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Chapter 4
Cognitive, Developmental, and Neurobiological Aspects of Risk Judgments

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Abstract In this chapter, we explore the literature on the cognitive, developmental, and neurobiological aspects of risk and show how work in this area is important in explaining and understanding decisions relating to risk. We outline different theories of risk preference and risk taking, including prospect theory, traditional dual-process theories, fuzzy-trace theory, and construal level theory. We focus on how cognitive differences can account for differences in risk preference and risk taking and examine how cognitive developmental trends can explain the observation that adolescents (and young adults) are prone to unhealthy risk taking. We outline important work in this area showing that the way information is mentally represented influences decisions relating to risk, in addition to more traditional factors such as reward sensitivity and inhibition. We explain how accounting for the role of mental representation can explain and predict counterintuitive findings in the literature on risk taking. In addition, we consider the neural underpinnings of risk taking and what research into the neural underpinnings of risk taking can tell us about cognitive aspects of risk.

Research investigating cognitive, developmental, and neurobiological aspects of risk is an emerging area in which there is much new work showing an important role of mental representations in decisions regarding risk. In the first part of this chapter, we describe important traditional theories that have provided insight into the cognitive aspects of risk—prospect theory and traditional dual-process theories—and explain how these theories contribute to understanding and explaining decisions relating to risk. We then consider two theories—fuzzy-trace theory and construal level theory—that add to prospect theory and traditional dual-process theories by

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recognizing an important construct that has been shown to influence decisions relating to risk: how information is mentally represented and, hence, processed. In the second part of this chapter, we consider findings in the risk taking literature and show how these findings are explained by theories of risk that account for cognitive constructs. We show how understanding the role of mental representations can add to traditional theories and predict counterintuitive findings in the developmental and adult literatures. For example, we discuss fuzzy-trace theory's prediction that adolescents are technically more rational in their risk preferences, but are also prone to unhealthy risk taking such as participation in crime, reckless driving, and unprotected sex (Figner & Weber, 2011; Reyna, Chapman, Dougherty, & Confrey, 2012; Reyna & Farley, 2006). We mention this prediction, in particular, because it distinguishes alternative theories and because it bears directly on ways to improve risky decisions. In the final part of the chapter, we discuss the neural underpinnings of risk taking, with reference to the distinctions introduced in the earlier parts of the chapter.

Theories Providing Insight into Cognitive Aspects of Risk

Prospect Theory

Early accounts that aimed to explain people's decision making regarding risk relied on *expected utility theory* (von Neumann & Mortgenstern, 1944). According to expected utility theory, when making a decision about whether to take a risk, the most desirable course of action is to choose the option with the highest subjective value to the individual. So, if an individual is making a choice between a sure option (e.g., receiving $5,000 for sure) and a risky option (e.g., a 50% chance of $10,000; otherwise, nothing), they should pick the option with the highest value to them (the highest subjective value). The highest subjective value is different from the expected value of an option, which is calculated as the sum of each objective outcome multiplied by its probability of occurrence (e.g., 0.50 × $10,000 = $5,000). This is illustrated by the fact that most people choose the sure option in the task, despite the fact that the sure option and the risky option have equal expected values (Fox & Tannenbaum, 2011). Expected utility theory, which goes beyond expected value, can explain why people do this. That is, expected utility of outcomes is thought to be nonlinear; as outcomes (e.g., dollars) increase, their utility (or subjective value) does not increase one for one in terms of objective value. Instead, there are *diminishing returns*, so that the outcomes in a sure option (smaller numbers) are discounted less than those in a risky option of equal expected value (larger numbers), making the sure option more valuable (see Fox & Tannenbaum, 2011; Machina, 1982; Tversky & Kahneman, 1986; see also Birnbaum, Chap. 8).

Despite explaining that most adults are risk averse (they prefer the sure option over the risky one), expected utility theory cannot explain other findings in the risk taking literature—notably, the large body of research showing that superficial changes in the wording of information (e.g., wording the same options as gains or losses), known as *framing*, can have a large influence on risk preferences.

The risky-choice framing task is important to understand because it produces inconsistency in risk preference. When preferences change on the basis of superficial differences in the wording of options as gains or losses, this is known as a *framing effect* (Reyna et al., 2011; Tversky & Kahneman, 1981; 1986). In the gains version of the task, participants choose between a sure option and a gamble of equal expected value, as in the earlier example (gaining $5,000 for sure vs. a 50% chance of gaining $10,000); as discussed, most people choose the sure $5,000. In the losses version, a decision-maker may be given $10,000 but must choose between losing $5,000 for sure or taking a 50% chance of losing $10,000 and a 50% chance of losing nothing. Note that the gains and losses versions describe the same options (e.g., $10,000 - $5,000 = $5,000). Despite these options being the same, adults change their preferences from risk aversion (choosing the sure option) when *gains* are described to risk seeking (choosing the gamble) when *losses* are described, which is referred to as a standard framing effect. Because the options are the same, shifts in choice selection across frames are viewed as a violation of a fundamental axiom of expected utility, that of preference consistency.

Prospect theory built on expected utility theory and explained framing effects. According to prospect theory, outcomes are coded as gains or losses relative to a reference point, such as the status quo (Tversky & Kahneman, 1986). Therefore, what is important is not absolute values, but changes in values. For example, for a person expecting a raise in their salary, their salary with the raise would become the reference point and not getting a raise would be considered a loss. In framing problems, in the gain frame the reference point is $0, but in the loss frame the reference point is the initial endowment. So, in a loss frame problem where you are given $10,000 and have to choose between losing $5,000 for sure and a 50% chance of losing $10,000 and a 50% chance of losing nothing, people generally code the sure loss of $5,000 as a downward deviation from $0 (the reference point), rather than an overall gain of $5,000.

Framing effects are explained by the way that people value outcomes, as well as a probability weighting function that overweights small probabilities and underweights moderate to large probabilities. According to prospect theory, the valuation of outcomes changes at the reference point ($0 in the gain frame and $10,000 in the loss frame) and can be described by an S-shaped value function. In problems involving gains, the value function is concave (e.g., dollars become worth less as value increases, so the first $5,000 gain is valued higher than the second $5,000 gain). This means that people value $10,000 less than twice as much as they value $5,000. Therefore, when asked to pick between $5,000 for sure and a 50% chance of $10,000, people are likely to value $5,000 more highly than half of $10,000 (as the value of $10,000 is less than twice the value of $5,000). This leads to a preference for the sure option. In contrast, the reference point in the loss frame is $10,000, and options are coded as losses relative to this $10,000. In problems involving losses, the value function is convex (e.g., dollar losses become less bad as value increases, so the first $5,000 loss hurts more than the second $5,000 loss). This means that people dislike a loss of $10,000 less than twice as much as they dislike a loss of $5,000. Therefore, when asked to pick between a $5,000 loss for sure and a 50% chance of a $10,000 loss, people are likely to dislike the sure loss of $10,000 less than twice as much as they dislike the loss of $5,000. This leads to a preference for the risky option in the loss frame, as a 50% chance of a $10,000 loss is valued as less bad than a $5,000 loss for sure.

