Reyna, V. F., Rahimi-Golkhandan, S., Garavito, D. M., & Helm, R. K. (2017). The fuzzy-trace dual-process model. In W. De Neys (Ed.), *Dual process theory 2.0* (pp.82-99). London: Taylor & Francis.

6

THE FUZZY-TRACE DUAL PROCESS MODEL

Valerie F. Reyna, Shahin Rahimi-Golkhandan, David M. N. Garavito, and Rebecca K. Helm

Overview

In this chapter, we provide an overview of the basic tenets and empirical findings that are relevant to fuzzy-trace theory (FTT). FTT is part of a movement that involves rethinking the traditional dual process model that distinguishes intuition from deliberation, conserving its strengths but moving beyond it. Our framework allows reasoning, judgment, and decision-making to be understood in a new way that makes meaning central to cognition and places intuition – defined as meaningful gist-based thinking – at the apex of advanced cognition. However, the theory is not just a framework for new thinking. Rather, FTT encompasses findings generated from multiple perspectives, with the aim of bringing them together in a parsimonious and predictive theory. First, we discuss the assumptions of the theory, followed by critical tests of predictions and key differences from alternative approaches.

Tenets of fuzzy trace theory

FTT distinguishes *verbatim* representations of information that are literally similar to information as presented from gist representations of information – the essential meaning of that same information (Abadie, Waroquier, & Terrier, 2013; Reyna, 2012). FTT's verbatim–gist distinction was inspired by classic psycholinguistic findings, including those of Bransford and Franks (1971) and Clark and Clark (1977). However, FTT's assumptions about verbatim and gist representations and core predictions differ from those in classic psycholinguistics (Reyna, 2012). Bransford and Franks (and others) claimed that verbatim representations of the surface form of presented sentences (e.g., The ants ate the sweet jelly; the jelly was on the table.) are processed to extract gist representations of meaning (e.g., The ants ate the jelly on the table.) and then the verbatim surface form is discarded, such that actually presented sentences and gist-consistent inferences cannot be discriminated.

However, both the psycholinguistic assumptions about semantic abstraction and the findings of no discrimination were called into question (e.g., Alba & Hasher, 1983; Reyna, Corbin, Weldon, & Brainerd, 2016; Reyna & Kiernan, 1994). Sensitive tests showed that verbatim and gist representations were not related to one another; for example, forgetting of verbatim memories was not related to misrecognition of gist-based inferences as having been presented. Instead, verbatim and gist memories were stochastically independent, which means that recognizing the presented sentences had no relationship with misrecognizing the inferences. In addition, when recognition instructions were clarified by giving examples of gist-consistent inferences that should be *rejected*, people discriminated presented sentences from inferences – in contrast to Bransford and Franks' (1971) key result of no discrimination (e.g., Reyna & Kiernan, 1994).[1] Many other effects and re-analyses of data from multiple (skeptical) laboratories have confirmed FTT's assumptions about verbatim versus gist representations (e.g., Brainerd & Reyna, 1992). Thus, the use of the terms "verbatim" and "gist" does not involve merely recycling the same ideas used in earlier theories. Although there is some overlap in definitions, the assumptions and predictions of FTT differ substantially from those of earlier verbatim–gist conceptualizations (Reyna & Brainerd, 1995).

In FTT, each kind of mental representation generally supports a different kind of processing: gist representations tend to support "fuzzy" (imprecise) impressionistic, generally unconscious processing, whereas verbatim representations tend to support more precise processing (Kühberger & Tanner, 2010). The outputs of processing include recognition judgments, logical inferences, probability judgments, and risky choices, which are produced by applying verbatim and gist processing in parallel (Reyna & Brainerd, 1992). Other dual process theories do not make this verbatim–gist distinction the cornerstone of their approaches.

Mental representations of information are needed, regardless of whether reasoners use working memory to represent information that is written down (and currently visible) to solve a problem or whether they retrieve information from long-term memory to solve a problem. The inputs or stimulus – the premises of a logical argument, the numbers in a mathematical problem, or the options in a decision task – must be mentally represented in order to be operated on by the mind. FTT proposes that these mental representations are encoded from the stimulus in two roughly parallel streams: verbatim (precise words, numbers, pictures, etc.) and gist (imprecise meanings). Multiple gist representations of the same stimulus are routinely encoded that vary in precision, but only one may be used to answer the question at hand (Reyna, Lloyd, & Brainerd, 2003). Gist representations are not just imprecise in the sense that they are vague – they also distill the meaning of experience into its *essence*. Gist representations also reflect limitations in people's understanding, for example, representing stereotypes (De Neys & Vanderputte, 2011[2]).

Once encoded, representations of stimuli cue memorized operations or general principles that are applied to the encoded representations. An example of a general reasoning principle is "more frequent is more probable" (i.e., if two classes of events vary in their frequency of occurrence, whichever class is more frequent is more probable, all else being equal). Because of the encoding specificity property of retrieval (i.e., like cues like), precise verbatim representations tend to cue precise rote operations, and general gist representations tend to cue general principles (Reyna & Brainerd, 1995). By encoding specificity, we mean that recall is enhanced if the circumstances surrounding recall match that of encoding. That is, the form of the cue determines the form of the recalled memory: verbatim cues elicit verbatim memories, and gist cues elicit gist memories. Encoding, retrieval, and processing also proceed roughly in parallel and can cycle multiple times to produce a response.

For example, if asked what 2 multiplied by 8 equals, many adults retrieve a memorized rote response (the answer of 16) from long-term memory. This kind of "reasoning" corresponds to stimulus–response learning. At the same time, adults encode the approximate magnitude of the numbers, the gist: these are all pretty small numbers, compared to numbers like 100,000 (Reyna, Nelson, Han, & Dieckmann, 2009). If the task were choice, the gist of numbers such as 16 and 100,000 (small vs. large) might be sufficient to accomplish the task of choosing. For instance, a general principle, such as more money is better than less money, could be applied to a choice between $16 and $100,000, and $100,000 would be preferred without regard to the exact numerical difference. An exact response is required to the multiplication question, but a vague ordinal number sense is all that is needed for the choice task (Thompson & Siegler, 2010).

