·决策心理学专栏(Special Column for Decision-making Psychology)·

编者按：

模糊痕迹理论不仅为研究判断与决策行为提供了一个有效的分析模型，在法律、行为医学和公共健康等领域也有着广泛的应用前景。作为这一理论的开创者，Valerie Reyna 教授和她的团队合作者们应邀为本刊的决策心理学专栏撰写了专文，介绍人们对信息和线索的模糊处理如何影响记忆、推理、风险认知和决策。Reyna 教授现任康奈尔大学心理学系教授及人类神经科学研究所主任、行为经济学及决策研究中心共同主任。她还担任美国教育部特聘的资深研究顾问和美国心理科学杂志的副主编。

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An Overview of Judgment and Decision Making Research Through the Lens of Fuzzy Trace Theory

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Abstract: We present the basic tenets of fuzzy trace theory, a comprehensive theory of memory, judgment, and decision making that is grounded in research on how information is stored as knowledge, mentally represented, retrieved from storage, and processed. In doing so, we highlight how it is distinguished from traditional models of decision making in that gist reasoning plays a central role. The theory also distinguishes advanced intuition from primitive impulsivity. It predicts that different sorts of errors occur with respect to each component of judgment and decision making: background knowledge, representation, retrieval, and processing. Classic errors in the judgment and decision making literature, such as risky-choice framing and the conjunction fallacy, are accounted for by fuzzy trace theory and new results generated by the theory contradict traditional approaches. We also describe how developmental changes in brain and behavior offer crucial insight into adult cognitive processing. Research investigating brain and behavior in developing and special populations supports fuzzy trace theory's predictions about reliance on gist processing.

Key words: decision making; fuzzy trace theory; risk; rationality; neuroscience; development

We review fuzzy trace theory (FTT), a model of memory and decision making that deviates from the traditional dual-process models and argues that reasoning based on gist—intuitive, bottom-line meaning— underlies advanced cognition (Reyna, 2008a). We first present the basic tenets of FTT and highlight how it is distinguished from other traditional models of decision making in that gist reasoning plays a central role. We proceed by discussing powerful effects such as the framing effect (e.g., altering preferences based on superficial wording), the conjunction fallacy, and spontaneous false memories. Although all of these effects are interpreted as errors according traditional theories, they are predicted by FTT as adaptive byproducts of meaning-making. As we explore evidence from

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experiments with children, adolescents, older adults, and experts, we describe the patterns of these effects through development, noting an increase in specific errors with age that results from an increasing reliance on gist-based thinking posited by FTT. Evidence from experiments with special populations (e.g. those with Autism Spectrum Disorder or Attention Deficit Hyperactivity Disorder) lends further support to FTT by shedding light on how certain cognitive and neurological impairments often reflect deficits in gist processing that can be improved with gist-based interventions.

Specifically, in describing these effects, we demonstrate that a focus on the bottom-line meaning of information (e.g., “saving now means I will have more money later”) has the propensity to greatly improve the quality of decision making. While we do not argue that reliance on gist is always superior, qualitative gist-based processing tends to be at the root of advanced reasoning. More specifically, processing that relies less on exact details can produce better reasoning performance in many laboratory tasks across healthy and non-healthy populations, and has been found to translate to healthier real-world outcomes (e.g. Fraenkel et al., 2012; Reyna & Lloyd, 2006; Reyna & Mills, 2014; Wolfe et al., 2014). Risky decisions pervade our everyday lives, spanning domains of law, health and medicine, economics, and social relationships. “Should I get vaccinated for the flu even though I do not feel vulnerable? How much should I put toward personal savings in order to still maintain an active social life? Do I root for Argentina, an archrival, or Germany among a crowd of Argentina fanatics watching the World Cup finals?” While risks transpire in a variety of ways, risk preferences tend to correlate with one another, peak at similar ages, and even engage common neural circuits of risk and reward valuation (Jessor, 1991; Levy & Glimcher, 2011; Porcelli & Delgado, 2009; Reyna 2012b). Understanding risk preferences and how they are shaped by perceptions of reward is integral to analyzing real-life risk taking.

We begin by describing some of the basic theoretical principles that constitute FTT, and then briefly contrast it with some other traditional theories of reasoning and development. We then briefly describe the kinds of reasoning and judgment errors that are predicted by FTT and how they arise from different elements of reasoning: knowledge, representation, retrieval, and processing. Building off of these elements, we then explain how the theory predicts several canonical effects in the judgment and decision making literature, as well as some counterintuitive manipulations and developmental trends found in these effects. After describing the relationship between some of these developmental patterns and their neurobiological underpinnings, we conclude by describing some of the predicted effects FTT has for special populations, as well as some future research directions.

Fuzzy Trace Theory

FTT is a comprehensive theory of memory and reasoning that is grounded in research on how information is represented, retrieved, and processed. Drawing on research in the field of psycholinguistics, the theory makes a distinction between two kinds of memory representations, verbatim and gist (Reyna & Brainerd, 2011). Whereas verbatim memory captures precise detail of experiences, gist memory captures the bottom-line meaning, regardless of the exact details of the experience. Using these memory representations, the theory specifically describes how these processes change with development, expertise, and social context (Wilhelms, Corbin, & Reyna, 2014). Unlike other dual-process accounts of reasoning, FTT distinguishes intuition from impulsivity, and predicts that deliberative analytic reasoning is a frequent route to risk-taking, especially in adolescence (Reyna, Chapman, Dougherty, & Confrey, 2012).

This theory is based on four foundational principles (Rivers, Reyna, & Mills, 2008). The first principle is the proposition that information is encoded with varying levels of precision in multiple representations. These representations form a hierarchy from verbatim to gist, with verbatim representations preserving surface form and low-level details on one end of the continuum, and gist representations preserving the essential meaning at the other end. This continuum is roughly analogous to scales of measurement, with distinctions between exact numerical values, ordinal, and categorical distinctions.