Prospect theory also explains framing effects through a probability function, where people overweight small probabilities and underweight moderate to large probabilities. This means that in cases involving moderate to large probabilities, people underweight the probability (50% in our example). This means that in the gain frame where the choice is between $5,000 for sure and a 50% chance of $10,000, people underweight the 50%, treating this option as less than 50% of 10,000. This leads to a preference for the sure option. In the loss frame where the choice is between losing $5,000 for sure and a 50% chance of losing $10,000, people underweight the 50%, treating this option as a less than 50% chance of losing $10,000. This leads to a preference for the risky option.

Although prospect theory offers an explanation of framing effects that has to do with the perception of outcomes and probabilities, it does not discuss the types of non-perceptual cognitive processes involved in decisions relating to risk. Other accounts of risk have attempted to provide such an explanation.

Traditional Dual-Process Theories and Type 1/Type 2 Thinking

Traditional dual-process theories explain risky decision making through the distinction between fast and intuitive thinking, called *Type 1* thinking, and slow and deliberative thinking, called *Type 2* thinking, replacing earlier System1/System2 terminology (Evans & Stanovich, 2013; Kahneman, 2003). According to dual-process theories, Type 1 thinking is intuitive and experiential in contrast to Type 2 thinking that involves logical and rational cognitive capacities. Type 2 thinking operates when a need to override Type 1 thinking is detected, for example, when an individual notices that gain and loss framed problems are the same, they may calculate expected value, thus attenuating framing effects (see Stanovich & West, 2008). Type 2 thinking interrupts Type 1 thinking, suppresses its default responses, and substitutes a logical or rational response (Evans & Stanovich, 2013; Kahneman, 2011). Recent extensions to dual-process theories recognize two components of Type 2 thinking—the cognitive capacities for rational judgments (such as intelligence) and cognitive propensities for reflective thinking (such as need for cognition, actively open-minded thinking, and the tendency to collect information before making up one's mind) (Evans & Stanovich, 2013).

According to these theories, reliance on Type 1 thinking can result in biases when making decisions, including those regarding risk. For example, when analyzing the risk of an environment or activity, reliance on Type 1 may lead to attribute substitution. This is where a harder to evaluate characteristic is substituted for an easier to evaluate characteristic, even when the easier to evaluate characteristic is less accurate (Evans & Stanovich, 2013; Kahneman & Frederick, 2002). For example, in judging the probability of an accident, people can substitute the vivid availability in memory of a single observed accident on a slide for a quantitative analysis of the frequency of accidents on slides (Evans & Stanovich, 2013; Kahneman, 2003). Some traditional dual-process approaches have associated framing effects with Type 1 processing (Kahneman, 2003; Stanovich & West, 2008). When the same person received both gain and loss problems (in a within-subjects design), successfully engaging in Type 2 processing has been shown to reduce framing effects, as it causes the person to notice the similarity between gain and loss frames and inhibits framing differences (Stanovich & West, 2008). In addition, neuroimaging research has provided some evidence that framing effects are caused by an initial emotional evaluation and can be reduced by suppression of this initial response (De Martino, Kumaran, Seymour, & Dolan, 2006; Kahneman & Frederick, 2007).

In addition, certain conceptions of traditional dual-process theories associate Type 1 thinking with *affective* and *emotionally charged* thinking (Epstein, 1994; Slovic, Finucane, Peters, & Macgregor, 2006). This thinking has also been associated with unhealthy attitudes to risk (see also Tompkins et al., Chap. 5). For example, Type 1 thinking has been linked to the decision to engage in smoking. Slovic (2001) suggested that young smokers gave little or no conscious thought to the risks of smoking but were instead driven by affective impulses such as wanting to do something new and exciting and have fun with their friends (but see Reyna & Farley, 2006, for a review of the role of affect and emotion in risk taking and Rivers, Reyna, & Mills, 2008, for an alternative explanation of emotion and risk in adolescent decision making).

Neurodevelopmental imbalance theories of risk taking take a similar approach to that of Slovic, associating affective thinking with unhealthy attitudes to risk, particularly in adolescents. These theories have similar intellectual roots to traditional dual-process theories and distinguish between a *hot* motivational affective system (much like Type 1 thinking) and *cold* deliberation and inhibition (much like Type 2 thinking) (Somerville & Casey, 2010; Steinberg, 2008). According to these models, risk taking in adolescence is caused by an imbalance between the development of brain regions responsible for control and *affective* brain regions. Specifically, regions implicated in control (prefrontal cortical regions) develop linearly with age and begin to stabilize by adolescence, while subcortical *affective* brain regions develop faster and are hypothesized to be hyperresponsive in adolescence (Casey, Jones, & Hare, 2008; Defoe, Dubas, Figner, & van Aken, 2015; Somerville, Hare, & Casey, 2011; Steinberg, 2008). This imbalance between cold control systems and hot affective systems is predicted to cause adolescents to become biased toward arousing rewards, leading to increased risk taking (Somerville et al., 2011; Steinberg, 2008). Dual-process approaches have been applied to explain real-life risk taking such as adolescent drug taking and addiction (Gladwin, Figner, Crone, & Wiers, 2011). These theories predict an increase in risk taking from childhood to adolescence, which then declines in adulthood (Dahl, 2004). However, a comprehensive meta-analysis of experiments on risky decision making showed that risk preference declines from childhood to adolescence, disconfirming predictions of dual-process imbalance models (Defoe et al., 2015). Theories such as fuzzy-trace theory and construal level theory are able to explain findings not explained by traditional dual-process theories by accounting for the role of mental representations in decisions relating to risk.

Fuzzy-Trace Theory: Gist and Verbatim Representations

Fuzzy-trace theory builds on traditional dual-process theories, but it adds crucial constructs that explain prior findings and that make new predictions. Consistent with traditional dual-process theories, fuzzy-trace theory distinguishes metacognitive capacities such as inhibition and reflection from motivational/affective influences such as reward sensitivity and emotion (Rivers, Reyna, & Mills, 2008). However, fuzzy-trace theory also incorporates an additional cognitive distinction between verbatim versus gist mental representations—not found in traditional theories (Reyna, 2012; Reyna, Wilhelms, McCormick, & Weldon, 2015). Therefore, fuzzy-trace theory encompasses three constructs that are important in risk taking—*hot* motivational/affective factors such as reward sensitivity and emotion (similar to Type 1), *cold* metacognitive factors such as reflection and inhibition (similar to Type 2), and gist versus verbatim mental representations.

