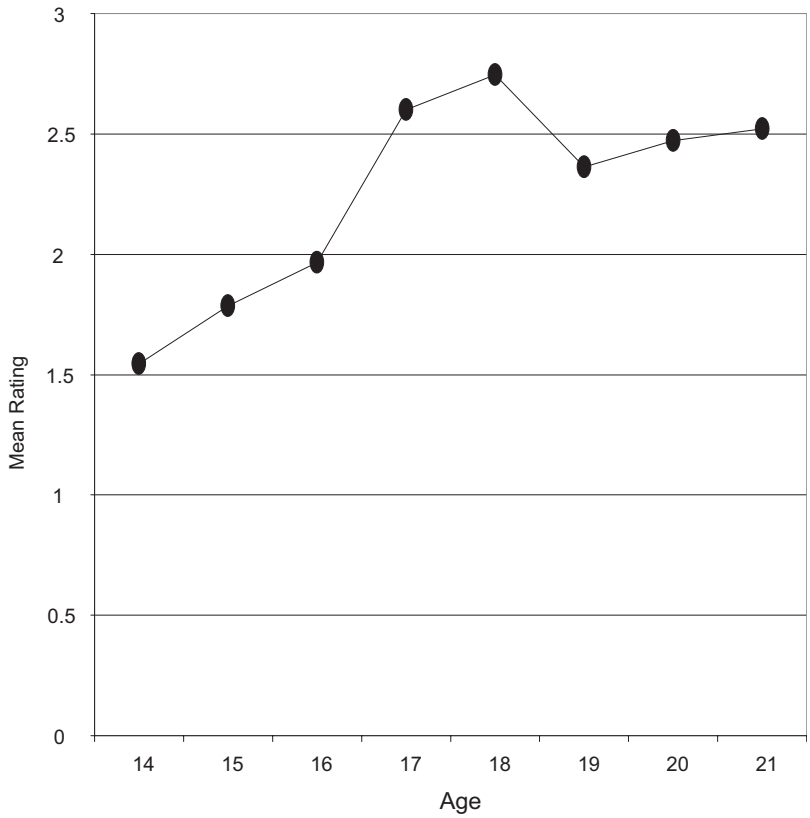

Figure 6. Mean ratings for behavioral intentions to have sex across age.

solutions). We input—in addition to the four gist measures, two verbatim measures, and three neurobiological and motivational measures—age in years and two measures drawn from the framing task, shown in Table 2. An overall measure of framing was calculated for each participant by subtracting the number of gamble choices in the gain frame from the number in the loss frame; positive scores reflect standard framing, but negative scores reflect reverse framing. The number of times the gamble was selected, regardless of frame, was also input into the analysis, for a total of 12 variables. Therefore, the number of times youths gamble overall can be distinguished from specific framing patterns of responding ranging from standard framing to reverse framing. (Although there was a small bivariate correlation of gender with perceived benefits as well as with sensation seeking, gender made no independent contribution to any of the outcome variables.) Note that it is a strong test of fuzzy-trace theory to find out whether any of the individual gist and verbatim measures share variance as predicted.

Five factors with eigenvalues above 1.0 were extracted, and these accounted for 64.24% of the variance. Table 2 displays all factor loadings of .4 and higher. As can be seen in the table, the measures grouped in theoretically sensible ways. All four gist measures loaded on the first factor, accounting for the most variance. As expected, global risk perception, categorical thinking about risk, and gist-principles endorsement all loaded positively, and global perception of the benefits of sex loaded negatively on this factor, which can be interpreted as a gist-based risk-protective factor. Age and BIS loaded on the second factor; increasing age and increasing inhibition were associated with what could be called a maturational factor. Also as expected, the remaining individual-differences measures of sensation seeking and BAS loaded together on the third, reward-sensitivity neurobiological factor. Along with the two verbatim measures of risk perception for sex (specific risk and quantitative risk perception), reverse framing loaded highly on a fourth factor. The variable is referred to as "reverse framing" because it loaded negatively on this factor; the more that participants chose the gamble in the gain frame and the sure option in the loss frame, the higher the loading (which was distinct from overall gambling or risk taking). (Factor loadings were similar when participants showing no bias were removed, contrasting only reverse framing and standard framing; thus, it is not the case that an absence of framing is responsible for the factor loadings.) Finally, total number of gambling choices in the framing task loaded on a separate, fifth factor. Separate analyses within each age group produced similar factors. Note that we did not put any of these variables together by combining scores in any way; rather, these theoretically predicted groupings emerged from the factor analyses.

Regression Analyses Predicting Risk Taking

Factor scores for the five factors derived from the aforementioned principal components analysis were input to a multiple regression analysis with behavioral intentions to have sex as a dependent measure. (Factor scores take advantage of aggregation,