The second principle on which this theory is based is that both gist and verbatim representations are encoded, stored, and retrieved independently and in parallel. Because these representations are processed independently (Reyna & Brainerd, 2011), it is possible for people to have distinct and even contradictory representations of the same experience or information. For example, this independence has been supported by research that reveals that accuracy of memory for frequencies (a verbatim representation) is independent of accuracy of reasoning in probability judgments (using gist representations; Reyna, 2012a; see also Reyna & Kiernan, 1994). Additionally, this independence allows for paradoxical effects in which risk judgments can differentially correlate either positively or negatively with risk taking, depending on whether the question cues either verbatim or gist representations (see below; Mills, Reyna, & Estrada, 2008, Reyna et al., 2011).

Third, FTT posits that adults exhibit a “fuzzy processing preference,” meaning that they tend to rely on the simplest gist necessary to complete a task. This preference has been used to explain other effects and biases, including the risky choice framing task (Kühberger & Tanner, 2010). Manipulating the common risky choice framing task to remove redundant information can differentially emphasize or deemphasize the meaningful (gist-based) distinctions between the two options, resulting in an increase or decrease in the framing effect, respectively, compared to the common form of the task (see below).

The final principle on which FTT is based is that there is an increase of the preference for reliance on gist representations with age and expertise (Reyna, Lloyd, & Brainerd, 2003; Wilhelms et al., 2014). From this principle, FTT introduces testable predictions which are in contrast to traditional dual-process theories that describe development as a progression from mainly emotional or mainly heuristic processing to deliberative and analytic processing (e.g., Evans & Stanovich, 2013). Among the findings supporting this principle are developmental reversals, or the increases of predicted biases and errors with age. These developmental reversals can be found in gist-based errors such as framing effects and spontaneous false memories, both of which increase with age (Brainerd, Reyna, & Zember, 2011; Reyna, Chick, Corbin, & Hsia, 2014; Reyna et al., 2011).

Contrasting FTT with traditional approaches

Many traditional theories in research on adult decision making—including the theory of reasoned action, the theory of planned behavior, prospect theory, and standard dual-process models—are largely consistent with the premise that individuals are best served by multiplicatively weighing risks and rewards in making choices (e.g., Fishbein, 2008, Reyna, 2008b). This ability to multiplicatively weigh outcomes by their probabilities is characterized as a function of deliberative intelligence in dual-process models of reasoning. Although there are a variety of theories that share common assumptions about trading off (for summaries, see Kahneman, 2003; Evans & Stanovich, 2013), many share a general delineation between “Type 1” and “Type 2” thinking, in which the former is automatic, fast, intuitive, and does not require working memory, whereas the latter is slow, sequential, and correlated with general intelligence. Many of these theories are default- interventionist, meaning that Type 2 thinking only operates if a need for override of Type 1 thinking is detected—as opposed to parallel processing of representations in FTT. Although dual-process accounts associate Type 1 processing both with mindless biased responding and practiced automaticity (e.g., Kahneman & Klein, 2009), this explanation that Type 1 processing is both primitive and advanced is strained (Wilhelms et al., 2014). Moreover, it does not account for the role of insight or educated intuition as FTT does (Hogarth, 2001).

Standard dual-process models make predictions regarding when Type 2 thinking will be associated with normative, unbiased responses and when it will not. Specifically, these models indicate that when success can be achieved through Type 1 thinking, measures of cognitive ability associated with Type 2 thinking will be unrelated to normative (ideal, unbiased) responses (Evans & Stanovich, 2013). This principle, however, does not predict the developmental reversals observed in framing and other tasks (e.g., Reyna et al., 2014). (The term *developmental reversal* describes a pattern in which younger or less experienced individuals outperform older or more experienced individuals and, as a result, show fewer cognitive biases; Reyna et al., 2014.) According to dual-process and developmental versions of dual- process theories, the basic cognitive abilities that are needed to process information to make decisions are developed by adolescence, and "the logical reasoning and basic information-processing abilities of 16-year-olds are comparable to those of adults" (Steinberg, 2008, p.80). Instead, differences between adolescents and adults in risk-taking are explained by differences in socioemotional processing, such as reward sensitivity, sensation seeking, self-control, emotionality, and impulsivity (e.g., Figner, Mackinlay, Wilkening, & Weber, 2009). Two broad neural circuits are used to describe these differences: arousal mechanisms that map onto Type 1 processing and develop and peak during adolescence, and cortical control mechanisms that map onto Type 2 processing and have not yet finished developing until adulthood (Wilhelms & Reyna, 2013).

Although FTT acknowledges that these differences in sensation seeking and cortical control exist between adolescents and adults, this story is fundamentally incomplete as it ignores the cognitive changes in representation that occur during those ages. Specifically, the increase in risk-taking observed in adolescence is not merely the result of impulsive reactivity, but also, paradoxically, the greater reliance on deliberative, analytic reasoning compared to adults (Reyna & Farley, 2006). Thus, adolescents are not merely more impulsive or emotional than adults—they are often more deliberative about their risk-taking (Reyna et al., 2011). Their insights into the gists of important or life-threatening decisions are not yet mature. Moreover, decisions made by adults and advanced experts are characterized more by the use of intuitive, bottom-line gist representations compared to adolescents and those with less knowledge and experience (Reyna & Lloyd, 2006). These foundational principles behind the development of gist and verbatim processing predict reasoning, judgment, and decision making in many domains, predicting counterintuitive effects.

Irrational Decision Making

The independent and parallel processing of gist and verbatim representations can explain why people behave in "irrational" ways that run counter to principles of logic, as well as violate standard theories of utility maximization. This section briefly discusses criteria for rationality, and describes how FTT predicts that different sorts of errors may occur with respect to each component of judgment and decision making: background knowledge, representation, retrieval, and processing. We then proceed to discuss canonical errors in the judgment and decision making literature such as risky-choice framing and the conjunction fallacy, and how FTT accounts for them beyond current theories of decision making. We also briefly describe how spontaneous false memories arise from reliance on gist. More specifically, we highlight how intuitive gist-based thinking may be at the root of these so-called errors and then review evidence in support of how such thinking may underlie advanced cognition.