Fuzzy-trace theory posits two types of mental representations and associated processing types—gist and verbatim. When people are faced with a decision, they encode two types of mental representations of their options—the bottom-line meaning of the options (gist) and the exact details (verbatim; Reyna, 2012; Reyna & Brainerd, 2011). Usually, people encode multiple gist representations at varying levels of precision but all simpler and more meaningful than verbatim representations. Gist and verbatim representations are encoded simultaneously in parallel and stored separately (Reyna, 2012). Gist representations of a risky-choice framing problem start with the simplest nominal-scale distinction between some quantity and no quantity. Thus, the gist of the choice in the gain frame boils down to gaining something (for sure) versus possibly gaining nothing—two outcomes that are categorically different from one another. Verbatim representations are detailed representations of the surface form of information (e.g., in a risky-choice framing problem that the choice is between $5,000 for sure and a 50% chance of $10,000). The same information is encoded at multiple levels of precision from verbatim to simplest gist, roughly analogous to scales of measurement from verbatim to gist—exact numerical values (e.g., $5,000 and a 50% chance of $10,000), then ordinal distinctions (e.g., more chance of less money vs. less chance of more money), then categorical distinctions (e.g., some money vs. chance of some money or no money; Reyna, Chick, Corbin, & Hsia, 2014; Wilhelms, Helm, Setton, & Reyna, 2014). According to fuzzy-trace theory, when making a choice, some people rely more on the gist or the verbatim representations of information—but most adults have a preference for the simplest gist-based representations. They then apply values or moral principles to choose between options (e.g., valuing some money over no money). Thus, the representations that a decision-maker relies on and the principles they apply to those representations govern their decisions regarding risk.

Unlike traditional dual-process theories (which include intuition in Type 1 processing and inhibition in Type 2 processing), in fuzzy-trace theory intuition is not associated with a lack of inhibition. As noted above, fuzzy-trace theory encompasses the role of inhibition (a metacognitive factor encompassing reflection and promoting deliberation) (an aspect of Type 2 processing) and motivational/affective processes, including emotion and reward sensitivity (some of which are akin to those in Type 1). However, unlike traditional dual-process theories, fuzzy-trace theory breaks mental representation (simple meaning-based gist vs. more specific surface-level verbatim) out into separate constructs that have been shown to be dissociated and that are not found in other dual-process theories (see Reyna, 2012). Gist-based processing is referred to as intuition as it is typically fuzzy and qualitative rather than precise and analytical but gist-based intuition characterizes advanced cognition. It is a sophisticated way of thinking based on the meaning of information rather than literal surface details (Adam & Reyna, 2005; Reyna & Lloyd, 2006). So, fuzzy-trace theory would not categorize the unconscious gist-based intuitions of experts (e.g., cardiologists diagnosing a heart attack, Reyna & Lloyd, 2006) together with impulsive choices of adolescents (e.g., the decision to go out with friends instead of studying for a test) (Reyna et al., 2015).

Fuzzy-trace theory posits that when making decisions, adults (in the types of decisions they have experience making) and experts (particularly in their area of expertise) tend to rely on gist representations (resulting in gist-based processing), referred to as a fuzzy-processing preference, and this reliance tends to increase with age and experience (Reyna et al., 2014; Reyna & Brainerd, 2008; Reyna & Lloyd, 2006; Wilhelms, Corbin, & Reyna, 2015). So, for example, when making a decision on whether to go bungee jumping or not at a particular center, an adult would be likely to process both the verbatim probability of serious injury (e.g., 10%) and the gist that the chance of injury was relatively large, but would base his or her decision on the qualitative gist. Specifically, they would rely on the fact that the chance of serious injury was relatively large, rather than trading off precise risks and rewards. Laboratory and field experiments with children, adolescents, and adults and studies with experts and novices have confirmed this prediction (e.g., Reyna, 1996; Reyna et al., 2011; Reyna & Brainerd, 1994, 1995; Reyna & Ellis, 1994; Reyna & Lloyd, 2006), as have studies of real-life decision making (Mills, Reyna, & Estrada, 2008; Reyna et al., 2011; Reyna & Farley, 2006). The prediction that reliance on gist increases with age has also been supported by recent research in the context of risk taking using eye-tracking data, showing that, prior to decisions, adolescents acquired more information in a more thorough manner compared to adults, suggesting they were engaging in a more analytical processing strategy involving trading off decision variables (Kwack, Payne, Cohen, & Huettel, 2015). In addition, this prediction is supported by literature from a large number of cognitive tasks showing that reliance on gist-based representations increases with age and expertise (e.g., Brainerd, Reyna, & Ceci, 2008; Reyna & Ellis, 1994; Reyna & Lloyd, 2006).

The idea that intuitive gist-based processing supports sophisticated and developmentally advanced reasoning has been supported by results showing that reliance on gist-based processing promotes better decision making in practical contexts, for example, when doctors make choices about treatment options for patients with cardiac risk (Reyna & Lloyd, 2006) and when individuals make decisions about whether to risk HIV by engaging in unprotected sex (Reyna et al., 2011). This idea has also been supported by research showing that manipulations designed to encourage intuitive thinking improve decision making (e.g., participants are given a distraction task rather than being asked to think carefully about their decision), compared to manipulations designed to encourage analytic/deliberative thinking (e.g., participants were told to think carefully before making decisions), on a variety of reasoning tasks (Usher, Russo, Weyers, Brauner, & Zakay, 2011).

The implication for risky decision making is that as age and experience increase, precise quantitative processing of risks and rewards is predicted to give way to mature qualitative processing that captures the bottom-line meaning (the gist) of decision options. This development is predicted to have a protective effect against unhealthy risk taking when risks are objectively low and benefits are objectively high (e.g., the risk of arrest from a single instance of drunk driving for a short distance is low, and the benefits of driving may be high). Although the verbatim representation promotes risk taking because benefits outweigh risks, the gist representation of such a choice would be that there is a non-negligible possibility of a life-altering injury or a felony drunk-driving conviction. In addition to drunk driving, many other crimes have a low risk from a single instance of risky behavior, as do many public health risks (e.g., the risk of HIV from unprotected sex; Reyna et al., 2011; Reyna & Mills, 2014). Thus, processing less information more meaningfully—the core gist—generally reduces risk taking in cases in which objective risks are low and benefits are high. In cases where objective risks are high and benefits are high, there is likely to be less of a difference between reliance on gist and reliance on verbatim, as here processing the information meaningfully and conducting a trade-off of risks and benefits would often both lead to risk avoidance.

