DOI: 10.1111/risa.13914

Brust-Renck, P. G., & Reyna, V. F. (2022) Individual differences in numerical representations of risk in health decision making: A fuzzy trace theory. *Risk Analysis: An International Journal*. https://doi.org/10.1111/risa.13914

ORIGINAL ARTICLE

Individual differences in numerical representations of risk in health decision making: A fuzzy-trace theory approach

Priscila G. Brust-Renck[1] | **Valerie F. Reyna**[2]

[1]Programa de Pós-Graduação em Psicologia, Universidade do Vale do Rio dos Sinos, São Leopoldo, Rio Grande do Sul, Brazil

[2]Human Neuroscience Institute, Cornell University, Ithaca, New York, USA

Correspondence
Valerie F. Reyna, Human Neuroscience Institute, G331-D Martha Van Rensselaer Hall, Cornell University, Ithaca, NY, 14853, USA.
Email: vr53@cornell.edu

Funding information
National Science Foundation, Grant/Award Number: 1536238; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Grant/Award Number: BEX 0412/12-0; National Institute of Nursing Research, Grant/Award Number: R01NR014368-01; National Cancer Institute, Grant/Award Number: R21CA149796

Abstract

Fuzzy-trace theory predicts that decisionmakers process numerical information about risk at multiple levels in parallel: the simplest level, nominal (categorical *some-none*) gist, and at more fine-grained levels, involving relative comparison (ordinal *less-more* gist) and exact quantities (verbatim representations). However, little is known about how individual differences in these numerical representations relate to judgments and decisions, especially involving health tradeoffs and relative risks. To investigate these differences, we administered measures of categorical and ordinal gist representations of number, objective numeracy, and intelligence in two studies (*N*s = 978 and 956). In both studies, categorical and ordinal gist representations of number predicted risk judgments and decisions beyond objective numeracy and intelligence. Participants with higher scores in categorical gist were more likely to choose options to avoid cancer recurrence risks; those who were higher in ordinal gist of numbers were more likely to discriminate relative risk of skin cancer; and those with higher scores in objective numeracy were more likely to choose options that were numerically superior overall in terms of relative risk of skin cancer and of genetic risks of breast cancer (e.g., lower numerical probability of cancer). Results support parallel-processing models that assume multiple representations of numerical information about risk, which vary in precision, and illustrate how individual differences in numerical representations are relevant to tradeoffs and risk comparisons in health decisions. These representations cannot be reduced to one another and explain psychological variations in risk processing that go beyond low versus high levels of objective numeracy.

KEYWORDS
cancer risk, fuzzy-trace theory, gist, individual differences, numeracy, numerical cognition

1 | INTRODUCTION

Research has shown that individuals with lower objective numeracy, the ability to make judgments and computations about numbers, are more likely to show biases and errors in decision making (Peters, 2020; Reyna et al., 2009). Low objective numeracy can become particularly important in health contexts in which poor decisions are associated with reduced quality of life or death (Brust-Renck et al., 2015; Kutner et al., 2007; Levy et al., 2014; Petrova et al., 2017; Smith et al., 2015). For example, patients with moderate-to-severe asthma were found to have higher asthma-related quality of life when they had higher numeracy scores (Apter et al., 2009). Indeed, many real-world health decisions about risks involve quantitative tradeoffs between probabilities of side effects and of death (e.g., lower probability of side effects but higher probability of death), as well as judgments about relative risks, such as how genetics or health habits increase or decrease risks.

In this study, we build on theory postulating that decisionmakers extract multiple mental representations of numbers, such as numbers that convey risks, and on findings showing that individuals vary in the ability and tendency to extract these representations, which, in turn, relate in theoretically expected ways to their decisions (Reyna & Brust-Renck, 2020). We explore health decisions that involve magnitude comparisons of various kinds and that resemble those in real life (for an overview of cancer decision making, see Reyna, Nelson, et al., 2015). Specifically, we examine both preference-sensitive decisions, in which individuals' preferences depend on subjective differences in the relative weight of quality of life as opposed to cancer recurrence, and judgments that have objectively accurate answers about relative risks of skin cancer and breast/ovarian cancers (Gärtner et al., 2019). The latter judgments turn on avoiding surprisingly common ratio biases, that a 1 in 20 risk of skin cancer is smaller than a 1 in 100 risk (because, erroneously, 20 is less than 100) and conjunction fallacies, that the genetic risk of the conjunction of developing breast cancer and ovarian cancer is larger than the genetic risk of developing either breast cancer alone or ovarian cancer alone (Garcia-Retamero et al., 2010; Scherer et al., 2017; Wolfe & Fisher, 2013).