After a buffer task or delay after presentation of numbers, people might not remember verbatim numbers, but they usually remember the gist that the numbers were pretty small or that a presented fraction such as one-third was "less than half." When researchers contrive tasks that require exact numbers or precise wording to perform, the ability to use gist is constrained or eliminated, and such tasks do not necessarily reflect how people make judgments or decisions in the real world.

Even when adults have access to verbatim representations (i.e., they *remember* them) and perform numerical calculations, they nevertheless rely more on gist representations to *reason* in familiar domains. This is referred to as the "fuzzy-processing preference." For example, if 2 out of 7 patients are saved with Treatment A and 3 out of 5 patients are saved with Treatment B, the latter is preferred whether or not people calculate exact proportions (Furlan, Agnoli, & Reyna, 2016; Reyna & Brainerd, 1994). Similarly, many people prefer winning (a) $1 million for sure over (b) an 89% chance to win $1 million plus a 10% chance to win $5 million and 1% chance to win nothing (the "Allais" problem, so named because it was invented by Maurice Allais; Reyna & Brainerd, 2011). People prefer option (a) because they can rely on the simplest gist, even simpler than an ordinal distinction between small and large, to accomplish the task of choosing, which turns on the categorical possibility of receiving nothing in option (b). That is, the gist of the options boils down to winning (a lot of) money versus maybe winning nothing. This preference for the sure option frequently holds even for those who realize that option (b) is numerically superior to option (a); the gist trumps the verbatim representation (Reyna, 2012).

People are more likely to prefer the sure option when decision options are equivalent numerically compared with when they are not equivalent (i.e., one option is numerically superior), showing that both gist and verbatim representations of the options are processed (Reyna & Brainerd, 1995). Verbatim analysis (e.g., multiplying each probability by its outcome) reduces preferences for the sure option when options are not equivalent numerically (when the risky gamble is superior mathematically). However, as adults think more deeply and consider the *meaningful* distinctions between options, some are more likely to prefer the sure $1 million in the Allais problem noted earlier. One of the key aspects of the Allais problem is that it pits simple, meaningful gist distinctions against quantitative verbatim details, and many adults depend on the gist to make decisions.

We should point out that when we say "rely" on verbatim or gist representations, we do not imply that only those representations are encoded or processed. Research on FTT has shown that verbatim and multiple gist representations are encoded, but the default preference is typically the simplest gist that can accomplish the task (Reyna & Brainerd, 1995). The ability to accomplish the task is driven by the specificity of the required response, among other factors. Although most adults prefer gist, individual differences also have been shown to influence processing preferences (e.g., in aging or in autism; Reyna & Brainerd, 2011).

Important advantages of gist representations in reasoning are that they are imprecise, and thus fit many specific situations, and are meaningful and thus capture non-superficial conceptual relations (Reyna & Brainerd, 1995). For example, if 2 and 8 were the length in feet of the sides of a rectangle and a reasoner were asked to calculate the area of that rectangle, retrieving and applying the rote operation of length multiplied by width would yield the correct answer of 16 square feet (Wertheimer, 1982). However, if the figure were a parallelogram, the same rote formula would yield the wrong answer. Understanding why the formula for a rectangle generates the right answer facilitates successful transfer to the parallelogram problem.

Prior to FTT, Gestalt theorists studied reasoning and distinguished between thinking that was (a) non-productive, such as memorized operations that are rigid and do not transfer to new problems that differ superficially from previous learning (i.e., stimulus–response learning of the behaviorists), and (b) productive thinking that does transfer to novel problems because of deep conceptual understanding (Sternberg & Davidson, 1995). This distinction is echoed in FTT's verbatim–gist difference, although FTT contains assumptions not found in Gestalt theory, and many other aspects of Gestalt theory are not adopted in FTT. Thus, gist-based intuition in FTT is not associative processing (i.e., stimulus–stimulus or stimulus–response association) (cf. Sloman, 2002).

Surprisingly, many contemporary theories do not have mechanisms to account for near and far transfer (when superficial features of a "new" problem differ a little or a lot from old learning and yet reasoners apply the old learning). Critical empirical tests show that theories must include mechanisms for far transfer to explain such replicated effects as learning sets (e.g., specific features of a maze change, but maze-experienced subjects learn new mazes in a few trials), cognitive maps (e.g., subjects execute dissimilar responses to get to the same goal in a maze, such as swimming left rather than running right by using cognitive maps), transposition effects (e.g., subjects learn abstract relations among magnitudes and transfer this abstraction to new problems, rejecting options that match prior reinforced responses literally), comprehension of novel metaphors (e.g., subjects interpret expressions such as "Juliet is the sun" not as Juliet is literally hot and gaseous), and many other phenomena (Reyna & Brainerd, 1992, 1995). For these phenomena, the literal stimulus–response mappings of old learning do not apply to the new transfer situation, but successful reasoners rely on having meaningful insight into the gist of the concepts to solve new problems.

Meaningful insight into concepts does not necessarily imply insight into cognition itself, called "metacognition," which is a distinct construct in FTT (Liberali, Reyna, Furlan, Stein, & Pardo, 2012). Metacognition is, by definition, cognition about cognition and encompasses reflection about the processes or outputs of thinking (Evans & Stanovich, 2013). However, as demonstrated in research, a reasoner can understand the gist of concepts, such as probability or the area of a rectangle, without being able to articulate or be reflective about his or her understanding, which is recognized in FTT (Reyna & Mills, 2007). Moreover, detecting and inhibiting impulsive or inconsistent responses need not be conscious or effortful (Franssens & De Neys, 2009; Reyna & Mills, 2007) and may be linked to personality traits, such as behavioral inhibition and the need for cognition (Evans & Stanovich, 2013; Reyna et al., 2011).

People can exhibit biases in their reasoning under circumstances that do not prompt self-examination, but then engage in heightened monitoring, detection, and inhibition when their biases are more obvious (Reyna & Brainerd, 1994; Stanovich & West, 2008). For example, when the same information is framed in terms of gains and losses, but the framing difference is manipulated between subjects (i.e., each group receives a different frame), people show framing effects (e.g., greater risk seeking for losses than gains; see later). That framing effect is diminished when the gain and loss versions of the same information are presented to the same subjects. More generally, research on FTT has shown that monitoring and associated inhibition of compelling responses requires a parameter that is separate from parameters that capture verbatim and gist representations to adequately model memory, judgment, and decision-making (e.g., Brainerd, Reyna, & Howe, 2009; Reyna & Brainerd, 1998, 2011; Reyna & Mills, 2007).