When relying on gist-based representations and processing, an individual is more likely to make decisions based on simple bottom-line values and moral principles, for example, “avoid risk” or “better to be safe than sorry.” According to fuzzy-trace theory, these principles are represented in long-term memory as vague gists and generally do not incorporate exact magnitudes of potential risks and benefits (see Helm & Reyna, 2017; Reyna & Casillas, 2009). This is because verbatim representations fade quickly and are too precisely specified to be applicable to a wide variety of decisions. These values and principles should be distinguished from the representations of options to which they are applied in order to make decisions, although they are related: That is, gist representations of values are more easily cued when an individual relies on gist representations of options because of their similarity to one another, a well-known property of retrieval cueing.

As noted above, according to fuzzy-trace theory, reliance on gist generally increases as age increases. Specifically, reliance on gist increases in decisions where an individual has some experience making that type of decision. When making decisions about risk, adults are predicted to have a fuzzy-processing preference (Reyna, 2012). This means that they have a tendency to rely on the simplest gist possible to make a decision. When two options are categorically different (e.g., win something vs. maybe win nothing or risk of death or serious injury vs. no risk of death or serious injury), adults will generally make their decisions based on this categorical difference and not more fine-grained distinctions. In contrast, many risk-takers (including many adolescents) rely on more fine-grained distinctions, operating closer to the verbatim end of the verbatim-gist processing continuum. These people, then, engage in more precise processing that supports risk-benefit trade-offs, which often results in risk taking when the benefits of risky behavior are high and the risks are objectively low.

For example, the risk of HIV infection from a single act of unprotected sex is objectively low (0.08% from one incident of unprotected sex, see Boily et al., 2009). People relying more on verbatim details (and therefore trading off risks and benefits) may choose to engage in unprotected sex (a risky behavior) (Mills et al., 2008). In contrast, those relying on gist would be likely to see their options as risking a life-threatening illness vs. not risking a life-threatening illness. The latter categorical representation is more likely to cue a categorical gist principle such as “it only takes once,” so that unprotected sex would be avoided (Mills et al., 2008; Reyna et al., 2011; Reyna & Mills, 2014; Wilhelms et al., 2014).

Therefore, fuzzy-trace theory recognizes two distinct routes to unhealthy risk taking. One route is reactive and characterized by a failure to inhibit behavior, succumbing to emotion or temptation. This route is recognized in the dual-process approach of neurodevelopmental imbalance theories described above (although note that traditional dual-process theories associates this route with intuition and fuzzy-trace theory does not) and also in literature on affective and emotional aspects of risk, sometimes referred to as “risk-as-feelings” (Loewenstein, Weber, Hsee, & Welch, 2001; Weber & Johnson, 2009). Emphasized in fuzzy-trace theory, a second (and distinct) route to risk taking is the route described in the previous paragraph, a reasoned route characterized by reliance on verbatim rather than gist processing that is particularly important in groups such as adolescents who are disposed to rely more on verbatim processing, compared to typical adults (Reyna & Farley, 2006). This route involves relying on fine-grained distinctions regarding the degree of risk and amount of reward such that they compensate for one another—higher rewards compensate for higher risks (Reyna et al., 2011). Thus, the counterintuitive prediction of fuzzy-trace theory is that much adolescent risk taking is a result of reasoning rather than being reactive or impulsive, which has been supported by research in a variety of domains of risk taking.

Construal Level Theory

Another theory that provides insight into how mental representations can influence risk perception and risk taking is construal level theory. Construal level theory proposes that psychological distance changes the way that individuals represent objects and events (Trope & Liberman, 2003, 2010). Psychological distance refers to the removal of the object or event being considered from the person making the decision, distance in terms of time, space, social distance, or hypotheticality (Fujita, Henderson, Eng, Trope, & Liberman, 2006; Trope & Liberman, 2000, 2010; Wakslak, Trope, Liberman, & Alnoy, 2006). Hypotheticality (possible as opposed to actual events) is also related to probability or risk, as contrasted with certainty. According to construal level theory, objects or events at a greater psychological distance are more likely to be represented in terms of abstract features conveying the meaning of the object, event, or individual (high-level construals). In contrast, objects, events, or individuals at a smaller psychological distance are more likely to be represented in terms of concrete-specific details (low-level construals) (Trope & Liberman, 2003). For example, moving to a new house next week is likely to be described in terms of concrete, specific actions such as packing boxes, while moving next year would be described in more abstract, global terms such as a new phase of life (Bonner & Newell, 2008).

Work in this area has suggested that psychological distance can influence (and sometimes improve) decision making. For example, an increase in psychological distance has been shown to increase the weighting of central (as opposed to peripheral) features when individuals are making decisions (e.g., a central feature when evaluating a movie would be the quality of the featured film rather than the quality of the commercials; Trope & Liberman, 2000; Fukukura, Ferguson, & Fujita, 2013). Research has shown that this relationship between weighting central features and the quality of decision making is accounted for by gist memory for features, as defined in fuzzy-trace theory (see Fukukura et al., 2013; note that centrality is not sufficient to characterize gist, which has special memorial and reasoning properties; Reyna, 2012). Participants primed to think in a more abstract (psychologically distant) way had more gist memory for features of cell phones they were told about and subsequently made better decisions about which cell phones were the best. Importantly, memory for gist representations accounted fully for the relationship between psychological distance and decision quality (Fukukura et al., 2013).

Research has also examined the relationship between psychological distance and risk taking and has shown that construal level influences risk taking. Higher construal level leads to more risk taking behavior than a lower construal level (Lermer, Streicher, Sachs, Raue, & Frey, 2016; Raue, Streicher, Lermer, & Frey, 2014; Sagristano, Trope, & Liberman, 2002). For example, research on medical decision making has shown that framing risks associated with mononucleosis (a contagious viral infection) as occurring "every day" (e.g., 1 incident occurs every day) increased risk perception and reduced intentions to take risks compared to framing risks as occurring "every year" (e.g., 365 incidents occur every year), despite the fact that the risks are mathematically the same (Chandron & Menon, 2004). This effect has been explained by temporal immediacy—a more proximal risk (risks every day) seems more concrete, immediate, and threatening than a more distant risk (risks every year; see also Bonner & Newell, 2008).

Another study looking at the effect of construal level on risk used the Balloon Analog Risk Task (BART; in this task, participants accumulate money each time they pump air into a computerized balloon but lose the accumulated money if the balloon bursts; Lermer, Streicher, Sachs, Raue, & Frey, 2015). Participants were primed to think in an abstract or concrete way using categorization priming (adapted from Fujita et al., 2006); they were asked to name either a subordinate or a superordinate category for 30 items. Participants primed to think in a more abstract way took more risks than those who were primed to think in a concrete way. This influence of construal level on risk taking was shown to be mediated by game strategy, meaning whether a participant endorsed a strategy of "few pumps, consistent winnings of small amounts and little losses" more than a strategy of "many pumps, high gains but more losses." The difference between strategies was greater for concrete thinkers than for abstract thinkers, with abstract thinkers favoring the higher risk game strategy. This suggests that a concrete mind-set was linked to safer strategies (Lermer et al., 2015).

