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Development of Risky Decision Making: Fuzzy-Trace Theory and Neurobiological Perspectives

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Abstract

Developmental differences in mental representations of choices, reward sensitivity, and behavioral inhibition (self-control) explain greater susceptibility to risk taking. Ironically, relying on precise representations in reasoning promotes greater risk taking, but this reliance declines as adolescents mature. This phenomenon is known as a *developmental reversal*; it is called a reversal because it violates traditional developmental expectations of greater cognitive complexity with maturation. Fuzzy-trace theory (FTT) predicts reversals by proposing two types of mental representation (gist and verbatim), and that risk takers rely more on verbatim processing when making decisions. In this article, we describe the main tenets of FTT and explain how it can account for risky decision making. We also explore the neural underpinnings of development and decision making in the context of distinctions from FTT. FTT's predictions elucidate unanswered questions about risk taking, providing directions for research.

Keywords

adolescence; developmental reversal; decision making; risk taking; memory

Adolescence is marked by increased physical maturity and exceptional physical vitality, but also increased risk taking that promotes death, disease, and injury (1). For example, adolescents contract sexually transmitted diseases at disproportionate rates, experiment with dangerous drugs, and drive recklessly (2). It was once thought that cognitive capacities used in risky decision making had developed by adolescence and therefore could not explain this uptick in risk taking (see 3). However, adolescents differ cognitively from adults in their mental pictures of risky options and consequently, in their decision processes. This developmental difference in mental *representations* accounts for substantial risk taking, beyond effects of other factors (4). How young people interpret their options is as important as objective facts about those options.

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Ironically, adolescent risk taking reveals *hyperrationality* because it involves trading off risks and rewards roughly as described in rational choice theory—even when trading off seems unwise to mature adults. Trading off means that the magnitude of rewards compensates for the magnitude of risks and vice versa. For example, the benefits of sex might outweigh the risks of HIV infection, but it seems foolish to many adults to take that risk by having unprotected sex. Adolescents usually do not underestimate risks; they frequently overestimate risks, but rewards tip the scales to promote risk taking (5).

Most theories of decision making stress the advantages of computing tradeoffs between magnitudes of risks and rewards.¹ Unlike these standard theories, fuzzy-trace theory (FTT) distinguishes such computation (verbatim processing) from appreciating the bottom-line meaning of options (gist processing) and stresses the advantages of gist processing. According to FTT, mature adults avoid unprotected sex because they rely more on representations of the simple gist of the options, such as the categorical *possibility* of death from HIV, than on verbatim details about perceived *magnitudes* of risk and reward. Risk-taking adolescents have the opposite tendency. Controlled experiments as well as observations of real-world decision-making support FTT's predictions (6, 7).

To illustrate these points, we briefly introduce FTT and its mechanisms, comparing it to other dual-process approaches. We then explain how FTT accounts for risk taking in adolescents, including predicted developmental reversals, and how this explanation motivates interventions to reduce unhealthy risk taking. We conclude by discussing how FTT provides insights into risky decision processes and their development in the brain.

Background

Representation and Processing

FTT describes mental representation as a continuum from verbatim to gist. People encode many types of gist, such as categorical and ordinal. An example of a categorical gist is representing amounts of risk as *some* versus *none*; ordinal gist would be *less* versus *more*. Adults rely on simplest gist when processing information, beginning with the lowest level of gist (categorical) and only recruit higher (more precise) levels for decision making if the lower levels do not provide sufficient discrimination between options (8). Children operate closer to the verbatim end of the continuum, metaphorically, focusing on the trees rather than the forest (7). Adolescents vary in the representations they use and thus occupy a place between children and adults (9).