In addition to representational distinctions and processes that inhibit impulsive or inconsistent responses, FTT integrates other building blocks of motivation (e.g., reward-seeking motivation), emotion (e.g., valence and arousal), and social/moral values (e.g., human lives should be saved) (Bookbinder & Brainerd, in press; Broniatowski, Hilyard, & Dredze, 2016; Reyna, Wilhelms, McCormick, & Weldon, 2015). Thus, although FTT began as a cognitive theory that focused on mental representations, it has grown to include concepts that translate mental representations into behavior that serves motivational, emotional, and social goals. The theory accomplishes this translation by assuming that cognitive representations combine with socioemotional and motivational factors to jointly determine behavior.

For example, how people mentally represent options interacts with their attraction to rewards (Reyna et al., 2011). The Allais problem mentioned earlier presents options that vary in both risk and reward. A verbatim analysis of the precise numbers highlights the tradeoff between risk and reward, the classical analysis of choice in economics: from this perspective, the certainty of a lower reward ($1 million) may be more than offset by a risky but potentially higher reward ($5 million). In addition, there are individual and developmental differences in sensitivity to reward (Casey, Galvan, & Somerville, 2016; Steinberg, 2008). Therefore, adolescents, who are more likely to emphasize verbatim representations and are more sensitive to rewards compared with adults, are more attracted to risky options with higher rewards (Reyna & Farley, 2006). Cognitive representations (verbatim and gist) and reward sensitivity have unique but synergistic effects (Reyna et al., 2011).

Both adolescents and adults encode verbatim and gist representations of decision options, but adults' fuzzy-processing preference for gist means that their preferences hinge on the simple contrast between some and none: receiving some money for sure as opposed to either receiving some money or no money. Because some money is valued over no money, adults tend to prefer the sure option. As the emphasis on gist processing increases with development, risky preferences for choices such as these decline, a developmental trend that supports FTT (for a meta-analysis, see Defoe, Dubas, Figner, & van Aken, 2014). As we discuss later, developmental differences in verbatim and gist processing contribute to critical tests of FTT's fundamental assumptions.

Findings and empirical tests

Early studies on FTT showed that children and adults encoded verbatim and gist representations of problem information in many paradigms (e.g., probability judgment, conservation, mental arithmetic, transitive inference, class-inclusion reasoning, etc.; Reyna & Brainerd, 1995). People used verbatim memory to answer immediate questions about exact details of the problem information and used gist memory to reason or make inferences even when the exact details were accessible. Reliance on simple gist occurred as long as problems could be solved that way, and many problems could be solved better with gist than with verbatim memory for myriad reasons (e.g., gist was more meaningful, flexible, and memorable).

For example, if presented with photos of 7 women and 3 men and asked whether there were more women or more people, comparing 7 to 3 turns out to be a bad idea; it is a source of the typical class-inclusion error of answering "more women." The better that reasoners remember 7 women and 3 men, the more they commit the error; taking away a display with this information improves reasoning because the exact number of women and men becomes hazy in memory. Then, rather than focus on the verbatim information that is salient in the display, reasoners think about the gist. The simple qualitative gist that women *are* people comes into focus, and the details about how many more women than men there are recedes. Adults do not commit this error very often, but their response time is long, and they will err systematically under speeded conditions, implying an inhibitory process.

This systematic class-inclusion error is not due mainly to linguistic ambiguity or misinterpretation, although some responses occur because "people" in the question is interpreted as "men." There are multiple arguments against linguistic ambiguity, but one is that reasoners commit the error after they are asked to count the women, men, and people out loud and they correctly count 7, 3, and 10, respectively. Thus, the problem is confusing not because of ambiguity – although reasoners are thinking of the relative number of women and men when they answer the question incorrectly. All problems that involve overlapping "vertical" (e.g., the hierarchical relationship between women and people) and "horizontal" (e.g., the relative magnitude relationship between women and men) class-inclusion relationships are confusing. Piaget's explanation for this reasoning error was a deficit in logical reasoning, and others have argued that working-memory limitations play a role; both explanations have been ruled out with careful experiments. For example, problems with a higher memory load – with more classes – were easier to solve than the standard class-inclusion problems when the classes did not overlap, although memory performance was lower under specific conditions (see Table 6.1). Similarly, increasing the number of premises in a transitive inference task (e.g., the green rod is longer than the orange rod, the orange rod is longer than the purple rod, and so on) decreases memory, but improves reasoning (the ability to infer that the purple rod is shorter

TABLE 6.1 Illustrative arrays for class inclusion problems

Type of problem					
One superordinate set	C C	S S	G G	D D	H H
	C C	S S	G G	D D	
	C C	S S	G G		
	C C	S S			
	C C				
Two superordinate sets	C C	H H		V V	P P
	C C			V V	P
	C C			V V	
	C C			V V	
				V	

Note. The problem at the top includes one superordinate set (C = cow, S = sheep, G = goat, D = dog, H = horse), and the one at the bottom includes two (C = cow, H = horse, V = violin, P = piano). The problems with a higher memory load – with more classes – were easier than the standard class-inclusion problems, but memory performance was worse under specific conditions (see Brainerd & Reyna, 1995).

than the green rod) because the pattern of decreasing length becomes more obvious (see Reyna & Brainerd, 1995). Moreover, in another empirical test of FTT, verbatim memory for the number of objects in each class was found to be stochastically independent of reasoning performance grounded in gist (e.g., the gist that women and men are people, so people are more; Reyna & Brainerd, 1995, 2008).

Applying FTT, similar explanations were advanced to explain conjunction fallacies (e.g., ranking Linda as more likely to be a feminist bank teller than to be a bank teller because of a compelling verbal description that evokes a stereotype of feminism; Tversky & Kahneman, 1983) as well as other logical reasoning errors that again involve overlapping classes, including disjunction fallacies, base-rate neglect, conversion errors in conditional probability judgments, and other class-inclusion confusions (Reyna, 2004). The argument that using frequencies (or counts) rather than probabilities reduces these fallacies turns out not to be true. Instead, the key to these fallacies are overlapping classes that confuse the reasoner along with a compelling gist that competes with the gist required by the question, thereby usurping reasoning. Therefore, a critical test of FTT's explanation is to eliminate overlapping classes to determine whether the fallacies are reduced or eliminated.