Research in judgment and decision making has previously characterized judgments according to either coherence or correspondence criteria (Adam & Reyna, 2005). Coherence measures whether reasoning is internally consistent and in line with formal rules of logic and probability theory, for example, that the same consequences must be treated the same way (e.g, an 80% chance of survival from surgery must be treated the same way as a 20% chance of mortality; Gilovich, Griffin, & Kahneman, 2002). Decision makers are thought to be incoherent or irrational when, for example, their preferences change due to superficial wording changes (e.g., when gambles are posed as gains versus losses) that do not involve changes in meaning, as in the classic dreaded disease problem (Tversky & Kahneman, 1981). Correspondence criteria refer to accuracy of knowledge about real-world outcomes (e.g., the likelihood of cancer given a positive test result) and the resulting judgments (e.g., a positive/negative reaction to test result) that lead to the best possible outcomes (e.g., which treatment, if any, will lead to the highest quality of life; Reyna & Farley, 2006). In this view, people are said to be rational if they have accurate knowledge about outcomes such that a beneficial decision is made. Laboratory tasks often demonstrate observed effects that reflect *incoherent* judgments and decisions (Reyna et al., 2003).

FTT posits that reasoning is subject to errors at various stages: knowledge, representation, retrieval, and processing (see also Wilhelms, Reyna, Brust-Renck, Weldon, & Corbin, in press). The simplest possible errors stem from lacking the necessary knowledge to answer a given question and often arise when the knowledge needed to answer a question is domain-specific, such as whether females have a greater biological susceptibility to sexually transmitted infections (STI) than males (Reyna & Adam, 2003). In this case, medical professionals with the appropriate training are more likely to provide more accurate estimates than non-experts. Crucially, a lack of knowledge interferes with the ability to extract the necessary gist of information about risk perception (see Adam & Reyna, 2005).

Errors may also extend from the representation used to encode information, as FTT assumes that both verbatim and gist representations are created independently, an assumption that has been tested in numerous empirical tests (Reyna & Brainerd, 1995). For example, when asked about condom effectiveness for reducing the risk of contracting STIs, medical and health professionals underestimated the risk of contracting an STI and overestimated condom effectiveness (Reyna & Adam, 2003). Although medical professionals are aware that HPV and herpes simplex virus are transmitted through skin-to-skin contact, the gist of STIs is represented as fluid-borne illnesses and condoms as a physical barrier against them (e.g., Reyna, 1991). For this reason, FTT predicts that risk estimates of contracting an STI would be underestimated because atypical (HPV, herpes simplex virus) cases are not transmitted only via fluids; people fixate on the gist of condoms being a physical barrier against illness. The effectiveness of preventative methods (i.e. condoms and other barrier methods) conceived on the basis of the gist of risk (i.e. fluid-borne STIs) can therefore be overestimated (Reyna & Adam, 2003; Reyna, 2004).

Retrieval of relevant knowledge is another important factor for accurate reasoning and is influenced by how stored knowledge is cued for retrieval. That is, some descriptions may serve as better retrieval cues than others (Reyna et al., 2003). For instance, risk estimates that are too low result when people estimate the risk of death for a 20-year- old male given that 20 is a young age. However, when asked to estimate the risk of death for a 20- year-old male from violence, automobile accidents, disease, and all other causes, estimates tend to increase. Corroborating FTT, studies have shown that unpacking sentences to include exemplars causes people to retrieve information about those exemplars (e.g. that young males tend to have an increased risk of death from violence and accidents), reducing errors in risk estimation (Reyna & Adam, 2003).

While errors may occur in the three aforementioned stages of knowledge, representation, and retrieval, processing errors also comprise a large group of errors prevalent in judgment and decision making tasks. For example, class-inclusion confusion occurs when overlapping classes of events, objects, or people are mixed up. To illustrate, people often confuse the probability of a woman developing breast cancer if she has an associated genetic mutation with the probability of a woman having a genetic mutation if she already has breast cancer (Reyna, Lloyd, & Whalen, 2001). People focus on the joint event of having breast cancer and a genetic mutation. However, because they are confused about overlapping classes, they forget about the denominators. The first probability is the probability of the joint event given that she has the gene, whereas the second probability is the probability of the joint event given that she has breast cancer. Confusion about the overlapping classes causes denominators to be ignored (Reyna et al., 2003). Even if all the necessary information is available to them--and they are equipped with adequate knowledge, appropriate representation, and retrieval of stored knowledge--people still err during the mechanics of processing.

To review, errors that occur during the knowledge, representation, retrieval, and processing stages of reasoning affect decisions by way of alteration to the captured gist. Such errors can be evaluated by coherence and correspondence criteria to determine whether people behave rationally in laboratory tasks and real-life decisions alike. Specifically, coherence criteria gauge adherence to logical consistency while correspondence criteria include accuracy in knowledge about real-world outcomes and the quality of outcomes that are ultimately chosen. FTT explains violations of coherence as errors that occur during the reasoning process and predicts that they arise from an advanced form of intuitive, gist-based thinking that may subsequently affect correspondence in real-world decisions.

Canonical Examples

Now that we have introduced the different stages at which errors can occur, we discuss classic examples of errors that are predicted by a fuzzy-processing preference in decision making, probability judgment, and memory. We explore risky choice framing, class-inclusion problems (e.g., base-rate neglect and the conjunction fallacy), and recall/recognition problems as examples of tasks with real-world applications in which errors in reasoning are found. More specifically, we detail how gist-based thinking rests at their core, by demonstrating how theoretical manipulation of the tasks can produce counterintuitive results.