The importance of game strategy, such as "many pumps, high gains but more losses," suggests that construal level has an effect by influencing the gist that individuals rely on. These simple game strategies reflect bottom-line gist principles, rather than a focus on precise verbatim analysis (Reyna, 2008). Indeed, bursts in the BART usually occur randomly making it difficult to learn precise risk-reward payoffs. As initially indicated by Trope and Liberman (2003), studies suggest that a greater psychological distance promotes reliance on gist, although other evidence suggests that greater distance favors risk taking because risks seem distant (such as high gains but more losses), whereas a smaller psychological distance favors safe strategies because risks seem close (such as consistent winnings and little losses). Unfortunately, results from the BART are ultimately difficult to interpret because the task confounds a number of known determinants of risky decision making.

Explaining Developmental Findings in the Risk Taking Literature

In this part of the chapter, we consider findings in the risk taking literature and show how these findings can be explained by theories on cognitive aspects of risk. We focus on developmental trends in risk taking, which can provide insight into different cognitive components of decisions regarding risk. Recognizing the influence of mental representations, in addition to more traditional aspects of risk taking such as affect and inhibition, can predict and explain findings in the risk taking literature that are not explained by other theories.

Finding 1: Adults Show More Standard Framing Effects than Adolescents in Risky-Choice Framing Tasks

Research has shown that adults shift risk preferences depending on superficial wording of options whereas adolescents do so to a lesser extent and sometimes show "reverse" framing effects (choosing the risky option in the gain frame and the sure option in the loss frame—the opposite of the standard framing effect) under predictable circumstances. For example, adults show the framing effect (picking the sure option in the gain frame and the risky option in the loss frame) to a greater extent than adolescents when options and expected values are equal (Reyna et al., 2011). Because options are numerically equivalent, this result suggests that adolescents are trading off risks and benefits (leading to the same decisions in gain and loss frames), whereas adults are more influenced by superficial differences in wording that imply a different gist. Research has also shown that adolescents who take more risks score lower on measures of gist thinking and higher on verbatim measures and also are less likely to showing standard framing effects, treating objectively equivalent options similarly (see Reyna et al., 2011; Reyna & Farley, 2006). Trading off risks and benefits, a deliberative rather than impulsive way of thinking, is associated with taking more risks and having poorer outcomes.

As noted above, the tendency to be risk seeking in the loss frame and risk averse in the gain frame is explained by prospect theory (Tversky & Kahneman, 1986). As also noted above, traditional dual-process theories have associated framing (and particularly within-subjects framing) with Type 1 processing. However, these traditional theories do not explain numerous effects predicted by fuzzy-trace theory (e.g., see Kühberger & Tanner, 2010; Reyna & Brainerd, 1995), such as developmental reversals that have been shown in framing effects—specifically children and adolescents are less susceptible to framing bias than adults (Reyna et al., 2011), and less-experienced risky decision-makers are less susceptible to framing bias than experts in the experts area of expertise (e.g., experts in making risky decisions such as intelligence agents have been shown to be more susceptible to framing bias than controls; Reyna et al., 2014).

Fuzzy-trace theory a priori predicts and explains framing effects and also developmental reversals in framing effects (e.g., Reyna & Ellis, 1994). Consider the risky-choice framing problem described above: in the gain frame, a decision-maker must choose between gaining $5,000 for sure or a 50% chance of winning $10,000 and a 50% chance of winning nothing. In the loss frame, a decision-maker is given $10,000 and must choose between losing $5,000 for sure or taking a 50% chance of losing $10,000 and a 50% chance of losing nothing. Note that processing equal expected value (as happens when relying on literal objective numbers or verbatim processing) in each problem leads to indifference ($5,000 vs. $5,000). In contrast, reliance on gist leads to differing preferences between the two frames (Kühberger & Tanner, 2010). In the gain frame, the gist of the choice is definitely winning some money (choice a) or possibly winning no money (choice b), as the choices are boiled down to their simplest gist (something vs. nothing). This leads to a preference for the sure option (option a), as definitely winning money is preferable to possibly winning no money. In the loss frame, the gist is a choice between definitely losing some money (option a) and possibly losing no money (option b), as again the choices are boiled down to their simplest gist (something vs. nothing). This leads to the standard framing effect—a preference for the risky option (option b) as possibly losing no money is better than definitely losing some money.

Research has shown that adolescents show reverse framing effects when outcomes are large and, hence, differences between outcomes are large (Reyna et al., 2011; Reyna & Ellis, 1994; Reyna & Farley, 2006). This result is important theoretically and must be explained by any theory of risk preference. Literal or verbatim processing does not, by itself, produce reverse framing effects. Verbatim processing produces indifference between literally equivalent options as found in young children (Reyna & Ellis, 1994). Research suggests that it is the combination of both verbatim processing and reward sensitivity (and consequent focus on large differences in outcomes) that produces reverse framing (Reyna et al., 2011). Thus, according to fuzzy-trace theory and confirmed by empirical findings, reverse framing effects occur when people pay more attention to precise numerical differences in risks and rewards and, also, when they especially value reward (e.g., preferring a possible $10,000 over a sure $5,000 and a sure loss of $5,000 over a possible loss of $10,000). Verbatim processing and reward sensitivity, then, promote choosing the risky option (win $10,000) in the gain frame and the sure option (lose $5,000) in the loss frame. Corroborating this explanation, emphasizing the categorical nature of a framing decision increases framing effects, whereas emphasizing numerical comparisons eliminates framing effects (Kühberger & Tanner, 2010).

By including a discrete role of mental representation relied on (gist/verbatim), we can understand the development of the standard framing effect from adolescence to adulthood, but without recognizing the role of mental representation, we cannot explain the transition from no-framing effect in childhood to the reverse framing effect to the standard framing effect in adulthood. Importantly, research has shown that framing responses in risky-choice framing laboratory tasks are predictive of real-life risk taking, such as decisions to engage in unprotected sex (e.g., Reyna et al., 2011).

Finding 2: Adolescents Take Fewer Risks than Children When a Diagnostic Task Is Used (a Sure/Safe Option Is Included)

A recent meta-analysis showed that adolescents took fewer risks than children on tasks with a sure/safe option versus a risky option with the possibility of a 0 outcome (such as $5,000 for sure or 50% chance of $10,000, when $5,000 for sure is the sure/safe option; Defoe et al., 2015). This task is crucial because it allows respondents who rely on simple categorical gist to choose an option based on that strategy (Reyna et al., 2011). Other risky decision making tasks make it impossible to use gist to make a choice by eliminating categorical contrasts between options, forcing responding based on verbatim distinctions (even individuals who generally rely on gist will not be able to do so where reliance on gist does not provide a distinction between options). Therefore, tasks with options that contrast winning some money versus winning none are able to *diagnose* the use of a categorical gist strategy. Fuzzy-trace theory also makes clear predictions when two risky options are presented (i.e., two gambles), namely, that people ratchet up their level of precision in order to discriminate the options (see Reyna, 2012).