As a critical test, that segregation of classes can be accomplished by using Venn diagrams, placing distinctive tags (e.g., on all of the photos so that the number of tags may be compared to the number of women), or with 2 × 2 tables (e.g., so that estimates can be made separately for the classes of feminists who are bank tellers, bank tellers who are not feminists, those who are both, and those who are neither). The marginal totals can be easily computed, and base rates (e.g., the probability of being a bank teller) can be distinguished from conditional probabilities that have different marginal totals as denominators (e.g., the probability of being a feminist given that one is a bank teller vs. the probability of being a bank teller given that one is a feminist; Reyna & Brainerd, 1994, 2008). As shown in a series of experiments, these simple manipulations are effective in reducing or eliminating class-inclusion fallacies (e.g., Wolfe & Reyna, 2010). For example, it is readily apparent from a 2 ×2 table (which reasoners fill in with their own probability estimates about Linda) that the probability of being a bank teller who is a feminist and the probability of being a bank teller who is not a feminist add up to the total (marginal) probability of being a bank teller. Reasoners are not told the answers; they have the competence to reason logically and coherently once the classes are discrete (Reyna & Brainerd, 1994; Reyna et al., 2003).

Competence to reason logically has also been assessed by asking children and adults to make transitive inferences, also called linear syllogisms (e.g., Reyna et al., 2016). Children as young as 6 years old are able to make transitive inferences (e.g., Carmen is older than Ida) from presented premises, such as Carmen is older than Ben and Ben is older than Ida. Reyna and Kiernan (1994) presented such sentences (plus filler sentences) for many stories, administering gist-based reasoning tests to one group and verbatim-based recognition tests to another group both immediately and after a week's delay. On the gist-based test, people were asked to judge whether sentences were true or false, regardless of whether they were explicitly presented, *based on* what was presented. Judgments for presented sentences were positively related to judgments for true paraphrases and true inferences because all of these were based on the gist of presented sentences (statistical tests were likelihood ratios of conditional and unconditional probabilities that determine whether there is any dependency at all between pairs of presented and unpresented sentences within each story; Reyna & Kiernan, 1994). As also expected by FTT, there was little effect of delay on dependencies because judgments consistently drew on stable gist representations.

For the verbatim group, people made old-new recognition judgments, again to presented sentences, paraphrases of presented sentences (e.g., Ben is younger than Carmen), true and false inferences with presented wording (e.g., Carmen is older than Ida), and true and false inferences with novel wording (e.g., Ida is younger than Carmen). Consistent with FTT's predictions, on the immediate test, recognition of presented sentences (based on verbatim memory) was stochastically independent of misrecognition of true inferences (based on gist memory). Verbatim memory was not only not perfectly correlated with gist memory for any of the true sentences, it was also completely unrelated, just as verbatim and gist memory had been unrelated in earlier research on cognitive development. However, after a delay, when verbatim memory became inaccessible and gist memory dominated judgments of both presented and unpresented true sentences, previously independent sentences and inferences became positively dependent, just as in the gist (meaning) condition.

Other experiments showed that boosting verbatim memory for sentences in stories (through repetition, etc.) created negative dependency on immediate tests, as expected by FTT, because people said "yes" more often to presented sentences but "no" more often to true paraphrases and inferences; they used verbatim memory to reject true sentences (Reyna & Brainerd, 1995). Similar effects are found with words and other meaningful stimuli. Another counterintuitive but predicted result was that people rejected gist-consistent distractors more often than unrelated distractors, called "false-recognition reversal." To illustrate, when people study a word list with "cat" on it, they tend to "falsely" recognize the related word "animal" on a later recognition test more often than the unrelated word "book" – called *false recognition*. However, if verbatim memory for "cat" is strengthened by repeating it on the study list, the test word "animal" elicits verbatim memory for "cat," so that "animal" is rejected more often (false-recognition *reversal*) than the unrelated word "book" (Reyna & Brainerd, 1995).

Each of these findings with the old-new recognition test and with the true-false meaning test were predicted by FTT (Reyna et al., 2016; Reyna & Kiernan, 1994). Along with other FTT findings of predicted dissociations, they are strong evidence for distinct representational and processing systems of this specific sort – verbatim and gist systems. These theoretical conclusions about sentences require testing verbatim-consistent and gist-consistent sentences (and also controlling for wording that matches presented wording) and varying instructions to different groups to affirm either verbatim-consistent or gist-consistent sentences. Subsequent work used these carefully designed types of test stimuli and instructions, including related distractors such as true inferences, to construct mathematical models that separated such processes as verbatim-based acceptance of presented sentences, verbatim-based rejection of true inferences (and paraphrases), gist-based acceptance of true inferences (and paraphrases), and the degree to which people inhibit responses (Reyna et al., 2016). These FTT models were tested for goodness of fit against real data, meaning that they could be rejected by the data if the theoretical assumptions of the model were wrong; they fit the data. Parameters also "jumped" in response to experimental manipulations in ways that validated their theoretical interpretations. FTT's approach to measurement and manipulation addresses criticisms of dual process theories, providing evidence against single-system accounts (cf. Keren & Schul, 2009; Osman, 2004). FTT also accounts for the sometimes vivid *phenomenology* of gist-based "false" memories (Reyna et al., 2016). These memories are called "false" because the item tested, such as a true inference, is not literally identical to what was experienced, and yet people can remember the gist as vivid under conditions predicted by FTT. FTT was the first (and only) theory to predict that such memories would increase from childhood to adulthood (Brainerd, Reyna, & Forrest, 2002; Reyna & Kiernan, 1994), a result later replicated over 50 times (Brainerd & Reyna, 2012). The developmental *increase* in technically *inaccurate* but substantive memories tells us something important about the human mind and functionality, underlining the likely advantages of gist for advanced cognition (Reyna, Chick, Corbin, & Hsia, 2014; Reyna & Lloyd, 2006). We called this pattern a "developmental reversal" because it violates the usual expectations about developmental increases in precision and accuracy.