1.1 | Numerical representation and numeracy in fuzzy-trace theory

Evidence indicates that people encode different representations from the same numerical information: categorical representations of the gist of numbers (e.g., some lives saved vs. no lives saved), ordinal representations of relative magnitudes (e.g., more lives saved vs. fewer lives saved), and verbatim representations of exact quantities, which can be input to computational rules applied by rote to those numbers (200 lives saved = 1/3 probability × 600 lives saved in terms of expected values; e.g., Broniatowski & Reyna, 2018; Kleber et al., 2013; Reyna & Brust-Renck, 2015; Siegler et al., 2011).

According to fuzzy-trace theory, although people encode these multiple levels of representation roughly in parallel, they tend to reason with the simplest categorical gist that can be used to accomplish a task (Reyna, 2012). For example, if a $54,232 price of one car is perceived as expensive and a $23,999 price of another car is perceived as inexpensive, there is no need to subtract these numbers from one another (and obtain the exact difference in price) to choose a car based on price. This kind of mental representation translates numerical information into meaningful qualitative distinctions: cancer recurrence is unlikely versus likely, one has the BRCA gene and are at-risk of cancer or does not have the gene and are not at-risk, and so on. If an option allows categorical risk avoidance, choices tend to gravitate to that option rather than veridically reflecting trading off degrees of probability against severity of outcomes (Brust-Renck et al., 2016).

When alternatives cannot be distinguished categorically, mental representations that subserve judgments and decisions escalate to an ordinal level of differentiation, which involves comparing relative magnitudes (see also Bostrom, 2017; Stevens, 2016). Finally, a more precise (e.g., verbatim) representation is necessary when tasks involve performing exact calculations, for example, mentally multiplying as shown above to determine expected value. Note that, as argued early in the development of fuzzy-trace theory, mathematical reasoning often does not rely on precise calculations using verbatim mental representations, even among mathematicians (see Reyna & Brainerd, 1995).

Each kind of representation has been shown to predict different results in decision making based both on the nature of the problem–how it is reduced to categorical gist, ordinal gist, or verbatim levels–and the individual making the decision (Broniatowski & Reyna, 2018; Reyna & Brust-Renck, 2020; Reyna et al., 2014). Categorical gist representations support a "fuzzy" approach, in which making a medical decision can boil down to "saving *some* lives" or "saving *no* lives." Ordinal gist representations connect to research on mathematical cognition, in which people have a basic mental representation of number in terms of relative or approximate magnitude (Brannon, 2006; Lyons & Beilock, 2013; Siegler et al., 2011). Many studies provide evidence for such a number system that represents numerical amounts on a mental number line using approximate magnitudes (e.g., Booth & Siegler, 2006; Peters & Bjalkebring, 2015; Peters et al., 2008; Schley & Peters, 2014).

1.2 | Health decisions

Our goal is to understand how different people with different skills and cognitive styles approach health decisions and judgments by investigating the kind of mental representations they rely on. Grounded in the literature, each scenario presents a kind of decision or judgment that people make based on their understanding of numbers such as percentages and probabilities. A measure of intelligence was included to rule out alternative explanations, namely, that differences did not specifically involve types of numerical processing (Cokely et al., 2015; Dieckmann et al., 2015).

The first scenarios we examine (Tasks 1 and 2) involve a tradeoff between serious health outcomes–cancer recurrence–and side effects that compromise quality of life. The two tasks differ only in whether treatments are referred to as Treatment A and Treatment B or as radiation and chemotherapy to control for specific attitudes people may hold about the latter treatments (e.g., "Chemotherapy is poison," Reyna, 2008). In both versions of this decision, there are tradeoffs in the probabilities of cancer recurrence and side effects with different treatments, but survival rates do not differ significantly, creating a challenging decision dilemma. The quantitative tradeoff involves a higher probability of bowel control problems from radiotherapy (60% in our example) than from chemotherapy (40% in our example) as contrasted with a lower risk of cancer recurrence from radiotherapy (5% in our example) than from chemotherapy (11% in our example). Thus, from decision analytical perspectives (see Fischhoff, 2015; Fischhoff & Broomell, 2020, for a review), decisions should turn on subjective perceptions of numerical and other details about the options, such as the *magnitudes* of probabilities and of outcomes, as contrasted with whether recurrence is a "real possibility" or not, a categorical representation.

Although fuzzy-trace theory suggests that all three types of mental representations of numbers are processed (Broniatowski & Reyna, 2018), recent work has shown that individuals vary in their reliance on these representations (Reyna & Brust-Renck, 2020). The empirical question here is whether typical health choices that involve numbers covary with measures that have been shown to reflect reliance on categorical representations (e.g., to avoid recurrence), whether they covary with ordinal representations (relative magnitudes of recurrence or side effects), or whether they covary with objective numeracy (Reyna & Brust-Renck, 2020). Naturally, choices could reflect one, some, or all three of these kinds of numerical representations since they are assessed separately, and orthogonal factors are extracted (and used for prediction of choices; see below).