Framing. Risky choice framing is an exemplar violation of coherence with a growing body of evidence pointing to gist-based thinking as its source. Kahneman and Tversky were the first to provide evidence for a framing effect, showing that people change their risk preferences based on how choices are framed. For example, given the choice between a sure $100 or a gamble with ⅓ chance of winning $300 (and ⅔ chance of winning nothing), people tend to prefer the sure option. If the same problem is asked in terms of losing money when $300 are at stake (a choice between losing $200 for sure or a gamble with ⅔ chance of losing $300 and ⅓ chance of losing nothing), people prefer the gamble. More specifically, even though the outcomes are equivalent, the superficial wording of choices alters risk preferences. Prospect theory explains these effects by proposing that people weigh risks and rewards and experience loss aversion (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992). Kahneman & Tversky (1979) describe people's subjective value of rewards and losses according to a subjective value function in which losses are valued more steeply than gains. So, a loss of $10 hurts more than a gain of $10 feels good. This aversion to losses explains why people reject a sure loss and prefer to gamble instead (see Reyna & Brainerd, 2011 for a more detailed explanation).

The explanation of framing effects goes beyond prospect theory. Framing problems are critical tests of FTT predictions about gist and verbatim representations since, by virtue of equal expected value outcomes, the verbatim information should lead to indifference. According to FTT, people must therefore rely on the underlying gist representation to reach a decision: a decision that essentially boils down to choosing between "some money" versus "some money or no money." Once these gists are formed, people retrieve the appropriate values and apply them to the different gain and loss contexts. Unlike prospect theory, which explains framing decisions through the calculation of subjective values from the numeric information in the problem, FTT predicts that categorical differences between the options are encoded as gist representations, and that people decide based on the essential meaning rather than on verbatim expected values. Different manipulations that remove redundant information from the risky option in the framing task will enhance or attenuate framing effects. For instance, removing the first part of the option (e.g., removing "⅓ chance of winning $300" leaving "$100 for sure OR ⅔ chance of winning nothing") elicits the gist "some money" versus "no money" and is thought to increase the framing effect. Removing the latter part of the risky option (e.g., removing "⅔ chance of winning nothing" and leaving "$100 for sure OR ⅓ chance of winning $300") elicits the gist "some money" versus "some money" and may thus attenuate framing effects. In other words, FTT predicts that altering the superficial wording effectively alters the extracted bottom-line meaning, because any gains are better than zero, and any losses are worse than zero. In fact, it has been repeatedly found that the manipulation that emphasized the categorical gist differences results in larger framing effects, whereas the manipulation that removed the categorical distinction attenuates framing effects (Kühberger & Tanner, 2010, Reyna et al., 2014).

The framing problem is analogous to many real-life contexts, including disease prevention decisions such as the choice of whether to vaccinate for the flu. Prevention research has shown that people generally view their options as gist representations of the possible outcomes (Reyna, 2012b). As an example, the choices may be viewed as not vaccinating and feeling okay for sure versus vaccinating and risking possibly feeling okay (e.g., no symptoms or side effects) and possibly not feeling okay (e.g., symptoms or side effects; Reyna, 2008a). If the decision to vaccinate is framed as a choice between feeling okay or possibly not feeling okay, people tend to decide against vaccinating. However, when the status quo is altered such that people have the flu, analogous to the loss frame of a typical framing problem, the risky option now has upside potential and there is something to be gained--a chance of feeling okay when currently not feeling okay. Again, how choices are framed determines which gist representations are elicited and thus resulting decisions.

Base-rate neglect. Well-studied examples of processing incoherence can be found in class-inclusion errors that stem from the confusion of overlapping classes during processing. Denominator neglect is an umbrella term that encompasses reasoning distortions that can be traced back to processing interference (Reyna, 2004). We proceed by discussing common examples of denominator neglect, including base-rate neglect and conversion errors with conditional probabilities, after which we describe how the conjunction fallacy stands apart from typical class-inclusion errors and how FTT accounts for the distinction.

Base rate neglect occurs even when people are provided a base rate of events. For example, when told that the base rate probability of a disease is 10%, and the accuracy of a diagnostic test is 80% (i.e., 80% of the time when people have a disease, the test comes out positive), the probability that a person has the disease given a positive test is actually quite small (about 27%). The chance of disease is small because very few people have the disease. People often think that the probability is 80%. Similarly, if you are trying to decide if slides are dangerous, the number of child slide accidents means little without knowing how often children use slides (Reyna, 2004). Without the appropriate denominators, risk perceptions can be strongly distorted. Confusion of conditional probabilities is a form of denominator neglect, because only the denominators differ for discriminating the accuracy of the test (the probability that that the test is positive given the patient has the disease) from the positive predictive value of a test result (the probability the patient has the disease given that the test is positive). Physicians, healthcare professionals, health educators, and high school students, for example, all confused the conditional probability of a positive result given a disease with the conditional probability of having a disease given a positive test result (Reyna & Adam, 2003). In other words, people neglected denominators for each and tended to focus on the class of interest (the probability of having the disease given a positive test result) to answer the question.

Evidence for FTT's account of class-inclusion errors has been found by demonstrating the effectiveness of a theoretically-motivated intervention. Emphasizing the discrete classes and subset relations using Venn diagrams (or 2 × 2 tables for participants to fill out for themselves) drastically diminishes these errors (Lloyd & Reyna, 2001; Wolfe & Reyna, 2010). An example of such a table can be found in Figure 1. More specifically, these methods reduced the tendency for medical decision makers to act like error-prone, verbatim calculators when updating disease probabilities after testing. Rather, medical professionals trained to use visual aids to convey bottom-line meaning and to ignore exact probabilities by focusing on the relations among classes (e.g., "there are many women with positive test results, but few of them have the disease") made better probability estimates of disease than they did without the visual aids (Lloyd & Reyna, 2001, Brust-Renck, Royer, & Reyna, 2013). Because risk perception by lay people often hinges on how medical professionals convey risks, simple but effective theoretically- motivated interventions may help the general public to form appropriate gists.

		Test Diagnosis		
		Positive	Negative	Total
Actual Presence of Disease	Yes	8	2	10
	No	18	72	90
	Total	26	74	100

Figure 1 Example of 2 × 2 table separating classes to reduce probability judgment fallacies (adapted from Brust-Renck, Royer, & Reyna, 2013).