Verbatim representations support precise but rote analysis (e.g., direct retrieval of multiplication facts), whereas gist representations support intuition—and intuition is a mainstay of cognition even for numerical problems (10). Intuition is fuzzy (vague and impressionistic), processed in parallel with verbatim-based analysis, and generally not conscious. Verbatim and gist processing develop from childhood to adulthood. From

¹By computation, we do not mean explicit calculation, but rather processing subjective values as assumed in standard decision theories (expected utility, prospect theory). Such theories are grounded in expected value, which involves trading off by definition: Expected value is probability multiplied by outcome (or payoff) to yield the overall value of an option, such as $0.5 \times \$1,000,000 + 0.5 \times 0 = \$500,000$. Thus, a high probability can compensate for a low payoff and vice versa: $1.0 \times \$500,000 = \$500,000$ (e.g., see 13).

childhood to adulthood, the ability to remember verbatim information and perform analyses increases. Simultaneously, the ability to remember the gist of information and the tendency to rely on gist processing also increases.

Comparisons to Other Dual-Process Approaches

Traditionally, dual-processes approaches contrasted System 1, variously described as intuitive or emotional, with System 2, analytical or logical thinking (11, 12). System 1 was assumed to be ontogenetically and phylogenetically less advanced. In contrast, according to FTT, gist-based intuition characterizes advanced cognition, confirmed in many studies of development from childhood to adulthood and from novice to expert (e.g., 13). FTT also differs from many dual-process accounts in being supported by dissociations, crossover interactions, and mathematical models in which each process (verbatim, gist, and inhibition) has been tested for fit to data.

More recently, dual-process approaches have emphasized automatic and impulsive (Type 1) versus analytical higher-order reasoning (Type 2) processes, combining impulsivity (lack of inhibition) and intuition as Type 1 processes (12). Contrary to this approach, FTT holds that impulsivity and intuition are not related processes, develop independently, and can affect behavior differently. FTT would not categorize unconscious intuitions of experts with impulsive choices of children. Experts are also not typically analytical in the sense of processing verbatim details. Rather than becoming bogged down in analyzing details, as is typical of novices, experts rely on gist-based intuition that is associated with more optimal decisions (14-16).

Developmental Predictions

FTT predicts developmental improvements in computational reasoning when tasks require rote answers (verbatim processing), but it predicts developmental reversals (adults' reasoning is simpler, and more biased, than children's) under specific circumstances when tasks tap meaning (gist processing). As examples, FTT predicted that false memories for words and sentences, and cognitive biases in judgment and decision making would *increase* from childhood to adulthood because these phenomena are based on meaningful gist (17-19; see 4). Children are less susceptible to heuristics and biases than adults, even when their knowledge is equivalent. Literal thinking frees children from bias—but it impairs judgment and decision making (7).

Risky Decisions

Verbatim Tradeoffs Versus Categorical Gist

According to FTT, analysis of risk-reward tradeoffs can lead to less healthy decisions, compared to gist-based intuition. For example, the risk of pregnancy from a single instance of unprotected sex is low, so the perceived benefits or rewards of that act can outweigh the small risk. Similarly, driving with a blood alcohol level of 0.08 is unlikely to lead to death or injury for a single trip, so the benefits of driving can tip the scales despite awareness of risks of drunk driving. Focusing on details about risks and benefits—verbatim processing—obscures the gist that these are bad decisions and promotes risk taking in adolescents (4).

In contrast, adolescents who engage in gist-based “it only takes once” thinking take fewer risks (e.g., 20). By relying on gist-based processing, it is not that the decision maker places little weight on any benefits—adults appreciate the benefits. Instead, experience instills all-or-none representations based on the catastrophic consequences of risks (e.g., “Even low risks add up to 100 percent if you keep doing it”) that trump verbatim representations of details (2). Moreover, gist-based intuition explains additional variance beyond reward sensitivity (sensation seeking) and impulsivity (9). These conclusions are supported by assessments that measure verbatim versus gist-based thinking, and results rule out the explanation that adolescents activate more categorical ideas (“just this once can’t hurt”) as a sign of blowing off the risks because of heightened arousal and incentive systems. On the contrary, risk takers are significantly less likely to endorse categorical descriptions of risk.