Developmental reversals are also observed for gain–loss framing effects (Reyna & Ellis, 1994; Reyna et al., 2011). In framing, as in the Allais problem, decision makers typically choose between a sure versus a risky option. In the gain frame, they might choose between $40 for sure or a two-thirds chance of winning $60 and a one-third chance of winning $0. In the corresponding "loss" frame, decision makers could be given an endowment of $60 but must choose between losing $20 for sure versus a two-thirds chance of losing $0 and a one-third chance of losing $60. Despite the net equivalence of the gain and loss versions of the decision (e.g., $60 – $40 = $20), adults prefer the sure option in the gain frame and the risky option in the loss frame (Tversky & Kahneman, 1986). However, children treat these frames as equivalent, modulating their risk preference based on probabilities and outcomes; framing differences emerge with age (Reyna & Ellis, 1994; Reyna et al., 2011; Weller, Levin, & Denburg, 2011). The ability to perform numerical computations improves during the same period that preference for relying on these details declines, consistent with FTT (Reyna & Brainerd, 1994; Weller et al., 2011).

There are numerous tests of FTT's explanation of decision-making phenomena such as the Allais problem and gain–loss framing effects (Reyna, 2012; Reyna & Brainerd, 2011). One of the straightforward tests involves truncating or deleting the zero part of the risky option in framing problems, the part that is responsible for the simplest qualitative distinction between options of receiving something or nothing. All of the elements needed to perform a quantitative analysis of the pros and cons of each option remain (e.g., $40 for sure vs. a two-thirds chance of winning $60). Moreover, the deleted zero part of the risky option (e.g., one-third chance of $0) is provided prior to choice to eliminate ambiguity. Nevertheless, deleting the zero part of the risky option for gains and losses eliminates framing effects, contrary to theories of risky decision-making other than FTT (Reyna & Brainerd, 1991). This and other types of truncation effects that test theoretical predictions have been replicated (Kühberger & Tanner, 2010; Reyna et al., 2014).

The advantages of FTT for advanced cognition, including decision-making, also have been examined experimentally by inducing gist-based thinking (Abadie et al., 2013; Fukukura, Ferguson, & Fujita, 2013; Reyna & Mills, 2014; Wolfe et al., 2015). Better decisions often reflect gist-based thinking (e.g., simple categorical thinking such as "it only takes once to get HIV-AIDS), rather than verbatim-based thinking (e.g., focusing on details and weighing the probabilities and potential outcomes of an array of options by trading off[3]). Thus, FTT predicts that adolescents who take risks are more likely to think in terms of risk–reward tradeoffs than adults, confirmed by Kwak, Payne, Cohen, and Huettel (2015). Using eye tracking, they showed that adolescents used a more detailed exhaustive approach to explore probabilities and outcomes than adults before making decisions in a risky-choice framing task. In contrast, decisions by young adults were influenced by task-relevant heuristics that simplified the decision problem.

FTT assumes that both gist and verbatim processing occur – those who rely on gist are often aware of the details and the tradeoffs, but they reject that way of thinking as the final arbiter of their decisions when the stakes are high. Instead of thinking that a low probability of a seriously bad outcome is okay because rewards are high, possibility (of the seriously bad outcome) rules over probability in decision-making. This is not because people do not understand probability, as evidenced by the fact that people who show this effect pass probability tests, but because possibility captures the essence of the risky option, as reflected in the adage that the probability is 100% if it happens to you (Reyna & Brainerd, 1994).

It is also not the case that gist thinkers necessarily have higher perceptions of risk; they are often aware that the objective probabilities of bad outcomes are, in fact, low. Critical tests of these hypotheses include randomizing adolescents to a gist-thinking versus verbatim-thinking curriculum about sexual risk taking, but maintaining all the same information about objective risks (Reyna & Mills, 2014). The gist curriculum facilitated health-promoting knowledge, attitudes, and thinking and was associated with better self-reported behavioral outcomes (e.g., delayed initiation of sex).

As an advanced type of cognition, in each of the domains of reasoning, judgment, and decision-making that we have discussed, FTT has predicted developmental increases in reliance on gist. Although gist-based intuition supports globally less error-prone reasoning and healthier decisions, it also produces systematic biases that paradoxically increase from childhood to adulthood. As discussed earlier, FTT motivated the first study on gain–loss framing effects in children (Reyna & Ellis, 1994), and it has subsequently been applied to a host of other reasoning, judgment, and decision-making biases. Conjunction fallacies, being determined by both compelling gist and class-inclusion confusion, also increase during this period when gist is pitted against verbatim details (e.g., as they are in the Linda and Allais problems). For example, Morsanyi, Chiesi, Primi, and Szűcs (2016) showed that children were more sensitive to numerical details about the frequencies of different classes and, hence, less likely to exhibit the conjunction fallacy. They also found that children's tendency to be less biased than adults was not due to their lack of knowledge about social stereotypes (e.g., as in the example of Linda), but rather their heavy reliance on explicit, literal information in the task description. False memory increases during this same period (shown to be due to gist by multiple empirical tests) and cannot be explained away by references to knowledge differences between children and adults: when materials were normed to equate knowledge requirements for children and adults, the predicted growth of gist-based memory and judgment biases was retained (Brainerd & Reyna, 2012). Although we have discussed effects separately, recent research has related them empirically to one another; for example, individuals who show framing biases have more gist-based false memories (Corbin, Reyna, Weldon, & Brainerd, 2015; Helm & Reyna, in press).

Conclusions, implications, and how theories differ

We have presaged many of the differences between FTT and alternative theories in the prior sections because tests of FTT have also been tests of alternatives. These effects include independence of verbatim and gist representations in logical inference; variations of this independence effect with delay and with instructions; better reasoning once problem information is forgotten; better reasoning with higher cognitive load; developmental reversals in memory, judgment, and decision-making; framing in risky choice and a variety of truncation effects; reduction of conjunction and other class-inclusion fallacies, including base-rate neglect with 2 × 2 tables (using probabilities not frequencies); and effects of inducing gist thinking on real-world judgments and decision-making. Note that methods reported in the original studies matter. For example, we are not saying that reasoning is always better when problem information is forgotten; instead, that effect holds when verbatim details support judgments that contradict the gist of problem information (Reyna et al., 2003). The bottom line is that FTT predicts these effects, and traditional dual process theories do not explain them easily. Indeed, many results clearly refute predictions of those theories (e.g., of prospect theory; Kahneman, 2011).