Prospect theory is not a developmental theory (so makes no prediction), and traditional dual-process theories do not predict this pivotal finding that children take more risks than adolescents when a diagnostic task is used. However, by accounting for a role of mental representations, fuzzy-trace theory can predict and explain this finding. As noted above, according to fuzzy-trace theory, reliance on gist-based representations increases with age and experience (Reyna et al., 2014). When a task has a sure/safe option and a risky option with the possibility of a 0 outcome (e.g., no money won, or no lives saved), the gist of the decision at the simplest level is no risk versus some risk (promoting reliance on the sure/safe option). When a task has two risky options (both of which have the possibility of a 0 outcome), the simplest level of gist is some risk versus some risk. Here, the simplest level of gist will not provide a choice between the two options, and so individuals have to rely on more precise representations. This is because the simplest gist will be something vs. something, forcing reliance on more fine-grained distinctions to make a decision. So, when the decision is between $5,000 and a 50% chance of $10,000, reliance on the simplest gist (something vs. something or nothing) leads to preference for the sure option, whereas reliance on verbatim ($5,000 vs. $5,000) leads to indifference. This means that increasing reliance on gist (as occurs with age according to fuzzy-trace theory) would be expected to influence individuals only in tasks with a sure/safe option (as compared to two risky options), as appears to be the case from the recent meta-analysis. Traditional dual-process theories do not predict or explain this result. Imbalance models in particular, which predict a general increase in risk taking from childhood to adolescence due to neurobiological developments, do not explain this finding, which is the opposite developmental difference.

Finding 3: Adolescents Trade-Off Risks and Benefits More than Adults in Real Life but Have Poorer Outcomes

One seemingly paradoxical finding in the risk taking literature is that adolescents trade off risks and benefit more than adults in real life (see Reyna et al., 2011; Reyna & Farley, 2006), but have poorer outcomes, for example, they are prone to unhealthy risk taking such as participation in crime, reckless driving, and unprotected sex (Figner &

Weber, 2011; Reyna et al., 2012). Traditional dual-process theories cannot explain this, as these theories suggest that a risks and benefits analysis (Type 2 thinking) should have a protective effect against unhealthy risk taking by promoting careful consideration and accurate analysis of risks (Evans & Stanovich, 2013; Steinberg, 2008).

Fuzzy-trace theory explains this effect, because although gist processing can lead to predictable violations of coherence criteria of rationality (though this effect is mitigated when expected values actually differ), it is also predicted to have a protective effect against unhealthy risk taking in the real world. This is because in the real world, many unhealthy risks are taken when the risks are low and the benefits are high, and so a direct trade-off of risk and reward leads to risk taking. For example, the risks of getting HIV from unprotected sex are low, and the benefits may be seen as high, and the risks of getting caught for committing a crime are often low, but the benefits can be high. In these cases, direct trading-off of risk and reward (verbatim processing) is predicted to increase unhealthy risk taking. In contrast, someone relying on simpler, meaning-based categorical distinctions would see the decision as one between no risk of a bad outcome and a benefit with some risk of a bad outcome. When this bad outcome was particularly serious (such as HIV or a criminal record), a person relying on this gist would be likely to pick no risk of the bad outcome rather than some risk of the bad outcome, despite potential benefits (Reyna & Mills, 2014).

Therefore, fuzzy-trace theory predicts greater levels of unhealthy risk taking in individuals relying on verbatim processing, and less unhealthy risk taking in individuals relying on gist processing. Research has confirmed this prediction by showing that reliance on simpler levels of gist (simpler, more categorical distinctions, as opposed to fine-grained distinctions) increasingly has a protective effect against risk taking (this means that cognitively we would expect children to take the most risks absent other confounding factors, which is what is seen in laboratory experiments; see Defoe et al., 2015; Mills et al., 2008). One study gave adolescents alternative measures of risk perception that differed in cue specificity and response format. Measures that emphasized verbatim retrieval and cued fine-grained verbatim processing produced positive correlations between perceived risk and risky behavior (higher risk perceptions were associated with more risk taking). In contrast, measures that assessed gist-based judgments of risk and cued gist processing produced a negative correlation between risk and risky behavior (higher risk perceptions were associated with less risk taking). Endorsement of simple gist values and principles (such as "no risk is better than some risk") provided the greatest protection against risk taking (Mills et al., 2008). In addition, the simpler a gist principle was, the greater its protective effect against risk taking—when looking at one type of unhealthy risk taking in adolescents, initiation of sex (a risky behavior in adolescents due to the risks of negative outcomes such as sexually transmitted infections or unintended pregnancy), adolescents who endorsed an ordinal principle ("less risk is better than more risk") were more than twice as likely to take risks than those who endorsed a categorical principle ("no risk is better than some risk") (Mills et al., 2008).

This reliance on either gist or verbatim processing has been shown to have a discrete influence on risky decision making and has an effect even when controlling for inhibition and motivational or affective factors such as reward sensitivity. For example, Reyna et al. (2011) showed that verbatim- and gist-based processing when making decisions about risk predicted risk taking beyond what was predicted by traits commonly associated with risk taking (or risk avoidance) such as sensation seeking (seeking sensory pleasure and excitement) and behavioral activation (moving toward something that is desired), representing affective factors, and inhibition. Importantly, gist or verbatim processing was the most consistent predictor of real-life risk taking—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, and intentions to have sex and numbers of partners increased when verbatim-based reasoning was triggered by different retrieval cues in questions about perceived risk (Reyna et al., 2011).

The protective effect of gist processing has also been shown in the context of juvenile crime. One study looked at delinquent 18-year-olds and compared them to nondelinquent 18-year-olds and an older nondelinquent sample. Framing tasks were used to assess participants' reliance on gist or verbatim representations. Consistent with the predictions of fuzzy-trace theory, there was a developmental trend from delinquent 18-year-olds (who had broken the law and were involved in an alternative to incarceration program) who showed the least standard framing effects, to nondelinquent 18-year-olds who showed an intermediate level of standard framing effects, to older nondelinquents who showed the strongest standard framing effects (indicating the most reliance on gist; Helm, Reyna, Corbin, Wilhelms, & Weldon, 2014). These results support the prediction that reliance on gist-based representations is associated with a mature, healthy approach to risk taking.

Finally, the relationship between gist processing and risk can be seen in the effect that endorsing certain gist representations has on risk taking. It has been shown that teaching and emphasizing gist representations can reduce unhealthy risk taking. For example, this teaching has been used to successfully reduce sexual risk taking by delivering interventions giving simple gist facts (e.g., unintended pregnancy is virtually certain to occur if unprotected sex is engaged in repeatedly over time), in addition to more complex verbatim information (e.g., 90% risk of pregnancy after a year of unprotected sex), producing sustained effects on behavioral outcomes and psychosocial mediators of adolescent risk taking (Reyna & Mills, 2014).