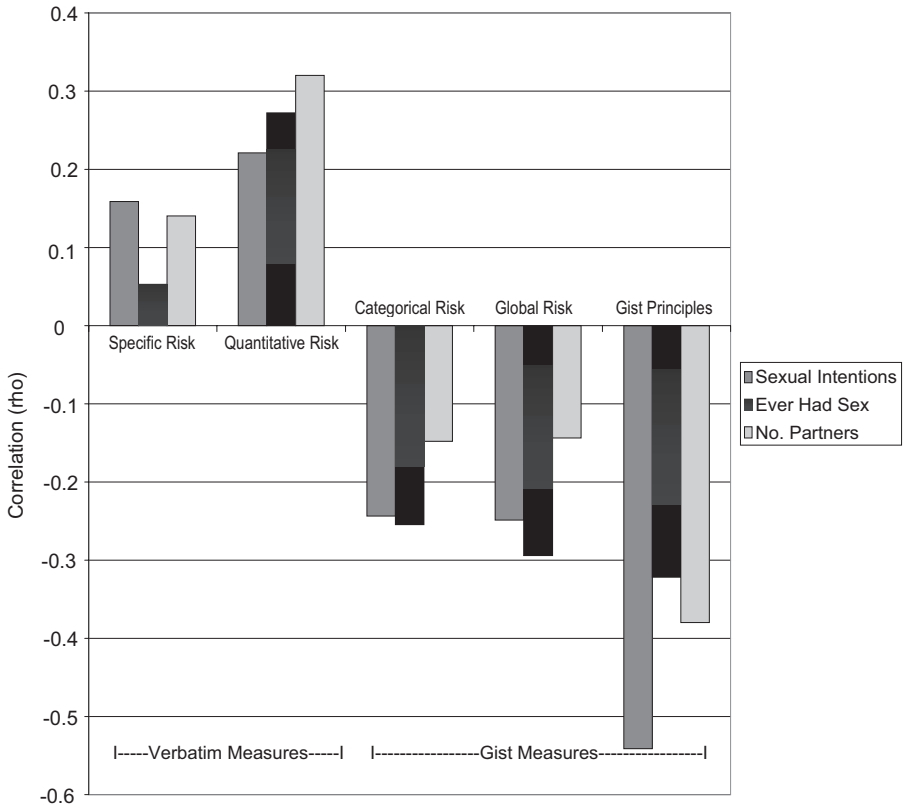

Figure 7. Correlations between measures of risk perceptions and attitudes (verbatim measures are Specific Risk and Quantitative Risk scales, and gist measures are Categorical Risk, Global Risk, and Gist Principles scales) and behavioral intentions to have sex, initiation of sex, and total number of sexual partners.

making predictors more reliable, and they address issues of multicollinearity because these scores are orthogonal.) As shown in Table 3, all but the fifth factor (Total Gambling) significantly predicted behavioral intentions (R^2 = . 43). The largest standardized beta weight (accounting for the most variance) belonged to the Gist factor. The negative weight indicates that higher scores were associated with lower intentions to have sex (i.e., gist-based risk avoidance). All other factors were risk-promoting. Note that the Verbatim/Reverse Framing factor was a significant predictor, but it was distinct from the Sensation Seeking/Behavioral Activation factor and accounted for unique variance.

Using the same factor scores as predictors, we conducted a logistic regression using sexual behavior (whether participants were sexually active or not) as the dependent variable (see Table 3). The first two factors, Gist and Age/BIS, were significant predictors of sexual behavior (Nagelkerke R^2 = . 44; 74% of participants were classified correctly by the model). Again, the first factor was associated with less risk taking, indicated by negative weight and an odds ratio less than 1, but the second factor was positively associated with sexual behavior. Although BIS (fear of negative consequences) might be expected to have a negative association with sexual behavior and intentions, its association was positive in bivariate correlations and in regression models, probably reflecting its linear relation with age (which was related to greater risk taking).

A multiple regression with total number of sexual partners as a dependent variable was also conducted (see Table 3). The first (Gist) factor and the fourth (Verbatim/Reverse Framing) factors were significant predictors of behavior; the second (Age/BIS) factor just missed significance (R^2 = .15). The two significant predictors had comparable beta weights, but they were of opposite signs: The Gist factor was associated with fewer sexual partners, but the Verbatim/Reverse Framing factor was associated with more sexual partners. (Reverse Framing alone was also significantly correlated with number of sexual partners in bivariate correlations (r = –.198, $p < .05$).

Because the prior regression included participants who had zero partners, it might be argued that results were driven by differences between those who were sexually active or not. In addition, risk taking could be argued to be more extreme as the number of partners increased, especially for this young population. Furthermore, because distinctions among the number of sexual partners above zero involve distinctions among degrees of risk (as opposed to a categorical contrast between the presence vs. absence of risk), a prediction unique to fuzzy-trace theory is that verbatim-based factors would exert relatively more influence when restricting the analysis to sexually active participants, controlling for influences such as maturation. Therefore, we conducted a subsequent multiple regression including only those participants who were sexually

Table 2
Factor Solution for Potential Predictors of Risk Taking

Measures	Gist	Age/BIS	SS/BAS	Verbatim/Reverse Framing	Gambling
Gist measures					
Gist Principles	.767				
Categorical Risk	.741				
Global Benefit	−.701				
Global Risk	.612				
Verbatim measures					
Specific Risk					.641
Quantitative Risk					.690
Framing[a]					−.626
Individual differences					
SS				.651	
BAS				.891	
BIS			.759		
Age in years			.768		
Gambling[b]					.833
% of variance	19.47	14.07	11.54	10.60	8.57

Note. All factor loadings greater than .40 are shown. BIS = Behavioral Inhibition Scale; SS = Brief Sensation Seeking scale; BAS = Behavioral Activation Scale.
[a] Refers to the number of gambles selected in the gain frame subtracted from the number in the loss frame (higher = standard framing, lower = reverse framing; range: −9 to +9). [b] Refers to the total number of gambles selected in the framing task (range: 0 to 18).

active (46% of the sample). Consistent with the latter prediction, only the fourth factor (Verbatim/Reverse Framing) was a significant predictor of variation in the number of sexual partners (R^2 = .13; see Table 3). Again, the weight was positive: The higher the score on the Verbatim/Reverse Framing factor, the greater number of sexual partners.

Considering the results as a whole, some caveats are in order. Although the two age samples are similar, there might be hidden differences between them. For example, cohort effects, such as greater sensation seeking in adolescents (vs. young adults) due to societal trends, could explain developmental differences. Similarly, brain maturation and experience are difficult to disentangle, especially because pruning in the adolescent brain occurs as a result of experience (Reyna, Chapman, Dougherty, & Confrey, in press). In addition, although results were similar across age groups when analyses were conducted separately, loss of sample size reduced some effects (e.g., the fifth factor, Gambling, was sometimes nonsignificant in factor analyses).