Findings such as independence between verbatim-based memory performance and gist-based reasoning performance may seem to contradict many findings that memory and reasoning correlate. However, that contradiction is more apparent than real. In FTT research, contingencies were computed within each story or problem; for instance, presented premises were related only to the true inferences that followed from those premises, as opposed to relating memory in general to reasoning in general. Using this approach, it is possible to assess whether accurate reasoning performance depends – even to a small degree – on working memory for problem information, a defining feature of current dual process models (Evans & Stanovich, 2013). The answer in many instances appears to be "no" because advanced reasoning bypasses the constraints of verbatim memory by relying on gist.

Traditional dual process models capture fundamental aspects of human thinking that should be conserved in newer approaches that expand our notions of intuition beyond a lazy default, which requires intervention to engage advanced processing and reduce biases, to parallel processes that incorporate intuitive insight (De Neys, 2012; Reyna, 2012). To be sure, there are reasoning and decision-making errors attributable to fast cognitive tempo (Kahneman, 2011), inadequate reflection (Evans & Stanovich, 2013), and immature executive processes (Casey et al., 2016; Steinberg, 2008), as recognized in FTT. However, literal thinking and failures to "get the gist" – failures of meaningful insight – cannot be remedied simply by slowing down processing and adding more "RAM" to augment human computation. Although some errors are reduced when individuals process more details more slowly and precisely, life skills can be impaired; gist-based thinking, rather than verbatim-based thinking, is often associated with healthier outcomes (Blalock & Reyna, 2016; Reyna & Brainerd, 2011). Relevant to real-world outcomes, FTT underlines the difference between processing *more* versus processing *more meaningfully*. As is well known in psycholinguistics, context, knowledge, and experience shape the meaning (or interpretation) of information, and thus FTT incorporates these factors by emphasizing essential meaning as central to cognition and its development.

Development offers an important perspective on adult competence. Unless development is devolution, which is unlikely, the increase in many systematic biases and fallacies cannot be ignored by theories of adult reasoning and decision-making (for a list of such developmental reversals, see Weldon, Corbin, & Reyna, 2013). Traditional dual process approaches assume an evolutionarily and developmentally advanced role for Type 2 (reflective) processing in reducing biases produced by Type 1 (intuitive) processing. More recent approaches (e.g., Stanovich, West, & Toplak, 2011) have acknowledged that development of intuitive biases might conform to an inverted U-shaped function, rather than decreasing from childhood to adulthood, as traditional theories assume. However, the observed developmental relationships from multiple laboratories tend to be monotonic, not an inverted U-shape.

Two types of biases or fallacies have been conflated from the perspective of FTT: those that involve failures of executive processes (e.g., of computation or inhibition) that decrease from childhood to adulthood and those that involve gist-based intuition that increase during this period (or, equivalently, increase with greater experience and expertise; Reyna et al., 2014). This conclusion is buttressed not just by the increase in such systematic biases with development, but by the detailed process models of those biases that we have only touched on briefly. The critique that counterintuitive developmental patterns were a side effect of using materials that were inappropriate for young children (e.g., that biases drew on knowledge they had yet to acquire) has been ruled out in studies on gist-based false memory, framing effects, the conjunction fallacy, and other phenomena (cf. De Neys & Vanderputte, 2011; Stanovich et al., 2011; Toplak, West, & Stanovich, 2014; see

Morsanyi et al., 2016; Weldon et al., 2013). Therefore, the evidence supports the theoretical ideas that motivated predictions of developmental reversals, and it is not necessary to turn to post hoc speculations to explain these effects.

Our analysis leaves many open questions, such as whether reasoning is the implementation of concrete beliefs, abstract structures, or something else entirely (Evans, Thompson, & Over, 2015). Verbatim and gist are both symbolic representations, but verbatim is more concrete and literal than is gist. However, gist is not an abstract (i.e., contentless) representation. Gist consists of schematic representations that incorporate semantic and pragmatic knowledge. Reasoning is, then, a process of applying general but not universal principles to meaningful representations of information. However, formalisms that capture meaningful content, not mindless associations that simulate effects of meaning, are needed. Additional work is also needed to characterize levels of gist and the processes through which representations are simplified to distill the nub of information to arrive at the gist. In the era of big data and overwhelming access to detailed information, appreciating the essence of information is more important than ever to improve human reasoning, judgment, and decision-making.

Acknowledgements

Valerie F. Reyna, Shahin Rahimi-Golkhandan, David M. N. Garavito, and Rebecca K. Helm are affiliated with the Human Neuroscience Institute and Department of Human Development, Cornell University. Preparation of this manuscript was supported in part by grants from the National Institutes of Health grant (award R01NR014368–01), National Science Foundation (award 1536238), and National Institute of Food and Agriculture (awards NYC-321423 and NYC-321436) to V. F. Reyna. Correspondence should be directed to Valerie F. Reyna, Human Neuroscience Institute, Cornell University, MVR G331, Ithaca, NY 14853 USA. E-mail: vr53@cornell.edu.

Notes

1 Note that people still erroneously accept gist-consistent inferences as presented more often than they accept gist-*in*consistent sentences as presented.
2 Stereotypes may also reflect memorized superficial features that are applied verbatim (i.e., without thinking).
3 The definition of a "better" decision has been written about in FTT (Adam & Reyna, 2005; Reyna & Brainerd, 1994; Reyna et al., 2003; Reyna & Farley, 2006).

References

Abadie, M., Waroquier, L., & Terrier, P. (2013). Gist memory in the unconscious-thought effect. *Psychological Science*, *24*, 1253–1259. doi:10.1177/0956797612470958

Adam, M. B., & Reyna, V. F. (2005). Coherence and correspondence criteria for rationality: Experts' estimation of risks of sexually transmitted infections. *Journal of Behavioral Decision Making*, *18*(3), 169–186. doi:10.1002/bdm.493

Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin*, *93*(2), 203–231.