The next scenario (Task 3) invites people to judge the difference between two ratios about how people who get more sun exposure can be at a higher risk of getting skin cancer. This scenario taps ratio biases, a common problem in understanding probabilities, that involves confusing the roles of numerators that contain target events (e.g., cancer) and denominators that include target and nontarget events (e.g., cancer and noncancer; Garcia-Retamero et al., 2010; Reyna & Brainerd, 2008). Conversely, doing well on such ratio comparisons could be based on nominal or categorical comparisons of risk (e.g., perceiving a troubling risk vs. nontroubling risk of skin cancer), ordinal judgments of relative magnitudes of presented ratios (perceiving 1/20 as larger than 1/100), and objective numeracy, which taps computational competence (calculating that 1/20 is exactly 5 times larger than 1/100; Reyna & Brainerd, 1994; 2008).

The last scenario (Task 4) concerns judging whether combined risks of breast and ovarian cancer due to a genetic mutation are lower in probability than the more inclusive class of either breast cancer or ovarian cancer; developing both cancers is less likely than developing one or the other. Technically, exact numbers are not needed to make such a judgment because each component includes the conjunction (Reyna & Brainerd, 2008). Developing both breast and ovarian cancer implies developing breast cancer (or ovarian cancer) just like Linda being a feminist bank teller implies being a bank teller (Scherer et al., 2017; Tversky & Kahneman, 1983; Wolfe & Reyna, 2010). However, processing the numbers is another way to make this judgment and it also supports selecting the correct response if probabilities are multiplied appropriately. Again, research suggests that people also process the relative magnitudes of these numbers, the ordinal gist. Such gist could also support correct judgments because these judgments accurately reflect approximate differences in relative risk, which is all that is needed to choose between our response options.

In summary, for all four tasks, our analyses are aimed at understanding how individual differences in numerical tendencies and abilities are related to judgments and choices about health risks. We should note that the measures of categorical gist, ordinal gist, and objective numeracy have been shown to load on separable dimensions, and this result has been replicated (see Reyna & Brust-Renck, 2020). Moreover, these scales successfully predicted choices and judgments in major paradoxes, as predicted by fuzzy-trace theory, including reversals in preferences in the Allais paradox (risk aversion when one sure option is available becomes risk seeking when both options are transformed into gambles; Broniatowski & Reyna, 2018) and the loss-bet paradox (a no-loss bet is rated as better than the same bet with a small loss; Peters et al., 2019). Unlike these problems, many health risks do not involve a categorical option, such as no risk versus some risk. Ostensibly, medical decisions about risk typically involve tradeoffs and relative risks. However, people might perceive differences in risk as belonging in different qualitative categories. For example, the average woman might be construed as having a nonnegligible lifetime risk of invasive breast cancer (worth screening for but not worrying about), but those with BRCA mutations might be construed as having a high risk (worth worrying about and perhaps enduring prophylactic mastectomy to prevent). The question is whether individual differences in numerical processing, that run the gamut from qualitative gist to quantitative numeracy, generalize to predicting variations in these kinds of decisions and judgments.

2 | METHOD

2.1 | Participants

Data were collected from two independent studies with a large sample of undergraduates recruited from the participant pool at Cornell University. All participants provided written consent, and the project was approved by the Cornell Institutional Review Board. In Study 1, there were 978 participants (mean age = 19.98, *SD* = 1.50). Among participants, 70% were female, 64% identified as White, 5% as Black, 22% as Asian, and 9% as mixed/other; 10% were Hispanic. In Study 2, there were 957 participants (mean age = 21.10, *SD* = 3.39). Among participants, 79% were female, 55% identified as White, 5% as Black, 34% as Asian, 6% as mixed/other; 10% were Hispanic.

2.2 | Materials and procedure

Tasks were presented online in random order (randomized for each participant) in both Studies 1 and 2, with the constraint that health-risk Tasks 1 and 2 were counterbalanced across participants and the first task appeared in the first half of the session and the second task appeared in the last half of the session. Participants then completed a demographic survey, indicating their age, gender, race, and ethnicity. Other measures were gathered to be published in other papers; the order of these tasks was randomized with the rest of the problems.