The correlational nature of some results raises the inevitable question about the direction of cause and effect: For example, might youths with higher perceptions of risk on verbatim measures construct their reports of risky behavior in a biased manner, producing the observed positive correlation (a direction of causation that is the opposite of the one posited here)? Without a gist–verbatim distinction, it would be hard to argue that such construction should not also apply to the overall global risk question—but the observed correlation was negative, not positive. Or, perhaps gist measures are unrelated to beliefs and attitudes, contrary to what is assumed in this account. Ideally, verbatim versus gist reasoning would be manipulated experimentally to evaluate effects on risky behaviors; such evidence has been gathered and is consistent with our account (Reyna, Mills, & Estrada, 2008).

Conclusions

This is the first study comparing risk taking of adolescents versus young adults in a classic decision-making task, the framing task. We also relate these measures from the framing task, and other measures that are at the core of dominant theories of risk taking, to real-life sexual behaviors. One might argue that the range of real-life risk taking in these samples was modest, but the proof is in the empirical pudding; that is, we nevertheless obtained numerous significant findings. These findings provide support for standard dual-process and neurobiological approaches, but they also open the door to some new ideas concerning risky decision making by building on prior research in memory and cognition (Klaczynski, 2001; see also Weber & Johnson, 2009).

On the one hand, supporting standard dual-process approaches, one set of factors was related to age: According to prior theory and data, sensation seeking and behavioral inhibition develop during adolescence and young adulthood (see e.g., Casey et al., 2008; Galvan et al., 2006; Nawa et al., 2008; Steinberg, 2008). In this view, dual processes of reward sensitivity compete with behavioral inhibition (and sensitivity to punishment) in a developmental tug of war. As illustrated in Figure 3 and predicted by neurobiological models in particular, a steady rise in inhibition is offset during adolescence by a rise in sensation seeking, but the latter gradually falls, creating a widening separation between approach and avoidance tendencies in risk taking (see e.g., Somerville, Jones, & Casey, 2010; Van Leijenhorst et al., 2010). Thus, age is expected to be associated with increases in risk taking in adolescence, followed by later declines. Effects of age can be traced to maturational changes in the brain, but aging in this period also brings with it cultural expectations and risk opportunities (e.g., less parental monitoring, a known risk factor) that can also contribute to increased risk taking in adolescence (Gerrard, Gibbons, Houlihan,

Table 3
Regressions Using Factor Scores to Predict Risky Behaviors and Behavioral Intentions

Intention/behavior and factor	*B*	SE	β	*t*
Sexual intentions				
Gist	−0.641	0.070	−.579	−9.19**
Age[a]/BIS	0.200	0.070	.181	2.87**
SS/BAS	0.228	0.070	.206	3.27**
Verbatim[b]/Reverse Framing[c]	0.144	0.071	.128	2.04*
Gambling[d]	0.027	0.070	.025	0.39
			Wald	*OR*
Sexual behavior				
Gist	−1.38	0.267	26.84	0.251**
Age[a]/BIS	1.06	0.243	18.88	2.87**
SS/BAS	0.035	0.200	0.030	1.03
Verbatim[b]/Reverse Framing[c]	0.164	0.207	0.628	1.18
Gambling[d]	−0.132	0.206	0.407	0.524
			β	*t*
Sexual partners				
Gist	−0.807	0.242	−.265	−3.33**
Age[a]/BIS	0.463	0.242	.152	1.91†
SS/BAS	−0.040	0.242	−.013	−0.166
Verbatim[b]/Reverse Framing[c]	0.702	0.245	.228	2.87*
Gambling[d]	0.113	0.242	.037	0.469
Sexual partners–active only				
Gist	−0.058	0.642	−.013	−0.091
Age[a]/BIS	−0.372	0.636	−.084	−0.584
SS/BAS	−0.084	0.432	−.024	−0.194
Verbatim[b]/Reverse Framing[c]	1.17	0.433	.333	2.71*
Gambling[d]	0.408	0.463	.111	0.881

Note. Factor scores are derived from four gist measures: Gist Principles, Categorical Risk, Global Benefits, and Global Risks. BIS = Behavioral Inhibition Scale; SS = Brief Sensation Seeking scale; BAS = Behavioral Activation Scale; *OR* = odds ratio.
[a] Age in years. [b] Verbatim measures (Specific Risk, Quantitative Risk). [c] Framing is determined by the number of gambles selected in the gain frame subtracted from number in the loss frame (higher = standard framing, lower = reverse framing; range −9 to +9). [d] The total number of gambles selected in the framing task (range: 0 to 18).
† $p = .06$. * $p < .05$. ** $p < .001$.

Stock, & Pomery, 2008). Although sensation seeking was significant in only one of the regression analyses, age was generally significant. Because both sensation seeking and inhibition are correlated with age (albeit not always linearly), it is likely that the Age/BIS factor reflected net contributions of these and other maturational and developmental factors.

On the other hand, although two factors were related to age, two other factors remained significant when age was controlled for: a gist and a verbatim factor. In other words, the Gist and Verbatim factors explained unique variance in risk taking that went beyond the age-related factors. Four diverse measures of gist-based thinking loaded highly on one factor that consistently predicted lower levels of risk taking. All three verbatim measures, eliciting superficially similar but more precise judgments of risk perceptions and attitudes, loaded on a separate factor that was related in opposite ways to risk taking (i.e., it predicted higher levels of risk taking).