Developmental Reversals

In accord with FTT, mature adults and adolescents who avoid risk rely on cruder distinctions than risk takers (e.g., 20). For example, endorsing categorical avoidance of risk—“no risk is better than some risk”—predicts taking fewer unhealthy risks, as well as lower intention to take such risks, relative to endorsement of an ordinal principle—“Less risk is better than more risk.” Although both principles express negative views of risk, the ordinal principle makes finer distinctions—thus being closer to verbatim processing on the continuum from gist to verbatim. For one key measure of unhealthy risk taking in adolescents—early initiation of sex—those who endorsed only the ordinal principle (61 percent) were more than twice as likely to have initiated sex than those who endorsed only the categorical principle (30 percent). Endorsement of neither or both principle was associated with an intermediate level of sexual initiation. Therefore, adolescents who endorsed more precise representations were more likely to take risks than those who endorsed more gist-based, categorical representations. This is an example of a developmental reversal because more advanced cognition is less precise, contrary to traditional developmental expectations.

Another example of a developmental reversal can be found in risky-choice framing, in which participants must choose between a safe and a risky option when the identical problem is presented as a gain or loss. For example, imagine a choice with \$90 at stake, with the options of either winning \$30 for sure or a 1/3 chance of winning all \$90 and a 2/3 chance of winning nothing. When the problem is phrased as a gain (winning), most people pick the safe \$30. However, when the same outcomes are phrased as losses—\$90 at stake with a choice between a sure loss of \$60 and a 2/3 chance of losing all \$90—people tend to pick the risky option. FTT explains this change in risk preference in terms of categorical gists of options, to which simple gist values/principles are applied. In the gains version, encoded gists are “win some money for sure” or “win some money or maybe win nothing.” The simple value that “winning money is good” favors the sure option. In the losses version, the encoded gists are “lose some money for sure” or “lose some money or maybe lose nothing,” and the simple value that “losing money is bad” favors losing nothing.

According to this explanation, if people base choices on categorical gists, then emphasizing (or de-emphasizing) categorical differences—by omitting mathematically redundant information from the risky option in both frames—should increase (or decrease) the framing

effect. For example, the 2/3 chance of winning nothing is redundant information, given that people understand that a 1/3 chance of winning something means a 2/3 chance of winning nothing (tests confirm understanding). However, omitting the redundant winning-nothing information changes the gist to a choice between “winning some money” and “possibly winning some money,” de-emphasizing the categorical some-none difference, and forcing more precise (verbatim) comparisons. Thus, if this explanation were true, the framing effect should be reduced or eliminated, which is what occurs (6, 13).

Standard models of decision making, such as prospect theory or utility theory, have no explanation for this outcome, and indeed predict a comparable framing effect based on the same verbatim numerical values since the options are mathematically equivalent with and without the zero. Eliminating the zero information simulates what FTT predicts that children and adolescents do, namely, use more precise, verbatim-based processing of risks and rewards, which makes them frame *less* (9). Because they trade off risks and rewards, and are less influenced by gist or the context of gains or losses, their choices are more consistent and technically, more rational. Hence, as predicted, adults show more risky-choice framing biases than children.

Combining Representation, Reward, and Inhibition to Predict Risk Taking

In the framing task, when possible gains in risky options are large, adolescents will reverse frame (prefer risky gains and sure losses), revealing not only greater reliance on verbatim processing but also increased sensitivity to differences in rewards and other outcomes—preferring larger rewards in the risky option and lower losses in the sure thing. This prediction was tested in a study that not only compared young adults to adolescents in their responses to framing tasks, but also assessed the relationship between the framing effect and risk taking in the real world (9). Compared to the adults who showed the standard framing effect—risk averse for gains, risk seeking for losses—adolescents displayed the reverse when the potential gains from the risky option were high (see also 4). These findings suggest a greater emphasis on verbatim quantities in the decisions instead of categorical contrasts, as predicted by FTT. Furthermore, the extent to which adolescents reverse frame—indicating the extent to which they incorporate verbatim quantities into their risky choices—predicted the number of sexual partners they had and their sexual intentions (9), even after controlling for reward sensitivity (sensation seeking) and inhibition (see also 21). Endorsement of the gist and categorical principles, too, predicted sexual intentions, behavior, and number of partners, all explaining variance beyond what was explained by reward sensitivity and inhibition. (See Figure 1 for an FTT model integrating these factors.)