Finding 4: Errors that Go Beyond Representations: Other Processing and Retrieval "Errors" When Making Risky Decisions

As noted above, traditional dual-process theories associate biases in risk preference with Type 1 processing (Evans & Stanovich, 2013). Fuzzy-trace theory provides a different explanation of biases in risk preference. According to fuzzy-trace theory, framing effects occur due to cognitive representations of sure and risky options (as described above). This is one explanation of why adults have seemingly "irrational" risk preferences, but this is not the only reason. Biases in risk preference and decision making can occur at other stages of the decision making process—for example, the processing of information. Errors in reasoning about risk can arise as a result of processing interference resulting in base rate neglect. For example, overlapping classes involved in a decision can cause processing interference which can lead to biases in risk preference. For example, when people are asked to make a judgment about the likelihood of a patient having a disease given a positive test result, e.g., when 80% of people with a positive test result have the disease, 80% of people with a negative test result do not have the disease, and 10% of people in the entire population have the disease. Here, there are overlapping classes (e.g., people with the disease and people with a positive test result). Reasoners focus on target members of a class and lose track of the larger universe of possibilities. This applies to judgments of risk that involve a target class of events (e.g., patients who have a disease) and a larger class of events including both targets and nontargets (e.g., the patients with a positive test result). Here, people compare target and nontarget events (e.g., people who had a disease and people who did not have a disease) and automatically extract the gist of which class of events is "bigger." As noted earlier, people pay less attention to the more inclusive class, which is the denominator in the calculation of risk (e.g., the rate of the disease in the entire population). This phenomenon is a type of denominator neglect (ignoring the base rate and focusing on the numerator). This type of confusion is illustrated through the widespread misunderstanding of genetic risks. For example, people often confuse the probability of a woman developing breast cancer if she has BRCA1 or BRCA2 gene mutations[1] (which is a high probability) with the probability of a woman with breast cancer having BRCA1 or BRCA2 mutations (which is a low probability as a relatively large number of women have breast cancer and these women rarely have one of these gene mutations). Denominator neglect and simultaneous focus on the relative gist of numerators lead people to think that the latter probability is higher than it is (Reyna, Lloyd, & Whalen, 2001; Wolfe & Reyna, 2010; see Wolfe et al., 2015 for a fuzzy-trace theory-based intervention that eliminates denominator neglect using icons).

Similar processing errors also occur when evaluating other risks. For example, if people are told that in a given year children had 20 accidents playing on slides and 5 on swings, many of them will conclude that slides are riskier than swings, ignoring the fact that more children may play on slides (Brainerd & Reyna, 2005). The probability that children were on certain equipment given that they had an accident is confused with the probability that they had an accident given that they were on certain equipment. In fact, the frequency of accidents on a certain type of equipment could be higher because children played on that equipment more often. Research has shown that these processing errors are made even late in development and can

[1] BRCA stands for *br*east *ca*ncer susceptibility gene. People who have BRCA1 or BRCA 2 gene mutations have a greatly increased risk of breast cancer and (for women) ovarian cancer.

be easily remedied by keeping classes of events clearly distinct, for example, by using visual aids that clearly show the numbers in each class (Reyna, 2004; Reyna et al., 2001; Wolfe & Reyna, 2010).

Neuroscience of Risk

As discussed above, recognizing an influence of mental representation (specifically gist or verbatim) on decisions regarding risk predicts and explains many findings in the literature on risk. Mental representation of information has an effect on risk taking, independent of concepts traditionally associated with risk such as affective motivational factors (including sensitivity to reward) and inhibition. Research has begun to identify neural substrates of each of these constructs, helping us to understand risk taking in the brain. This research provides support for the hypothesis that cognitive representation of information has an influence separate from that of affect and inhibition, since different areas of the brain have been associated with each construct.

Reward Sensitivity

The most important affective/motivational factor when considering risky decisions is sensitivity to reward. The reward circuit of the brain consists of the midbrain dopamine areas (the ventral tegmental area and substantia nigra) and the basal ganglia structures they project to (the ventral striatum, the dorsal striatum, and the ventromedial prefrontal cortex (vmPFC)). Dopaminergic activity in these areas has been linked to current and anticipated rewards. Specifically, increased dopamine in the striatum is associated with anticipation of a reward (Glimcher, Camerer, Fehr, & Poldrack, 2009).

Studies have shown that reward sensitivity is somewhat generalizable across stimuli, so, for example, an individual who is sensitive to monetary rewards is likely to also be sensitive to social rewards or food rewards (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Levy & Glimcher, 2011). This "common currency" can also be seen in the brain, where common areas of neural activation (vmPFC and the dorsal striatim) have been shown to vary with reward valuations across domains (Levy & Glimcher, 2011). However, research suggests there are also discrete neural networks that respond to particular rewards. For example, the dorsal hypothalamic region has been shown to respond mainly to food rewards, whereas the posterior cingulate cortex has been shown to respond mainly to monetary rewards (Levy & Glimcher, 2011) (for a more detailed review of the literature regarding neural correlates of sensitivity to reward, see Reyna & Huettel, 2014).

Inhibitory Mechanisms

Activity in the dorsolateral prefrontal cortex (dlPFC) and anterior cingulate cortex (ACC) has been shown to activate with self-control and healthy behaviors, suggesting that they are involved when an individual avoids unhealthy risk taking (Casey et al., 2011; Hare, Camerer, & Rangel, 2009). This activity can be manifested as response inhibition, cognitive distraction (distancing), or reappraisal of the meaning of a stimulus (Ochsner & Gross, 2008; Venkatramen & Huettel, 2012). The dlPFC modulates the value signal encoded in the ventromedial PFC (vmPFC) (and other reward areas described below), and dlPFC activity is correlated with successful self-control (e.g., in go/no-go tasks (Casey et al., 2011) or when choosing healthy foods (Hare et al., 2009)). A recent electroencephalogram (EEG) study showed that people with higher dlPFC activity during resting state took fewer risks during a gambling task, suggesting that the dlPFC is involved in exercising self-control and avoidance of risk (Gianotti et al., 2009).

Mental Representations and Gist Processing

Memory studies and studies of decision making have provided insight into the neural substrates of gist and verbatim processing. These studies have provided insight into the brain regions associated with gist and verbatim processing and have also identified differences in functional connectivity depending on whether an individual is relying on gist or verbatim processing (see Reyna & Huettel, 2014).