The surprising pattern of opposite correlations between risk judgments and risk taking shown in Figure 7 was also reflected in the regression analyses and replicates and extends effects obtained by Mills et al. (2008) with a separate sample of adolescents. Thus, fuzzy-trace theory integrates earlier work (see e.g., Brewer et al., 2004), which identified influences of past behavior on perceptions of personal risk, with research on memory to predict when correlations between risk perception and risk taking would be positive versus negative. This kind of reversal pattern is a signature feature of an opponent-processes theory and is one test of the theory's explanation for risk taking.

Although opposite correlations can be rationalized after the fact, post hoc interpretation of results is a poor substitute for prediction. Moreover, although each direction of correlation can be made sense of separately, they are mutually contradictory. For example, one might conjecture that people who think that sex is risky are less likely to have sex (e.g., select "high risk" for the global gist question), but people who think they are more likely to have an STD (e.g., select a higher risk estimate for the verbatim question) think this because of their past risky behavior. So, for the gist question, people who think sex is high risk have less sex (and people who think sex is low risk have more sex), producing a negative correlation. For the verbatim question, people with higher STD estimates have more sex (and people with lower STD estimates have less sex), producing a positive correlation. However, these are, in fact, contradictory ways of thinking (i.e., they lead to different answers).

Further, why don't people think about their past risky behavior when asked whether their personal risk is low or high (the global gist question)? Why would beliefs drive answers to the first question, but behaviors drive answers to the second question? Why not base answers on beliefs for both questions, or on behaviors for both? Indeed, theorists generally assume that risk takers perceive lower risk (e.g., of STDs) than do nonrisk takers, which explains why they take risks (a predicted negative correlation between risk perception and risk taking, but a positive correlation was observed). It begs the question to simply assert that different processes (that lead to opposite answers) are involved in estimating risks for one risk-perception question rather than another. The particular pattern that is observed (beliefs here, behaviors there) requires prediction, which is provided by fuzzy-trace theory.

The current study connects verbatim-based analysis in a laboratory task, as reflected in reverse framing, with real-life risky decisions. Adolescents exhibited standard framing effects under most circumstances—so adolescents, like adults, displayed this irrational pattern of behavior. Although adolescents were as sensitive to risk as adults were, their reasoning changed when rewards were large: When differences in rewards were large, they exhibited reverse framing for choices and preference ratings, a pattern that reflects verbatim-based analysis of rewards. (Roiser et al., 2009, identify different neural substrates for standard and reverse framing that are broadly consistent with fuzzy-trace theory's predicted mechanisms.) Note that reverse framing is not simply a risk-seeking pattern; its interpretation is supported not only by theory but also by prior evidence. Consistent with the idea that reverse framing is linked to more precise processing that predicts sexual risk taking, reverse framing loaded highly on a factor on which perceptions of specific risks such as pregnancy and HIV–AIDS also loaded. Other laboratory tasks examining risk taking have also correlated performance with measures of real-life risk taking; these tasks include the balloon analogue risk task and the Iowa gambling task (see e.g., Galvan et al., 2006, 2007; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Parker & Fischhoff, 2005; Pleskac, 2008; Stout,

Rock, Campbell, Busemeyer, & Finn, 2005). Therefore, the categorical dismissal of laboratory findings as lacking ecological validity seems unwarranted.

The findings we have reviewed thus far—of age-related differences in reward sensitivity and inhibition along with differences in gist and verbatim thinking that predict risk taking—support Reyna and Farley's (2006) argument that there are two distinct routes to risk taking. One route is reactive and characterized by a failure to inhibit behavior and/or a succumbing to emotion or temptation (see also Levin & Hart, 2003; Reyna & Mills, 2007; Rivers et al., 2008; Steinberg, 2003). This route to risk taking is often accompanied by regret and an incompatibility between perceived risks and benefits and the decisions that are taken. The other is a reasoned route characterized by verbatim-based analysis and is the source of intentional risk taking in adolescence, in contrast to impulsive risk taking.

By verbatim-based analysis we mean taking account of the degree of risk and amount of reward and doing so multiplicatively (i.e., trading these quantitative dimensions off against one another, though not necessarily doing so perfectly). We argue that, in contrast to other dual-process accounts, there is more to risky decision making than a dichotomy between emotion, reward sensitivity, or System 1 processing, versus analytical, self-controlled, or System 2, processing. Specifically, fuzzy-trace theory separates the constructs of self-control or inhibition from analytical competence (Reyna & Rivers, 2008). Regarding analytical competence, there is abundant evidence that children as young as five can process tradeoffs between risk and reward multiplicatively, although task features can introduce extraneous performance demands that mask this competence (e.g., the need to remember outcomes or problem information; see Reyna & Brainerd, 1994). In many tasks, too, risk and reward are confounded (e.g., the riskier option is also lower in overall expected value), making it difficult to interpret results. In the framing task used here, these confounds and extraneous demands are not problems (see also Figner et al., 2009).

However, it might be assumed that it is impossible to infer analytical competence in this task because expected values are equal (although prior work has shown that young children are sensitive to unequal expected values; Reyna, 1996). Fortunately, people do not process risk and reward perfectly linearly, which produces preferences for one option over the other and trends across variations in risk and reward. In the present study, one can infer that adolescents differentiated levels of risk, and did so as well as did young college students, because they showed a decreasing preference for the gamble as risk increased. Although rewards increased in the gamble as risk increased, adolescents chose it less often, demonstrating an appreciation that risk and reward traded off. Adolescents also showed a magnitude effect for outcomes; as reward magnitude increased, they also chose the gamble less often, satisfied with the less risky but smaller (relative to the gamble) sure thing, again demonstrating a trading-off of risk and reward.