Conjunction fallacy. The conjunction fallacy is another phenomenon that can also be interpreted in terms of FTT as an error due to class-inclusion confusions and misleading gists (Reyna & Brainerd, 2008). When participants were presented with a short description of "Linda the bank teller," they were asked to rate the likelihood that Linda was a bank teller along with the likelihood that Linda was a bank teller and was active in the feminist movement (Tversky & Kahneman, 1983). Most people judged the conjunction of Linda as a feminist and a bank teller as more probable than Linda as a bank teller, alone. The Linda problem illustrates how, in certain circumstances, people are prone to conjunction fallacies, the belief that a co-occurrence of events is more probable than any of the individual events alone. Standard dual process proponents deem the conjunction fallacy a Type 1 error that results from relying on heuristics such as the representativeness heuristic to make decisions (Evans & Stanovich, 2013). That is, when cued with characteristics that would fit the common mold of a feminist, people relied on knowledge about a stereotype over logic for likelihood estimates. According to FTT, this is the result of processing interference (Wolfe & Reyna, 2010). Specifically, people commit a class-inclusion error, ignoring that "Linda the bank teller and feminist" is part of the more inclusive class, "Linda the bank teller" (Reyna et al., 2003).

People generally behave in similar ways even when tasks are performed in the laboratory or in real life (e.g. Fraenkel et al., 2012; Galvan et al., 2006; Galvan, Hare, Voss, Glover, & Casey, 2007; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Parker & Fischhoff, 2005; Pleskac, 2008; Reyna & Mills, 2014; Stout, Rock, Campbell, Busemeyer, & Finn, 2005). When people were asked to estimate the risk of a 40-year-old male dying of HIV-AIDS in the next year and the risk of a 40-year-old male dying from HIV-AIDS linked to intravenous drug use in the next year, people tended to choose the latter as more probable (Adam & Reyna, 2005). Again, people relied on prior knowledge about how HIV-AIDS is contracted to form gist representations and ignored objective knowledge that the conjunction is less likely than the broader class. Conjunction errors thus illustrate how people tend to rely on gist during decision making.

False Memory. False memory is another phenomenon that results from a reliance on gist. Spontaneous false memories arise from an inclination to connect meaning across events along with a difficulty in using verbatim traces to detail those events (Reyna & Brainerd, 2011). The Deese-Roediger-McDermott (DRM) paradigm is a widely used test for false memory in which participants are given words to study that are all related to an intruding word, a non-presented "critical distractor" (Deese, 1959; Roediger & McDermott, 1995). To illustrate, a list composed of the words *thread, pin, eye, sewing, sharp, point, pricked, thimble, haystack, pain, hurt,* and *injection* would be used to test the association for the critical distractor *needle*. Hence the task measures the propensity for people to find semantic association between related words. When asked to recall or recognize the words that they did actually see, participants who include the non-presented distractor are said to display a spontaneous false memory for that item. For example, adults falsely recognized critical distractors, such as *needle*, frequently as part of the shown list (Brainerd, Reyna, Wright, & Mojardin, 2003). FTT predicts that adults will rely on the semantic gist, the knowledge about connections between words, to help them remember and/or recall the presented words as well as words that are consistent with the meaning of the presented words. Hence, false memory is another intelligent error that occurs due to gist-based thinking.

In sum, research on extensively studied errors such as framing effects, the conjunction fallacy, and false memory support the mechanisms delineated in fuzzy trace theory. Critically, many of these effects have also been demonstrated to increase with age and experience, correlating with an increased reliance on gist-based thinking (Reyna et al., 2011; Jacobs & Klaczynski, 2002; Brainerd et al., 2011). It is therefore important to consider how these effects increase with development in order to fully characterize these reasoning processes.

Reasoning and Development

As we have noted, FTT is unique among dual-process theories in predicting that intuitive reasoning develops with age and is generally beneficial (Reyna & Brainerd, 2011). According to the theory then, the progression from child to adolescent to adult consists of an increased focus on the meaning of information alongside concurrent gains in analytical processing capacities (e.g., the ability to calculate expected value or to engage in logical reasoning). Although analytical ability increases, the tendency to rely on this type of deliberative thought actually decreases in comparison to bottom-line gist-based mental representations and processing (Reyna et al., 2011). During the progression from middle age to older adulthood, gist-based processing remains intact, whereas verbatim memory processes decline (Brainerd, Reyna, Petersen, Smith, & Taub, 2011). The progression from novice to expert is another type of development that also consists of a shift from reliance on verbatim, superficial, detailed facts to an emphasis on patterns and meaning (Wilhelms et al., in press). These behavioral changes in gist and verbatim processing are mirrored by developmental changes in brain structure.

FTT draws support from counterintuitive findings about the patterns of certain cognitive biases and errors with development, which are predicted as the ironic output of cognitively advanced gist-based thinking. For example, FTT predicts that young children would show fewer meaning-based biases than do adults. Consistent with this prediction, Reyna and Ellis (1994) found that younger children (e.g. preschoolers) did not display risky choice framing effects; instead, they made decisions consistent with calculation of expected value of the options. By fifth grade, however, children began to display typical framing effects. During adolescence, people often display reverse framing (risk aversion in the loss frame and risk seeking in the gain frame), particularly when potential gains in risky options are extremely high (Reyna et al., 2011). This effect during adolescence is the result of both adolescents' increased reliance on verbatim processing and the increase in reward sensitivity that occurs during that age. These findings are surprising from the perspective of standard dual-process theories because such theories emphasize a progression from simplistic, associative, unreflective thinking to logical, deliberative, and fact-based thinking (Reyna, 2012a). In contrast, the findings are consistent with the FTT prediction that with age comes increasing reliance on gist-based processing, which is generally beneficial.