A Gist-Based Curriculum To Promote Healthy Choices

Building on this model of risk taking, a gist-enhanced intervention has reduced sexual risk taking in adolescents (2). Reducing the Risk (RTR) is an evidence-based intervention that aims to increase abstinence (delaying the initiation of sex) and the use of protective measures (e.g., condoms) to reduce risk. The gist-enhanced RTR+ curriculum presented information from the regular RTR, but also emphasized gist representations of risk information. For example, when addressing the cumulative probability that a consequence will occur (e.g., more than 90 percent chance of pregnancy after a year of unprotected sex),

RTR+ presented the numbers but focused on the categorical contrast between an event ultimately occurring or not occurring (an all-or-none mental representation). Gist representations did not replace verbatim information about exact risks, but emphasized the bottom line (e.g., the gist that pregnancy *will* occur in about a year). The gist-based RTR+ intervention was more effective than the regular RTR for nine outcomes and outperformed the control group for 17 outcomes. The effectiveness of this curriculum suggests that gist representations of information can promote healthy choices, as is seen in other FTT interventions.

In summary, children and adolescents rely less on the simple categorical gists that produce sharp shifts in risk taking in adults and more on verbatim-based reasoning. Choices in these laboratory tasks predict risk taking that has important health consequences. Young people should take some healthy risks, but seeing the meaning in choices is central to discriminating healthy from unhealthy risks.

The Neuroscience of Risk Taking

We have developed a preliminary model that integrates research on neural substrates of memory (especially verbatim versus gist representations) with neuroscience research on development, decision making, and group differences in processing (11, 22-24; see 7, 25). To begin, dual-systems models of adolescent risk focus on the imbalance between heightened reward reactivity (e.g., to social rewards) in subcortical regions (e.g., ventral striatum and amygdala) and immature cognitive control systems (e.g., lateral prefrontal cortex [PFC] and anterior cingulate cortex [ACC]). Activity in the dorsolateral PFC and ACC is associated with cognitive control functions such as response inhibition, cognitive distraction (or distancing), and stimulus reappraisal. These inhibition-related areas activate with self-control and choosing healthy behaviors, suggesting that they may be involved when individuals attempt to avoid unhealthy risks (9, 26, 27).

In our model, we define reward sensitivity as reward-related approach motivation, as tapped by sensation-seeking measures that peak in adolescence (9, 28). Greater rewards encourage shifts to verbatim processing in childhood and adolescence, as demonstrated repeatedly, reflecting a more analytical (or reasoned) rather than reactive (or impulsive) approach to risk taking (4, 29). Such verbatim-based reward processing can exploit the emerging executive systems in adolescence (previously implicated in cognitive control) to attain rewards by taking calculated risks, consistent with existing evidence (30). Socioemotional context influences risk taking during adolescence, heightening reward sensitivity and acting as a symbolic reward. For example, adolescents behave more recklessly in the presence of peers, compared to adults, in simulated driving activating reward circuits (31). FTT emphasizes the power of gist representations to alter the salience of social rewards, which are influenced by cultural context as well as neurobiological development (32, 33).

Distinct from reward sensitivity, inhibition is an individual and developmental difference that is not analytical, encompassing the ability to withhold behavior in the face of reward-related approach motivation (e.g., as measured in emotional go/no go tasks; 26). Such inhibition of behavior is facilitated if decision makers reinterpret the gist of tempting rewards through cognitive reframing or distraction, a representational effect that reduces

reward or emotional salience (34, 35). Inhibition may also facilitate avoiding harm (e.g., avoiding losses or punishment; e.g., 36).