The present task also has the advantage of offering a safe choice in which something can be won without taking a risk of winning nothing (or of losing). In many other tasks, there is no way to avoid taking a risk. Instead, there are only smaller or larger degrees of risk taking if one wants to win anything, which excludes the possibility of qualitative, categorical contrasts between null outcomes (e.g., winning nothing) versus nonnull outcomes (e.g., winning something). As discussed in Reyna and Brainerd (1995), such task constraints force processing to a higher level of precision (toward verbatim processing) because finer discriminations must be made to choose options, and thus these tasks cannot be used to identify the simplest forms of gist-based processing. For example, Mills et al. (2008) showed that endorsement of the categorical gist principle that "No risk is better than some risk" but not the relative principle "Less risk is better than more risk," as opposed to the opposite pattern of endorsement, was associated with substantially lower levels of risk taking. This seemingly small difference in precision of virtually synonymous statements was associated with an increase in risk taking of over 100%, from 30% sexually active to 61% in a sample with an average age of 15 (intermediate patterns of endorsement were associated with intermediate levels of risky behavior).

Therefore, consistent with fuzzy-trace theory, the competence to make fine distinctions, and to process them multiplicatively, exists fairly early in development, but the propensity to use these distinctions in making risky decisions, as illustrated by the substitution of categorical thinking such as "it just takes once," declines. Ironically, despite advanced quantitative competence, standard framing effects in adults appear to hinge on these gist-based categorical contrasts between null and nonnull outcomes (see Kühberger & Tanner, 2010; Reyna & Brainerd, 1991, 1995). In a recent randomized controlled trial with 734 adolescents, these theoretical principles were used to enhance an HIV-prevention curriculum, that is, to inculcate gist-based categorical thinking about sexual risk taking. The enhanced curriculum was found to be effective across a range of outcomes (e.g., knowledge, attitudes, and behaviors) lasting as long as 12 months after program delivery (Reyna et al., 2008; also Reyna & Farley, 2006, Table 4).

In sum, we found, first, that reverse framing and other measures that relate to risk taking, such as sensation seeking and BAS, did not form a unitary dimension of risk-taking preference. Instead, five separate dimensions of risk taking were extracted from factor analyses that were theoretically coherent: All four gist measures loaded on the same factor, all three verbatim measures loaded on a different factor, and neither the gist nor the verbatim factor could be reduced to sensation seeking, a general tendency to gamble, or other dimensions.

Second, but perhaps more important, measures of gist-based thinking were consistently found to predict real-life risky behaviors and behavioral intentions. For adolescents, initiation of sexual activity and multiple sexual partners are more risky than similar behaviors in adults, for reasons ranging from interference with education because of premature pregnancy to inability to consistently and correctly use condoms to prevent disease. Gist-based thinking was a significant protective factor in all analyses of these behaviors and related behavioral intentions.

Third, verbatim thinking (including reverse framing) was associated with increased risky behavior and intentions. According to fuzzy-trace theory, verbatim thinking promotes unhealthy risk taking because the benefits of risky behavior are often high whereas the risks are often low, producing a rational calculus of risk promotion (see also Berns, Moore, & Capra, 2009). Reverse framing is consistent with reward sensitivity as that concept is used in neuroscientific studies (Delgado, Stenger, & Fiez, 2004; Nawa et al., 2008), which increases during adolescence, as reflected in

our results and in others' (Galvan et al., 2006; Romer & Hennessy, 2007; Steinberg, 2008). However, gist and verbatim thinking explain unique variance in risk taking beyond that explained by these developmentally significant variables, such as reward sensitivity and inhibition. Whether trade-offs occur between healthiness and tastiness, sooner smaller rewards and later larger ones, or smaller safer options and larger risky ones, it appears that cognitive, social, and motivational factors are required to fully account for fundamentally different mechanisms of risk taking.

References

Acredolo, C., O'Connor, J., Banks, L., & Horobin, K. (1989). Children's ability to make probability estimates: Skills revealed through application of Anderson's functional measurement methodology. *Child Development, 60,* 933–945. doi:10.2307/1131034

Arnett, J. J. (1990a). Contraceptive use, sensation seeking and adolescent egocentrism. *Journal of Youth and Adolescence, 19,* 171–180. doi:10.1007/BF01538720

Arnett, J. J. (1990b). Drunk driving, sensation seeking and egocentrism among adolescents. *Personality and Individual Differences, 11,* 541–546. doi:10.1016/0191-8869(90)90035-P

Arnett, J. J. (1992). Reckless behavior in adolescence: A developmental perspective. *Developmental Review, 12,* 339–373. doi:10.1016/0273-2297(92)90013-R

Berns, G. S., Moore, S., & Capra, C. M. (2009). Adolescent engagement in dangerous behaviors is associated with increased white matter maturity of frontal cortex. *PLoS ONE, 4*(8), e6773. doi:10.1371/journal.pone.0006773

Boyer, T. W. (2006). The development of risk-taking: A multi-perspective review. *Developmental Review, 26,* 291–345. doi:10.1016/j.dr.2006.05.002

Brainerd, C. J., & Reyna, V. F. (2005). *The science of false memory.* New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195154054.001.0001

Brainerd, C. J., Reyna, V. F., & Aydin, C. (2010). Remembering in contradictory minds: Disjunction fallacies in episodic memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 711–735.

Brainerd, C. J., Reyna, V. F., & Ceci, S. J. (2008). Developmental reversals in false memory: A review of data and theory. *Psychological Bulletin, 134,* 343–382.