Blalock, S. J., & Reyna, V. F. (2016). Using fuzzy-trace theory to understand and improve health judgments, decisions, and behaviors: A literature review. *Health Psychology*, *35*(8), 781–792. doi:10.1037/hea0000384

Brainerd, C. J., & Reyna, V. F. (1992). Explaining "memory-free" reasoning. *Psychological Science*, *3*(6), 332–339. doi:10.1111/j.1467–9280.1992.tb00042.x

Brainerd, C. J., & Reyna, V. F. (1995). Autosuggestibility in memory development. *Cognitive Psychology*, *28*(1), 65–101. doi:10.1006/cogp.1995.1003

Brainerd, C. J., & Reyna, V. F. (2012). Reliability of children's testimony in the era of developmental reversals. *Developmental Review*, *32*, 224–267. doi:10.1016/j.dr.2012.06.008

Brainerd, C. J., Reyna, V. F., & Forrest, T. J. (2002). Are young children susceptible to the false-memory illusion? *Child Development*, *73*(5), 1363–1377. doi:10.1111/1467–8624.00477

Brainerd, C. J., Reyna, V. F., & Howe, M. L. (2009). Trichotomous processes in early memory development, aging, and neurocognitive impairment: A unified theory. *Psychological Review*, *116*(4), 783–832. doi:10.1037/a0016963

Bransford, J. D., & Franks, J. J. (1971). The abstraction of linguistic ideas. *Cognitive Psychology*, *2*(4), 331–350.

Bookbinder, S. H., & Brainerd, C. J. (2017). Emotionally negative pictures enhance gist memory. Emotion, *17*(1), 102–119. doi: 10.1037/emo0000171.

Broniatowski, D. A., Hilyard, K. M., & Dredze, M. (2016). Effective vaccine communication during the Disneyland measles outbreak. *Vaccine*, *34*(28), 3225–3228. doi:10.1016/j.vaccine.2016.04.044

Casey, B. J., Galvan, A., & Somerville, L. H. (2016). Beyond simple models of adolescence to an integrated circuit-based account: A commentary. *Developmental Cognitive Neuroscience*, *17*, 128–130.

Clark, H. H., & Clark, E. V. (1977). *Psychology and language: An introduction to psycholinguistics.* New York, NY: Harcourt College Publishing.

Corbin, J. C., Reyna, V. F., Weldon, R. B., & Brainerd, C. J. (2015). How reasoning, judgment, and decision making are colored by gist-based intuition: A fuzzy-trace theory approach. *Journal of Applied Research in Memory and Cognition*, *4*, 344–355. doi:10.1016/j.jarmac.2015.09.001

Defoe, I. N., Dubas, J. S., Figner, B., & Van Aken, M. A. (2014). A meta-analysis on age differences in risky decision-making: Adolescents versus children and adults. *Psychological Bulletin*, *141*(1), 48–84. doi:10.1037/a0038088

De Neys, W. (2012). Bias and conflict: A case for logical intuitions. *Perspectives on Psychological Science*, 7(1), 28–38. doi:10.1177/1745691611429354

De Neys, W., & Vanderputte, K. (2011). When less is not always more: Stereotype knowledge and reasoning development. *Developmental Psychology*, *47*(2), 432–441.

Evans, J. St B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science*, *8*(3), 223–241. doi:10.1177/1745691612460685

Evans, J. St B. T., Thompson, V. A., & Over, D. E. (2015). Uncertain deduction and conditional reasoning. *Frontiers in Psychology*, *6*, 398, 1–12.

Franssens, S., & De Neys, W. (2009). The effortless nature of conflict detection during thinking. *Thinking & Reasoning*, *15*(2), 105–128. doi: 10.1080/13546780802711185.

Fukukura, J., Ferguson, M. J., & Fujita, K. (2013). Psychological distance can improve decision making under information overload via gist memory. *Journal of Experimental Psychology: General*, *142*(3), 658–665. doi:10.1037/a0030730

Furlan, S., Agnoli, F., & Reyna, V. F. (2016). Intuition and analytic processes in probabilistic reasoning: The role of time pressure. *Learning and Individual Differences*, *45*, 1–10. doi:10.1016/j.lindif.2015.11.006

Helm, R. K., & Reyna, V. F. (2017). Logical but incompetent plea decisions: A new approach to plea bargaining grounded in cognitive theory. *Psychology, Public Policy, and Law*, *23*(3), 367–380. doi: 10.1037/law0000125.

Kahneman, D. (2011). *Thinking fast and slow*. London, UK: Penguin.

Keren, G., & Schul, Y. (2009). Two is not always better than one: A critical evaluation of two-system theories. *Perspectives on Psychological Science*, *4*, 533–550.

Kühberger, A., & Tanner, C. (2010). Risky choice framing: Task versions and a comparison of prospect theory and fuzzy-trace theory. *Journal of Behavioral Decision Making*, *23*(3), 314–329. doi:10.1002/bdm.656

Kwak, Y., Payne, J. W., Cohen, A. L., & Huettel, S. A. (2015). The rational adolescent: Strategic information processing during decision making revealed by eye tracking. *Cognitive Development*, *36*, 20–30. doi:10.1016/j.cogdev.2015.08.001

Liberali, J. M., Reyna, V. F., Furlan, S., Stein, L. M., & Pardo, S. T. (2012). Individual differences in numeracy and cognitive reflection, with implications for biases and fallacies in probability judgment. *Journal of Behavioral Decision Making*, *25*, 361–381. doi:10.1002/bdm.752

Morsanyi, K., Chiesi, F., Primi, C., & Szűcs, D. (2017). The illusion of replacement in research into the development of thinking biases: The case of the conjunction fallacy. *Journal of Cognitive Psychology*, *29*(2), 240–257. doi:10.1080/20445911.2016.1256294.

Osman, M. (2004). An evaluation of dual-process theories of reasoning. *Psychonomic Bulletin & Review*, *11*, 988–1010.