Developmental changes in risk behavior, which are associated with increases in gist processing, also support the FTT distinction between intuition as impulsivity and meaning-based intuition (Reyna, 2012a). Whereas standard dual-process models explain adolescent risk taking as the result of an imbalance between heightened reward sensitivity and underdeveloped cognitive control, FTT distinguishes among reward responsiveness, mental representations, and inhibition. In other words, FTT subsumes the dual-process explanation but also emphasizes the influence of mental representations on risk taking. For example, mental representations that emphasize reward magnitude should encourage risk taking when the riskier option contains the higher-magnitude reward. In risky choice framing problems, the risky option always has a higher possible payoff than the sure option in the gain frame when the sure and risky options are constrained to have equal expected value. Therefore a focus on maximizing reward magnitude encourages taking the risk. On the other hand, mental representations that emphasize bottom-line meaning should discourage risk taking. In this example, a categorical comparison of options in the gain frame suggests that winning something for sure is preferable to the possibility of winning nothing. Gist-based thinking, in this case, should protect against risk taking, and this has been supported in reviews of the literature, including both survey and experimental evidence (e.g. Reyna & Farley, 2006).

Reyna et al. (2011) phrased questions about perceived risk in a way that encouraged retrieval of either gist or verbatim memory traces in order to test these predictions. Consistent with their predictions, Reyna et al. found that intentions to have sex, sexual initiation, and number of partners increased with verbatim reasoning, but decreased with gist reasoning (e.g., endorsement of the statements "better to be safe than sorry" and "avoid risk"). Strikingly, although sensation seeking and inhibition were positively and negatively predictive of risk taking respectively, gist and verbatim reasoning predicted risk taking beyond the variance explained by sensation-seeking. Thus, despite the important influences of emotion and self-control on risk behavior (Steinberg, 2008), cognitive factors such as mental representation interact with these developing traits to play at least as important a role in shaping risky decision making (Chick & Reyna, 2012; Reyna & Brainerd, 2011). Therefore, impulsivity is not the only route to risk taking; instead, deliberation, ironically, also encourages risk taking (Reyna & Farley, 2006).

The FTT account of adolescent risk taking is also supported by the results of an intervention that trained adolescents to think about risky decisions involving sex, drugs and alcohol in a more bottom-line, gist-based manner (Reyna & Mills, 2014). A standard risk reduction curriculum was augmented by communicating the gist of messages about risk. Activities encouraged adolescents to distill information into categorical "bins of risk" that they practiced mapping onto their own values. For example, the gist-enhanced version of the curriculum reframed the cumulative probability of unprotected sex as a categorical risk, since repeated episodes would almost certainly result in pregnancy, regardless of the relatively low risk of pregnancy during a single episode of unprotected sex. However, the low risk of pregnancy was acknowledged as part of the curriculum.

Compared to adolescents who completed the standard curriculum, those who completed the gist-enhanced version of the curriculum were more likely to perceive risks categorically (e.g., it only takes once to get HIV/AIDS), which lowered their risky behavior. Adolescents who received the gist-enhanced version were also better able to recognize warning signals of imminent risk, such as being alone with a significant other in dim lighting, and were also more likely to categorize these risks as low-versus high-danger. In addition, those who completed the gist-enhanced curriculum were more likely to delay the initiation of sex and to report fewer sexual partners. Crucially, although the gist-enhanced curriculum increased gist-based perceptions of risk, participants' verbatim knowledge of those same facts about risks, such as the quantitative risk of getting an STD from a single episode of unprotected sex, was similar to that of participants in the unmodified control curriculum. These results contradict the standard dual-process assumption that increasing knowledge within a risk-reward tradeoff framework (e.g., educating adolescents about the quantitative risk of getting pregnant or getting an STD) should decrease risk taking. The results support the FTT prediction that gist-based reasoning protects against risk, encompassing the influence of reward responsiveness. FTT emphasizes bottom-line representations of risk information that are stable in memory, and hence, easily recognized in novel situations and easily matched with personal values (e.g., the desire to complete an education before having children, see also Fujita & Han, 2009)

These data on behavioral changes from childhood to adolescence to adulthood are consistent with concurrent changes in brain structure and function. Grey matter is reduced from childhood to adulthood, presumably because unused synaptic connections are reduced in adolescence in a process called synaptic pruning (Berns, Moore, & Capra, 2009; Paus, Keshavan, & Giedd, 2008). Neuronal information transfer is further accelerated by increases in myelination, the neuronal insulation that speeds information transfer (Luna & Sweeney, 2004). These changes foster increases in processing efficiency (Giedd, 2004; Zielinski, Gennatas, Zhou, & Seeley, 2010), broadly consistent with the FTT assumptions that verbatim detail is typical of immature cognitive processing, whereas gist-based bottom-line thinking is advanced and develops with age and expertise (Reyna, 2012a).

Although FTT emphasizes cognitive processing in explaining developmental differences in risk taking, the theory also acknowledges the importance of other factors, including reward sensitivity and inhibition (Steinberg, 2008). Behaviorally, reward sensitivity peaks in adolescence, whereas inhibition linearly increases into adulthood (Reyna et al., 2011; Somerville, Jones, & Casey, 2010). These patterns are mirrored by curvilinear increases in brain activation of reward response regions (peaking in adolescence), in contrast to linear increases in activity reflecting maturity of the prefrontal cortex, which is associated with cognitive control functions (Galvan et al., 2006; Galvan, 2010; Van Leijenhorst, et al., 2010).

Just as FTT predicts that gist-based processing increases with age, the theory also predicts that gist-based processing increases with experience in a particular domain. Compared to novices, experts in a given field tend to process fewer pieces of information, but they are better able to select the most diagnostic facts and to see the pattern in a sea of facts (Reyna, 2008a). For example, Reyna and Lloyd (2006) asked experienced physicians and medical students to make admissions decisions for 9 hypothetical patients who differed in cardiac risk level. Compared to students, more experienced physicians processed fewer dimensions of information and relied more heavily on categorical all-or-none distinctions, yet their diagnoses were more accurate according to external correspondence criteria (i.e., national diagnostic guidelines). Thus, experts achieved better decisions based on less information. According to FTT, this is because experts are better able to “connect the dots” and find relevant patterns in the facts (Lloyd & Reyna, 2009; Reyna, 2008a).