Brannon, E. M. (2006). The representation of numerical magnitude. *Current Opinion in Neurobiology, 16,* 222–229. doi:10.1016/j.conb.2006.03.002

Brewer, N. T., Weinstein, N. D., Cuite, C. L., & Herrington, J. (2004). Risk perceptions and their relation to risk behavior. *Annals of Behavioral Medicine, 27,* 125–130. doi:10.1207/s15324796abm2702_7

Bruine de Bruin, W., Downs, J. S., Murray, P. M., & Fischhoff, B. (2010). Can female adolescents tell whether they will test positive for chlamydia infection? *Medical Decision Making, 30,* 189–193. doi:10.1177/0272989X09343308

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67,* 319–333.

Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. *Developmental Review, 28,* 62–77.

Chien, Y. C., Lin, C., & Worthley, J. (1996). Effect of framing on adolescents' decision making. *Perceptual and Motor Skills, 83,* 811–819.

Cohn, L. D., Macfarlane, S., Yanez, C., & Imai, W. K. (1995). Risk perception: Differences between adolescents and adults. *Health Psychology, 14,* 217–222. doi:10.1037/0278-6133.14.3.217

Delgado, M. R., Stenger, V. A., & Fiez, J. A. (2004). Motivation dependent responses in the human caudate nucleus. *Cerebral Cortex, 14,* 1022–1030. doi:10.1093/cercor/bhh062

Downs, J. S., Bruine de Bruin, W., Murray, P. J., & Fischhoff, B. (2004). When "it only takes once" fails: Perceived infertility predicts condom use and STI acquisition. *Journal of Pediatric and Adolescent Gynecology, 17,* 224. doi:10.1016/j.jpag.2004.03.006

Figner, B., Mackinlay, R. J., Wilkening, F., & Weber, E. U. (2009). Hot and cold cognition in risky decision making: Accounting for age and gender differences in risk taking. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 709–730. doi:10.1037/a0014983

Fischhoff, B. (2008). Assessing adolescent decision-making competence. *Developmental Review, 28,* 12–28. doi:10.1016/j.dr.2007.08.001

Fishbein, M. (2008). A reasoned-action approach to health promotion. *Medical Decision Making, 28,* 834–844. doi:10.1177/0272989X08326092

Furlong, E. E., & Opfer, J. E. (2009). Cognitive constraints on how economic rewards affect cooperation. *Psychological Science, 20,* 11–16. doi:10.1111/j.1467-9280.2008.02244.x

Galvan, A., Hare, T. A., Parra, C. E., Penn, J., Voss, H., Glover, G., & Casey, B. J. (2006). Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. *Journal of Neuroscience, 26,* 6885–6892. doi:10.1523/JNEUROSCI.1062-06.2006

Galvan, A., Hare, T., Voss, H., Glover, G., & Casey, B. J. (2007). Risk-taking and the adolescent brain: Who is at risk? *Developmental Science, 10,* F8–F14. doi:10.1111/j.1467-7687.2006.00579.x

Gerrard, M., Gibbons, F. X., Houlihan, A. E., Stock, M. L., & Pomery, E. A. (2008). A dual process approach to health risk decision-making: The prototype–willingness model. *Developmental Review, 28,* 29–61. doi:10.1016/j.dr.2007.10.001

Gray, J. A. (1987). *The psychology of fear and stress.* Cambridge, England: Cambridge University Press.

Gray, J. A. (1990). Brain systems that mediate both emotion and cognition. *Cognition & Emotion, 4,* 269–288. doi:10.1080/02699939008410799

Haines, B. A., & Moore, C. (2003). Integrating themes from cognitive and social cognitive development into the study of judgment and decision making. In S. L. Schneider & J. Shanteau (Eds.), *Emerging perspectives on judgment and decision research* (pp. 246–286). New York, NY: Cambridge University Press.

Harbaugh, W. T., Krause, K., & Vesterlund, L. (2002). Risk attitudes of children and adults: Choices over small and large probability gains and losses. *Experimental Economics, 5,* 53–84. doi:10.1023/A:1016316725855

Hoyle, R. H., Fejfar, M. C., & Miller, J. D. (2000). Personality and sexual risk-taking: A quantitative review. *Journal of Personality, 68,* 1203–1231. doi:10.1111/1467-6494.00132

Hoyle, R. H., Stephenson, M. T., Palmgreen, P., Lorch, E. P., & Donohew, R. L. (2002). Reliability and validity of a brief measure of sensation seeking. *Personality and Individual Differences, 32,* 401–414. doi:10.1016/S0191-8869(01)00032-0

Kerkman, D. D., & Wright, J. C. (1988). An exegesis of two theories of compensational development: Sequential decision theory and information integration theory. *Developmental Review, 8,* 323–360.

Kintsch, W. K. (1974). *The representation of meaning in memory.* Hillsdale, NJ: Erlbaum.

Klaczynski, P. A. (2001). Framing effects on adolescent task representations, analytic and heuristic processing, and decision making: Implications for the normative-descriptive gap. *Journal of Applied Developmental Psychology, 22,* 289–309. doi:10.1016/S0193-3973(01)00085-5

Kokis, J. V., Macpherson, R., Toplak, M. E., West, R. F., & Stanovich, K. E. (2002). Heuristic and analytic processing: Age trends and associations with cognitive ability and cognitive styles. *Journal of Experimental Child Psychology, 83,* 26–52. doi:10.1016/S0022-0965(02)00121-2

Kühberger, A., Schulte-Mecklenbeck, M., & Perner, J. (1999). The effects

of framing, reflection, probability, and payoff on risk preference in choice tasks. *Organizational Behavior and Human Decision Processes, 78,* 204–231. doi:10.1006/obhd.1999.2830

Kühberger, A., & Tanner, C. (2010). Risky choice framing: Task versions and a comparison of prospect-theory and fuzzy-trace theory. *Journal of Behavioral Decision Making, 23,* 314–329. doi:10.1002/bdm.656