One way to distinguish between gist and verbatim processing in the brain is to use tasks in which gist and verbatim strategies lead to different choices and measure activation in the brain while participants make these choices. For example, Venkatraman, Payne, Bettman, Luce, and Huettel (2009) explored the use of verbatim strategies (trading off risk and reward) versus gist strategies (categorical some/none thinking) using a risky-choice gambling task. They presented subjects with a series of five outcome gambles containing gain and loss outcomes (probabilities are shown in parentheses), such as \$80 (0.2), \$40 (0.25), \$0 (0.2), −\$25 (0.15), and -\$70(0.2). Subjects could improve the gambles, for example, by adding \$15 to either the \$0 outcome (so it became \$15) or the -\$70 outcome (so it became -\$55). Venkatramen and colleagues assessed three strategies: increasing the magnitude of the highest gain (Gmax), decreasing the magnitude of the worst loss (Lmin), or improving the probability of winning something by adding to the \$0 outcome (Pmax). The only strategy that created a simple categorical difference between the options was the Pmax strategy (this strategy increased the chance of winning something versus winning nothing). The other two strategies (Gmax and Lmin) did not focus on the probability of winning something versus winning nothing, but instead focused on maximizing the magnitudes of potential gains or minimizing losses. Gmax (i.e., maximizing expected value or utility) and Lmin changed fine-grained distinctions but not categorical distinctions and therefore represent more verbatim processing. Therefore, this task made it possible to diagnose cognitive representations relied on by analyzing the choices subjects made—subjects who used the Gmax or Lmin (adding to the maximum possible win or the maximum possible loss) strategies were likely to be relying on verbatim processing, and subjects who used the Pmax strategy (adding to the middle value and therefore maximizing the probability of winning *something*) were likely to be relying on gist processing.

In this study, Venkatraman et al. (2009) found that activation in the posterior parietal cortex and dlPFC predicted gist-based simplifying choices, whereas activation in the vmPFC and anterior insula predicted verbatim, analytical choices. Functional connectivity analysis showed positive correlation between the dorsomedial PFC (dmPFC) and the dlPFC for gist-based choices (simplifying strategies) and between the dmPFC and insula for verbatim-based choices (compensatory strategies). Areas associated with conflict (the ACC and dmPFC) showed increased activation when participants made choices that conflicted with their dominant strategy (e.g., when a participant who generally preferred a gist-based simplifying option made a compensatory choice). Further research should be carried out to confirm the relationship between these areas and different mental representations, in order to confirm and further explore these relationships.

Conclusions

Research into the cognitive aspects of risk can provide insight into how people make decisions regarding risks. Early work showed that risk preference did not just depend on expected utility for an individual by showing that superficial changes in the wording of questions regarding risk influenced people's decisions. Prospect theory provided a psychophysical explanation of inconsistent risk preferences, and traditional dual-process theories explored the types of cognitive processes involved in decisions relating to risk. Theories such as construal level theory and fuzzy-trace theory added to these traditional theories by identifying additional factors that are important in decisions to take risks—notably, how options are mentally represented. Recognition of mental representation as an important construct in risk taking helps to explain seemingly counterintuitive findings in the developmental literature, including findings suggesting that adolescents are more rational (in the sense of trading-off of rewards and risks), but are also more prone to unhealthy risk taking.

Some traditional dual-process accounts of risk taking focus on the relationship between impulsivity and inhibition/controlled deliberation. Other dual-process accounts emphasize distinctions between Type 1 processes which are generally automatic, fast, and intuitive and Type 2 processes which are generally slow, logical, and sequential (Casey & Caudle, 2013; Epstein, 1994; Evans & Stanovich, 2013; Kahneman, 2011; Steinberg, 2008). Fuzzy-trace theory goes beyond traditional dual-process accounts, incorporating the influences of affective/motivational factors (such as emotion and reward sensitivity) and inhibition, but predicting that risk taking is about more than the distinction between Type 1 and Type 2 thinking. While traditional dual-process theories suggest that reasoning is primarily Type 2 thinking, fuzzy-trace theory suggests that there is another type of reasoning—intuitive reasoning using gist representations. This intuitive reasoning is not associated with impulsivity. It is sophisticated and developmentally advanced. Specifically, this reasoning increases from childhood to adulthood and generally supports healthy decision making and is the natural tendency of most adults. Based on this important additional component, fuzzy-trace theory recognizes three constructs that are important in risk taking—hot motivational/affective factors such as reward sensitivity and emotion (similar to Type 1), cold metacognitive factors such as reflection and inhibition (similar to Type 2), and gist versus verbatim mental representations.

These three components work together when individuals make decisions about risk. The recognition of more impulsive vs. more deliberative thinking, but also an independent role of mental representations, means that fuzzy-trace theory recognizes two routes to risk taking. One route is the route recognized by traditional dual-process theories. It is reactive and characterized by impulsivity or a failure to inhibit behavior, succumbing to emotion or temptation (similar to Type 1 or socioemotional as in imbalance theory, but separating intuition as a distinct kind of thinking) (see Reyna et al., 2011; Reyna & Mills, 2014; Rivers et al., 2008; Steinberg, 2007). The other is a reasoned route characterized by more verbatim-based analysis (relying on surface-level information rather than bottom-line meaning), taking account of the degree of risk and amount of reward and doing so roughly multiplicatively (Reyna et al., 2011). Research suggests that the second route, based on the type of mental representation relied on (precise, surface-level verbatim, or simple meaningful gist), is a major source of adolescent risk taking (Reyna et al., 2011; Reyna & Farley, 2006). The important role of mental representations is also supported by work on construal level theory, which shows a direct influence of the way information is represented on decisions to take or avoid risks.

The recognition of the importance of mental representations allows fuzzy-trace theory to explain counterintuitive findings and trends in the risk taking literature. Specifically, through the distinction between gist and verbatim processing, fuzzy-trace theory predicts findings showing that reliance on precise representations decreases from adolescence to adulthood while risk taking also decreases, that consistency in gain/loss risk preference decreases from adolescence to adulthood while risk taking also decreases, and that reliance on gist can have a protective effect against risk taking.

These important distinctions can advance our understanding of how risk is represented in the brain. Research has suggested the neural underpinnings of reward sensitivity lie in the dopaminergic circuitry of the brain as well as the prefrontal cortex, and the neural underpinnings of inhibition are mainly in the dorsolateral prefrontal cortex and the anterior cingulate cortex. Research is now also providing insight into the areas of the brain that may be involved in capturing gist, suggesting that the posterior parietal cortex and prefrontal cortex may be important areas (Reyna & Huettel, 2014).

Overall, emerging research into the cognitive and neurobiological aspects of risk, including work on fuzzy-trace theory and construal level theory, suggests an important role of a representational component in risk preference and risk taking. This approach builds on prospect theory and traditional dual-process theories, but explains and predicts findings in the literature that cannot be explained through these traditional theories. This understanding of the cognitive aspects of risk can help promote healthy attitudes to risk through encouraging reliance on bottom-line meaning, rather than surface-level information.

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