Reyna, V. F. (2004). How people make decisions that involve risk: A dual-process approach. *Current Directions in Psychological Science*, *13*(2), 60–66. doi:10.1111/j.09637214.2004.00275.x

Reyna, V. F. (2012) A new intuitionism: Meaning, memory, and development in Fuzzy-Trace Theory. *Judgment and Decision-Making,* 7(3), 332–359.

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

Reyna, V. F., & Brainerd, C. J. (1992). A fuzzy-trace theory of reasoning and remembering: Paradoxes, patterns, and parallelism. In A. Healy, S. Kosslyn, & R. Shiffrin (Eds.), *From learning processes to cognitive processes: Essays in honor of William K. Estes* (Vol. 2, pp. 235–259). Hillsdale, NJ: Erlbaum.

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

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

Reyna, V. F., & Brainerd, C. J. (1998). Fuzzy-trace theory and false memory: New frontiers. *Journal of Experimental Child Psychology*, *71*(2), 194–209.

Reyna, V. F., & Brainerd, C. J. (2008). Numeracy, ratio bias, and denominator neglect in judgments of risk and probability. *Learning and Individual Differences*, *18*(1), 89–107. doi:10.1016/j.lindif.2007.03.011

Reyna, V. F., & Brainerd, C. J. (2011). Dual processes in decision making and developmental neuroscience: A fuzzy-trace model. *Developmental Review*, *31*, 180–206. doi:10.1016/j.dr.2011.07.004

Reyna, V. F., Chick, C. F., Corbin, J. C., & Hsia, A. N. (2014). Developmental reversals in risky decision-making: Intelligence agents show larger decision biases than college students. *Psychological Science*, *25*(1), 76–84. doi:10.1177/0956797613497022

Reyna, V. F., Corbin, J. C., Weldon, R. B., & Brainerd, C. J. (2016). How fuzzy-trace theory predicts true and false memories for words and sentences. *Journal of Applied Research in Memory and Cognition*, *5*(1), 1–9. doi:10.1016/j.jarmac.2015.12.003

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

Reyna, V. F., Estrada, S. M., DeMarinis, J. A., Myers, R. M., Stanisz, J. M., & Mills, B. A. (2011). Neurobiological and memory models of risky decision making in adolescents versus young adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1125–1142. doi:10.1037/a0023943

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making. *Psychological Science in the Public Interest*, 7(1), 1–44. doi:10.1111/j.1529–1006.2006.00026.x

Reyna, V. F., & Kiernan, B. (1994). Development of gist versus verbatim memory in sentence recognition: Effects of lexical familiarity, semantic content, encoding instructions, and retention interval. *Developmental Psychology*, *30*(2), 178–191. doi:10.1037/0012–1649.30.2.178

Reyna, V. F., & Lloyd, F. J. (2006). Physician decision making and cardiac risk: Effects of knowledge, risk perception, risk tolerance, and fuzzy processing. *Journal of Experimental Psychology: Applied*, *12*(3), 179–195. doi:10.1037/1076–898X.12.3.179

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

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

Reyna, V. F., & Mills, B.A. (2014). Theoretically motivated interventions for reducing sexual risk taking in adolescence: A randomized controlled experiment applying fuzzy-trace theory. Journal of experimental psychology: general, 143(4), 1627. doi:10.1037/a0036717.

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

Reyna, V. F., Wilhelms, E. A., McCormick, M. J., & Weldon, R. B. (2015). Development of risky decision making: Fuzzy-trace theory and neurobiological perspectives. *Child Development Perspectives*, *9*(2), 122–127. doi:10.1111/cdep.12117

Sloman, S. A. (2002). Two systems of reasoning. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 379–396). New York: Cambridge University Press.

Stanovich, K. E., & West, R. F. (2008). On the relative independence of thinking biases and cognitive ability. *Journal of Personality and Social Psychology*, *94*(4), 672–695. doi:10.1037/0022–3514.94.4.672

Stanovich, K. E., West, R. F., & Toplak, M. E. (2011). The complexity of developmental predictions from dual process models. *Developmental Review*, *31*(2), 103–118. doi: 10.1016/j.dr.2011.07.003.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk taking. *Developmental Review*, *28*(1), 78–106. doi:10.1111/j.1467–8721.2007.00475.x.

Sternberg, R. J., & Davidson, J. E. (Eds.). (1995). *The nature of insight*. Cambridge, MA: Bradford/MIT Press.

Thompson, C. A., & Siegler, R. S. (2010). Linear numerical-magnitude representations aid children's memory for numbers. *Psychological Science*, *21*(9), 1274–1281. doi:10.1177/0956797610378309

Toplak, M. E., West, R. F., & Stanovich, K. E. (2014). Rational thinking and cognitive sophistication: Development, cognitive abilities, and thinking dispositions. *Developmental Psychology*, *50*(4), 1037–1048. doi:10.1037/a0034910

Tversky, A., & Kahneman, D. (1983). Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review*, *90*, 293–315.

Tversky, A., & Kahneman, D. (1986). Rational choice and the framing of decisions. *Journal of business*, *4*(2), S251–S278.

Weldon, R. B., Corbin, J. C., & Reyna, V. F. (2013). Gist processing in judgment and decision making: Developmental reversals predicted by fuzzy-trace theory. In H. Markovits (Ed.), *The developmental psychology of reasoning and decision-making* (pp. 36–62). New York: Psychology Press.

Weller, J. A., Levin, I. P., & Denburg, N. L. (2011). Trajectory of risky decision making for potential gains and losses from ages 5 to 85. *Journal of Behavioral Decision Making*, *24*, 331–344. doi:10.1002/bdm.690

Wertheimer, M. (1982). *Productive thinking* (Enlarged ed., Phoenix ed.). Chicago: University of Chicago Press.

Wolfe, C. R., & Reyna, V. F. (2010). Semantic coherence and fallacies in estimating joint probabilities. *Journal of Behavioral Decision Making*, *23*(2), 203–223. doi:10.1002/bdm.650

Wolfe, C. R., Reyna, V. F., Widmer, C. L., Cedillos, E. M., Fisher, C. R., Brust-Renck, P. G., & Weil, A. M. (2015). Efficacy of a web-based intelligent tutoring system for communicating genetic risk of breast cancer: A fuzzy-trace theory approach. *Medical Decision Making*, *35*, 46–59. doi:10.1177/0272989X14535983