LeBoeuf, R. A., & Shafir, E. (2003). Deep thoughts and shallow frames: On the susceptibility to framing effects. *Journal of Behavioral Decision Making, 16,* 77–92. doi:10.1002/bdm.433

Lejuez, C. W., Aklin, W. M., Zvolensky, M. J., & Pedulla, C. M. (2003). Evaluation of the balloon analogue risk task (BART) as a predictor of adolescent real-world risk-taking behaviors. *Journal of Adolescence, 26,* 475–479. doi:10.1016/S0140-1971(03)00036-8

Levin, I. P., Gaeth, G. J., Schreiber, J., & Lauriola, M. (2002). A new look at framing effects: Distribution of effect sizes, individual differences, and independence of types of effects. *Organizational Behavior and Human Decision Processes, 88,* 411–429. doi:10.1006/obhd.2001.2983

Levin, I. P., & Hart, S. S. (2003). Risk preferences in young children: Early evidence of individual differences in reaction to potential gains and losses. *Journal of Behavioral Decision Making, 16,* 397–413. doi:10.1002/bdm.453

Levin, I. P., Hart, S. S., Weller, J. A., & Harshman, L. A. (2007). Stability of choices in a risky decision-making ask: A 3-year longitudinal study with children and adults. *Journal of Behavioral Decision Making, 20,* 241–252. doi:10.1002/bdm.552

Levin, I. P., Weller, J. A., Pederson, A. A., & Harshman, L. A. (2007). Age-related differences in adaptive decision making: Sensitivity to expected value in risky choice. *Judgment and Decision Making, 2,* 225–233.

Mills, B.., Reyna, V. F., & Estrada, S. (2008). Explaining contradictory relations between risk perception and risk taking. *Psychological Science, 19,* 429–433. doi:10.1111/j.1467-9280.2008.02104.x

Millstein, S. G., & Halpern-Felsher, B. L. (2002). Perceptions of risk and vulnerability. *Journal of Adolescent Health, 31*(Suppl. 1), 10–27. doi:10.1016/S1054-139X(02)00412-3

Nawa, N. E., Nelson, E. E., Pine, D. S., & Ernst, M. (2008). Do you make a difference? Social context in a betting task. *Social, Cognitive, and Affective Neuroscience, 3,* 367–376.

Parker, A. M., & Fischhoff, B. (2005). Decision-making competence: External validation through an individual-differences approach. *Journal of Behavioral Decision Making, 18,* 1–27. doi:10.1002/bdm.481

Peters, E., Slovic, P., Västfjäll, D., & Mertz, C. (2008). Intuitive numbers guide decisions. *Judgment and Decision Making, 3,* 619–635.

Pleskac, T. J. (2008). Decision making and learning while taking sequential risks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 167–185. doi:10.1037/0278-7393.34.1.167

Reyna, V. F. (1995). Interference effects in memory and reasoning: A fuzzy-trace theory analysis. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 29–59). San Diego, CA: Academic Press.

Reyna, V. F. (1996). Conceptions of memory development with implications for reasoning and decision making. *Annals of Child Development, 12,* 87–118.

Reyna, V. F. (2004). How people make decisions that involve risk. A dual-processes approach. *Current Directions in Psychological Science, 13,* 60–66. doi:10.1111/j.0963-7214.2004.00275.x

Reyna, V. F. (2008). A theory of medical decision making and health: Fuzzy-trace theory. *Medical Decision Making, 28,* 829–833. doi:10.1177/0272989X08327069

Reyna, V. F., & Adam, M. B. (2003). Fuzzy-trace theory, risk communication, and product labeling in sexually transmitted diseases. *Risk Analysis, 23,* 325–342. doi:10.1111/1539-6924.00332

Reyna, V. F., Adam, M. B., Poirier, K., LeCroy, C. W., & Brainerd, C. J. (2005). Risky decision-making in childhood and adolescence: A fuzzy-trace theory approach. In J. Jacobs & P. Klaczynski (Eds.), *The development of children's and adolescents' judgment and decision-making* (pp. 77–106). Mahwah, NJ: Erlbaum.

Reyna, V. F., & Brainerd, C. J. (1991). Fuzzy-trace theory and framing effects in choice. Gist extraction, truncation, and conversion. *Journal of Behavioral Decision Making, 4,* 249–262. doi:10.1002/bdm.3960040403

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

Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Learning and Individual Differences, 7,* 1–75. doi:10.1016/1041-6080(95)90031-4

Reyna, V. F., & Casillas, W. (2009). Development and dual processes in moral reasoning: A fuzzy-trace theory approach. In B. H. Ross (Series Ed.) & D. M. Bartels, C. W. Bauman, L. J. Skitka, & D. L. Medin (Eds.), *Psychology of Learning and Motivation: Vol. 50. Moral judgment and decision making* (pp. 207–239). San Diego, CA: Academic Press.

Reyna, V. F., Chapman, S., Dougherty, M., & Confrey, J. (in press). *The adolescent brain: Learning, reasoning, and decision making.* Washington, DC: American Psychological Association.

Reyna, V. F., & Ellis, S. C. (1994). Fuzzy-trace theory and framing effects in children's risky decision making. *Psychological Science, 5,* 275–279. doi:10.1111/j.1467-9280.1994.tb00625.x

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making: Implications for theory, practice, and public policy. *Psychological Science in the Public Interest, 7,* 1–44.

Reyna, V. F., & Lloyd, F. J. (2006). Physician decision-making and cardiac risk: Effects of knowledge, risk perception, risk tolerance, and fuzzy processing. *Journal of Experimental Psychology: Applied, 12,* 179–195.