Thus, risk taking in adolescence can result from increased reward sensitivity, decreased inhibition (though inhibition in cognitive tasks can be similar to adults'), and verbatim analysis of risk-reward tradeoffs as opposed to gist-based intuition. Although the ventromedial PFC has been identified with the reward system, it reflects overall subjective value of options, integrating both risk and reward (thus covarying with reward magnitude).

Frontoparietal circuitry, distinguishing verbatim from gist processing, is activated differentially in memory and decision making (25). For example, in memory research, verbatim memory activated lateral PFC and inferior parietal areas, whereas gist memory activated medial PFC and superior parietal areas, among others. Similarly, in decision-making research, activation in the vmPFC and anterior insula predicted verbatim analytical, compensatory choices, maximizing gains and minimizing losses, whereas activation in the posterior parietal cortex and dorsolateral PFC predicted gist-based, simplifying choices in a decision task (see Table 1; 37). The memory research was designed around FTT's predictions, but the decision-making research is also diagnostic of FTT's predictions because the task provides critical tests of prior hypotheses.

Finally, FTT also makes explicit predictions about aging, autism, and Alzheimer's disease, among other group differences (7). Individuals with autism show weaker gist-based processing but stronger verbatim processing than controls (i.e., processing is high-verbatim/low-gist; see also 38). FTT predicts that such processing should produce smaller framing effects, which is what researchers found (39). Conversely, when verbatim processing (processing the exact numbers) is induced experimentally in neurotypical adults, their choices resemble those of individuals with autism. Recent analyses suggest that autism and neurotypical development are not differentiated by short versus long-range connections, instead pinpointing underconnectivity of frontal and parietal centers (11, 40).

Conclusions

FTT predicts developmental differences in risky decision making that are not predicted by other views. Adults would be expected to be more rational than children. Instead, as predicted by FTT, many cognitive biases increase from childhood to adulthood, exhibiting developmental reversals. Adolescents' risky decision making is closer to the economic ideal of trading off risks and rewards than adults', but ironically, verbatim trading off is associated with unhealthy risk taking, while inducing simpler gist-based intuition is protective.

FTT concurs with developmental dual-process theories in distinguishing reward sensitivity from behavioral inhibition, although imbalance between prefrontal control and reward systems is an incomplete explanation of developmental differences in risk taking. Indeed, greater reward sensitivity encourages recruitment of cognitive control areas, so many adolescents take calculated risks rather than act impulsively. FTT emphasizes the interplay among representation, reward sensitivity, and inhibition, which researchers must distinguish

going forward. In particular, neuroimaging studies of the development of risky decision making should target verbatim and gist strategies, and corresponding neural substrates, identified in research on adults and on autism, including tests of frontoparietal connectivity hypotheses.

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Figure 1.

Theoretical model showing mutual influences of mental representation on reward sensitivity and inhibition, as well as effects of all three factors on risky decisions.

Table 1

Example Stimuli

Gamble		Choice	
\$80	p = 0.25	\$80	p = 0.25
\$40	p = 0.15	\$40	p = 0.15
\$0	p = 0.20	\$0 +\$20 = \$20	p = 0.20
-\$35	p = 0.20	-\$35	p = 0.20
-\$75	p = 0.20	-\$75 +\$20 = -\$55	p = 0.20

Note: Subjects were first shown a mixed gamble consisting of five potential outcomes, each associated with a probability of occurrence. Then, two alternatives for improving the gambles were highlighted (in bold), whereupon subjects had to decide which improvement they preferred. Here, the addition of \$20 to the zero outcome increases the probability of winning something as opposed to nothing, whereas the addition of \$20 to the extreme loss reflecting a choice to minimize losses. In other trials, subjects had a chance to add money to the extreme gain outcome, reflecting a choice to maximize gains.

Source: 37