To take another example, FTT also predicts that experts in the domain of risk (e.g., intelligence agents) would be more likely to process domain-relevant information in a bottom-line, gist-based manner. Consistent with this interpretation, Reyna et al. (2014) found that such experts (i.e., intelligence professionals trained to make decisions when lives or money are at stake) were more likely to show risky choice framing effects than were college students, and they were more confident about these “biased” decisions than were age-matched non-expert adults. Although this reliance on gist is generally beneficial in the field, as it facilitates drawing from experience-based intuition (Reyna, 2012a), it can also lead to seemingly irrational biases under specific circumstances, such as the framing task.

In summary, developmental changes in brain and behavior offer insight into adult cognitive processing. Intuition is advanced, and although relying on gist-based reasoning is generally beneficial, it can contribute to cognitive biases under predictable conditions. Cognitive development is characterized by a shift from relying on verbatim-based reasoning to relying on gist-based reasoning. This cognitive progression is mirrored by changes in brain structure, including synaptic pruning and increased myelination, both of which enhance integrative thinking according to FTT. These cognitive changes occur in addition to changes in reward circuitry. We now turn to studies with special populations that shed further light on cognitive and brain-related activity in support of gist-based thinking as an advanced form of reasoning.

Special Populations

Research with special populations (e.g., autism, aging, traumatic brain injury) also offers evidence in support of FTT. From a practical perspective, examining how predictions of FTT apply to mental representation, memory, and reasoning in special populations can offer insight into neurological disorders. From a theoretical perspective, research investigating brain and behavior abnormalities in clinical populations can be integral to informing FTT predictions about reliance on gist processing across development in typically-developing individuals.

Neurodevelopmental disorders are often characterized by cognitive, social, or personality differences. One example is autism spectrum disorder (ASD), a neurodevelopmental disorder in which there are deficits in global processing and a tendency to focus on the parts rather than the whole, a processing bias referred to as “weak central coherence” (Happé & Frith, 2006). Frith describes how people with ASD process information as “seeing the woods for the trees” – as engaging in local processing (focusing on the individual trees) rather than global processing (representing multiple trees as “woods”). For example, individuals with autism show more difficulty perceiving coherent motion (Bertone, Mottron, Jelenic, & Faubert, 2003) and reduced gestalt grouping (Brosnan, Scott, Fox, & Pye, 2004). FTT has drawn from gestalt theory, in particular the prediction that there is a distinction between productive thought (a type of thought that draws patterns and connections between parts of information, similar to gist processing) and non-productive thought (a type of thought that involves rote memorization but does not synthesize the information into a whole, similar to verbatim processing; Reyna, 2013; Wolfe & Reyna, 2010).

According to FTT, people with ASD have difficulty extracting the gist of information, a skill which requires integration of information, and rely more on verbatim processing, which in turn, leads to superior performance on tasks that require focus on detailed parts (see citations above; Reyna, 2013; Reyna & Brainerd, 2011). Individuals with autism are thus better at finding embedded figures in a visual paradigm (first reported by Shah & Frith, 1983), are less susceptible to visual illusions (Happé, 1996), and show superior discrimination learning for extremely confusable and complex patterns (Plaisted, O’Riordan, & Baron-Cohen, 1998). These effects are generally attributed to more objective and less context- dependent processing (see also Doherty, Campbell, Tsuji, & Phillips, 2010). People with ASD have also been shown to process metaphors and proverbs literally, demonstrating that difficulty in derive the underlying meaning (Dennis, Lazenby, & Lokyer, 2001; Rundblad & Annaz, 2010), while typically developing individuals interpret metaphors by deriving the gist (Reyna, 1996; Reyna & Kiernan, 1995).

FTT also predicts that these deficits in gist-based processing would lead to fewer cognitive biases in individuals with ASD. De Martino, Harrison, Knafo, Bird, and Dolan (2008) found that subjects with ASD showed smaller framing effects than control subjects. These findings are consistent with the FTT prediction that framing effects are driven by the categorical, gist-based representation of choices (Kühberger & Tanner, 2010; Reyna & Brainerd, 2011). Individuals with ASD also do not show other cognitive biases that typically develop with age such as the conjunction bias. Morsanyi, Handley, and Evans (2010) investigated performance on several conjunction fallacy tasks in typically developing adolescents and adolescents with autism. They found that adolescents with autism were less susceptible to the conjunction fallacy, a result that was not driven by misinterpretation of social cues (since the conjunction fallacy problems pertained to animals and objects rather than people).

Further, individuals with autism outperform controls on a false memory task. Typically developing individuals tend to relate similar distractors to the presented items, and therefore, mistakenly think that those distractors were actually presented (see earlier discussion about spontaneous false memories). Individuals with autism rely less on meaning and context for memory and rely on rote memorization, which results in fewer false memory intrusions (Beversdorf et al., 2000). These findings are consistent with FTT predictions that individuals who tend to engage in verbatim processing (e.g., young children) would not be as susceptible to the gist-based biases and heuristics (such as those mentioned above) that typically emerge with age in normally developing individuals (Reyna, 2013; Reyna & Brainerd, 2011).

Research on the neurobiology of autism suggests that neurological differences in the brains of people with ASD contribute to the observed differences in cognitive processing. Autism has been associated with greater local connectivity within brain regions, and researchers suggest that there may be functional and anatomical underconnectivity of long connections that may lead to the observed deficits in information integration (Just, Cherkassky, Keller, Kana, & Minshew, 2007; Just, Cherkassky, Keller, & Minshew, 2004). Barttfeld et al. (2011) found that people with ASD had weaker frontal-occipital (long-range) connectivity but stronger lateral-frontal (local) connectivity. Further, the authors found that this result varied as a function of the severity of ASD: short-range coherence increased and long-range coherence decreased as the severity of ASD increased. As mentioned, gray matter pruning (the reduction in gray matter, which is largely comprised of neuronal cell bodies) and increased myelination of axons are both hallmarks of neuromaturation in childhood and adolescence, and are thought to facilitate gist processing in typically developing individuals. Thus, differences in neural development observed in individuals with autism may be linked to the preference for verbatim processing.