Reyna, V. F., Lloyd, F. J., & Brainerd, C. J. (2003). Memory, development, and rationality: An integrative theory of judgment and decision-making. In S. Schneider & J. Shanteau (Eds.), *Emerging perspectives on judgment and decision research* (pp. 201–245). New York, NY: Cambridge University Press.

Reyna, V. F., & Mattson, S. (1994, November). *Risk and biases in decision making.* Paper presented at the 35th Annual Meeting of the Psychonomic Society, St. Louis, MO.

Reyna, V. F., & Mills, B. A. (2007). Interference processes in fuzzy-trace theory: Aging, Alzheimer's disease, and development. In C. MacLeod & D. Gorfein (Eds.), *Inhibition in cognition* (pp. 185–210). Washington, DC: APA Press. doi:10.1037/11587-010

Reyna, V. F., Mills, B. A., & Estrada, S. M. (2008, October). *Reducing risk taking in adolescence: Effectiveness of a gist-based curriculum.* Paper presented at the 30th Annual Meeting of the Society of Medical Decision Making, Philadelphia, PA.

Reyna, V. F., Nelson, W., Han, P., & Dieckmann, N. F. (2009). How numeracy influences risk comprehension and medical decision making. *Psychological Bulletin, 135,* 943–973. doi:10.1037/a0017327

Reyna, V. F., & Rivers, S. E. (2008). Current theories of risk and rational decision making. *Developmental Review, 28,* 1–11. doi:10.1016/j.dr.2008.01.002

Rice, C. L. (1995). The effects of outcome attractiveness and framing on children's risky decision making. Unpublished master's thesis, Department of Educational Psychology, University of Arizona, Tucson.

Rivers, S. E., Reyna, V. F., & Mills, B. A. (2008). Risk taking under the influence: A fuzzy-trace theory of emotion in adolescence. *Developmental Review, 28,* 107–144. doi:10.1016/j.dr.2007.11.002

Roiser, J. P., de Martino, B., Tan, G. C. Y., Kumaran, D., Seymour, B., Wood, N. W., & Dolan, R. J. (2009). **A** genetically mediated bias in decision making driven by failure of amygdala control. *Journal of Neuroscience, 29,* 5985–5991. doi:10.1523/JNEUROSCI.0407-09.2009

Romer, D. (Ed.). (2003). *Reducing adolescent risk: Toward an integrated approach.* Thousand Oaks, CA: Sage.

Romer, D., & Hennessy, M. (2007). A biosocial-affect model of adolescent sensation seeking: The role of affect evaluation and peer-group influence in adolescent drug use. *Prevention Science, 8,* 89–101. doi:10.1007/s11121-007-0064-7

Schacter, D. L., & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of the Royal Society of London B, 362,* 773–786. doi:10.1098/rstb.2007.2087

Schlottmann, A. (2001). Children's probability intuitions: Understanding the expected value of complex gambles. *Child Development, 72,* 103–122. doi:10.1111/1467-8624.00268

Schlottmann, A., & Anderson, N. A. (1994). Children's judgment of expected value. *Developmental Psychology, 30,* 56–66.

Schlottmann, A., & Tring, J. (2005). How children reason about gains and losses: Framing effects in judgment and choice. *Swiss Journal of Psychology, 64,* 153–171. doi:10.1024/1421-0185.64.3.153

Somerville, L. H., Jones, R. M., & Casey, B. J. (2010). A time of change: Behavioral and neural correlates of adolescent sensitivity to appetitive and aversive environmental cues. *Brain and Cognition, 72,* 124–133. doi:10.1016/j.bandc.2009.07.003

Stanovich, K. E., Toplak, M. E., & West, R. F. (2008). The development of rational thought: A taxonomy of heuristics and biases. *Advances in Child Development and Behaviour, 36,* 251–285. doi:10.1016/S0065-2407(08)00006-2

Steinberg, L. (2003). Is decision making the right framework for research on adolescent risk taking? In D. Romer (Ed.), *Reducing adolescent risk* (pp. 18–24). Thousand Oaks, CA: Sage.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review, 28,* 78–106. doi:10.1016/j.dr.2007.08.002

Steinberg, L., Albert, D., Cauffman, E., Banich, M., Graham, S., & Woolard, J. (2008). Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: Evidence for a dual systems model. *Developmental Psychology, 44,* 1764–1778. doi:10.1037/a0012955

Stout, J. C., Rock, S. L., Campbell, M. C., Busemeyer, J. R., & Finn, P. R. (2005). Psychological processes underlying risky decisions in drug abusers. *Psychology of Addictive Behaviors, 19,* 148–157. doi:10.1037/0893-164X.19.2.148

Szpunar, K. K., & McDermott, K. B. (2008). Episodic future thought and its relation to remembering: Evidence from ratings of subjective experience. *Consciousness and Cognition, 17,* 330–334. doi:10.1016/j.concog.2007.04.006

Tversky, A., & Kahneman, D. (1986). Rational choice and the framing of decisions. *Journal of Business, 59,* S251–S278. doi:10.1086/296365

Van Leijenhorst, L., Gunther Moor, B., Op de Macks, Z. A., Rombouts, S. A. R. B., Westenberg, P. M., & Crone, E. A. (2010). Adolescent risky decision making: Neurocognitive development of reward and control regions. *NeuroImage, 51,* 345–355. doi:10.1016/j.neuroimage.2010.02.038

Weber, E. U., & Johnson, E. J. (2009). Mindful judgment and decision making. *Annual Review of Psychology, 60,* 53–85. doi:10.1146/annurev.psych.60.110707.163633

Zuckerman, M. (1994). *Behavioral expressions and biosocial bases of sensation seeking.* New York, NY: Cambridge University Press.

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