Attention-deficit hyperactivity disorder (ADHD) is also characterized by a lower tendency to engage in gist processing. Gamino, Chapman, Hart, and Vanegas (2009) conducted a randomized control trial to test a program that specifically targeted gist-extraction skills in children with ADHD. This four-week long intensive Strategic Memory and Reasoning Training program involved nine to ten sessions focused on teaching ways to extract the gist from classroom courses, text, and internet material to optimize learning by thinking about the deeper-level meaning of information (rather than just rote memorization). The authors found that this gist-based intervention significantly improved gist-reasoning performance for those with ADHD, and that improvement was superior to results from interventions that focused on improving attention. Other studies have found that similar gist-based interventions improved performance on standardized testing among academically underperforming students (Chapman, Gamino, & Mudar, 2012; Gamino, Chapman, Hull, & Lyon, 2010). Therefore, just as verbatim processing can be cued (e.g., Mills et al., 2008), gist processing can also be facilitated and produces improved performance for children below a certain academic performance threshold. Other autism researchers have also found that cuing global processing can result in more gist-based processing in individuals with ASD (Happé & Frith, 2006).

Other examples of atypically developing brains include cases of traumatic brain injury. Gamino, Chapman, and Cook (2009) examined children and adolescents with moderate to severe traumatic brain injury one year post-injury to understand how brain injury affects gist-based and verbatim-based processing. They found that youth with traumatic brain injury tended to engage in verbatim processing as well as control subjects, showing comparable performance in recalling the details. However, the same subjects who suffered brain injury showed deficits in the ability to extract the bottom-line gist from the details as compared to control subjects. It should be noted that there were vast differences in the location of injury across subjects, but interestingly, the traumatic brain injury subjects still exhibited similar difficulties in grasping the gist.

It is important that we gain a theoretical understanding of information processing in typically developing individuals for many reasons. One important motivation is to extend this knowledge about mental representation and reasoning to special populations. In turn, research on special populations can help us understand how the healthy brain processes information.

Conclusions

To summarize, FTT predicts and explains judgment and decision making effects in hundreds of experiments. These tasks range from working memory and dual-task interference (memory for word sentences and narratives) to numerical cognition, risk perception, risk communication, and risky decision making. Although these effects are considered irrational biases in traditional theories, a perspective based in FTT would consider them to be the byproducts of an advanced adult cognition that emphasizes categorical differences. Because FTT proposes that both verbatim and gist processing increase with age from adolescence to adulthood, the prediction can be made that many adults will display intelligent errors in tasks that are driven by reliance on gist representations, such as framing tasks, conjunction fallacies, and spontaneous false memories in DRM lists. FTT differs from traditional dual process models of cognition which propose that more advanced thinking is characterized by deliberation and detail (Evans & Stanovich, 2013). Thus, it is important to understand developmental differences in order to understand the core constructs of decision making in adults. Additionally, evidence from studies with special populations, such as those with ASD or ADHD, reflects impairments with gist processing. The impairments can be improved by interventions that specifically target the formation of, and reliance on, gist representations.

Taken together, the evidence supports the proposition that adults, and especially experts, rely on bottom-line gist in making judgments and decisions. Focusing attention on healthy gist representations can greatly improve the quality of decisions. Although gist-reliance can produce systematic errors, focusing less on exact details and more on gist ultimately results in healthier real-world outcomes.

FTT predictions have been rigorously tested using behavioral and neuroscience techniques. In addition to laboratory studies, randomized experiments have shown that gist-based thinking can be induced in adolescents as well as adults for real-world decision making. In order to design effective interventions for risky decision making in youth, it is fundamental to achieve a clear understanding of the underlying mechanisms of decision making (for discussion, see Reyna & Huettel, 2014). Therefore, a logical step forward is to introduce neuroscience techniques to determine how the effectiveness of such behavioral interventions can be observed in the brain. Initial evidence suggests that different neural substrates may support different types of processing, gist-based versus verbatim-based (Reyna & Huettel, 2014). Further, brain networks involved in encoding of gist-based memories of information should show greater activation following a gist-based intervention. This work would complement previous studies that have demonstrated areas that are involved in true recollection (verbatim memory), such as the hippocampus and parts of the visual cortex (Dennis, Bowman, & Vandekar, 2014). There are also several studies that demonstrate activation in areas of the posterior parietal cortex and dorsolateral prefrontal cortex during a gist-based task (Venkatraman, Payne, Bettman, Luce, & Huettel, 2009). Together these prior studies provide evidence for a gist-verbatim memory distinction in the brain, laying the groundwork for a neuroscientific investigation of FTT predictions.

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判断与决策研究纵观：基于模糊痕迹理论的视角

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摘 要 模糊痕迹理论是用于解释记忆、判断与决策的综合性理论，该理论的提出和发展主要基于对信息存储、表征、提取和加工过程的研究。本文首先介绍了模糊痕迹理论的基本原则，在此基础上重点讨论了其要义(gist)如何发挥核心作用，使得模糊痕迹理论有别于其他传统的决策模型。该理论将高级直觉与原始冲动性进行了区分，并且预测决策误差来源于判断与决策的各种不同成分，如背景知识、信息表征、提取和加工过程等。模糊痕迹理论不仅可以解释诸如框架效应、合取谬误等传统决策与判断文献中常讨论的误差现象，同时基于该理论的研究还得到了一些与传统决策理论相悖的新发现。此外，对脑与行为如何发育性变化的研究为我们了解成人的认知过程提供了至关重要的新视角，这些对脑与行为的发育性研究和对特殊人群的研究结果也都支持了模糊痕迹理论对要义加工依赖的预测。

关键词 决策；模糊痕迹理论；风险；理性；神经科学；发展
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