2.2.1 | Gist numeracy tasks

We assessed gist numeracy of two distinct types from Reyna and Brust-Renck (2020): categorical gist and ordinal gist. Categorical gist was composed of two tasks: categorical gist-death (3 questions) and non-death (4 questions), drawn from examples of noncompensatory categorical reasoning in earlier publications on fuzzy-trace theory (e.g., Reyna & Farley, 2006; Reyna et al., 2003) and from the theory's predictions. For example, one question asked whether the participant would play Russian roulette for a million dollars; a subsequent question asked whether the participant would play Russian roulette for any amount of money. Saying "yes" to either question indicates willingness to trade off death against dollars, that is, compensatory (noncategorical) thinking because the amount of money compensates for the amount of risk, whereas saying "no" indicates noncompensatory categorical thinking (gist) because the categorical possibility of death determines responses regardless of the amount of money. Similarly, in the categorical nondeath questions, a "yes" response indicates willingness to trade off amounts of risk and reward for nondeath outcomes, for example, agreeing that "If someone is really hot, it is okay to take a small chance to risk getting HIV–AIDS from unprotected sex." (see Reyna et al., 2011). Again, a "no" response indicates rejection of trading off, instead reflecting noncompensatory gist-based categorical thinking: the categorical possibility of HIV-AIDS determines responses. Research has shown that answers to these categorical gist questions captured unique variance beyond standard risk aversion, the latter defined by aversion to variability in potential outcomes (Reyna & Brust-Renck, 2020). The theoretical prediction is that mature decisionmakers reject the premise that such risks should be traded off against amounts of money, instead exhibiting categorical thinking (e.g., "it only takes once to get HIV-AIDS"; Reyna et al., 2011). Each item was scored as 0 or 1 and averaged; higher values represent greater tendency to engage in categorical gist thinking. Cronbach's alpha was 0.70 and 0.66 (Reyna & Brust-Renck, 2020), which indicated the scale was acceptable with only seven items.

Ordinal gist was composed of tasks drawn from prior research on fuzzy-trace theory and on magnitude estimation that loaded together on principal component analyses (Reyna & Brust-Renck, 2020): (1) Memory representations of the relative magnitude judgments of low and high magnitude numbers (i.e., 48 questions about which objects were more, less, most, or least) presented after a short delay in four meaningful narratives (48 memory-based gist questions about which objects were more, less, most, or least, posed after a filled delay), based on Brainerd and Gordon (1994) and Thompson and Siegler (2010); (2) estimation of the relative placement of low and high whole numbers (e.g., 17 and 800) and fractions (e.g., 3/8) on a continuous line without demarcations (90 questions based on Siegler & Opfer, 2003; Siegler et al., 2011, and Thompson & Opfer, 2010); (3) ability to get a rough sense of the magnitude of numbers in approximation judgments of the most plausible result among numerically wrong responses for arithmetic problems, such as 12 + 6 = 20 or 10 (27 questions based on Dehaene & Cohen, 1991, and Hanich et al., 2001); and (4) numerical abilities in making ordinal comparisons through simple ratio comparison involving judgments of relative magnitude (e.g., 2/9 is smaller or larger than 5/7?) of two familiar fractions (16 questions based on Schneider & Siegler, 2010). Higher scores indicate accurate ordinal gist judgments of numbers in all tasks. Cronbach's alpha indicated high reliability of 0.94 and 0.92 (Reyna & Brust-Renck, 2020).

2.2.2 | Objective numeracy scale

We used the 15-item expanded version of the objective numeracy scale from Peters et al. (2007). The scale contains numerical processing items involving such operations as conversion of ratios, linear ordering, and multiplying (Liberali et al., 2012). Each item was scored as 0 (incorrect) or 1 (correct) and averaged; higher values indicate higher numeracy. Cronbach's alpha measure of reliability was 0.83 and 0.72 (Reyna & Brust-Renck, 2020).

2.2.3 | Advanced progressive matrices test

The advanced progressive matrices test assesses a nonverbal, nonnumeric measure of abstract reasoning, namely, fluid intelligence. We used the 12-item short form test proposed by Arthur and Day (1994), which is a variation of the original test from Raven et al. (1985). This test is widely used as a brief measure of fluid intelligence with acceptable validity and reliability, the latter confirmed in these samples (Reyna & Brust-Renck, 2020). The test consists of choosing which piece (from a series of options) best completes the design of a series of patterns. Higher values indicate higher fluid intelligence. Cronbach's alpha measure of reliability was 0.85 and 0.77 (Reyna & Brust-Renck, 2020). We included this measure to distinguish specific numerical abilities from fluid intelligence in general.

2.2.4 | Health tasks

Four tasks were administered involving numerical information about health risks. For Tasks 1 and 2, participants indicated their preferences if they were diagnosed with cancer. We defined radiation therapy (called Treatment A in Task 2) and chemotherapy (called Treatment B in Task 2) for cancer and described radiation as associated with a lower recurrence rate (5%) compared to chemotherapy (11%), but that it carried a 50% higher risk of sexual dysfunction and 33% higher risk of bowel control problems (see Supporting Information for complete wording). (Note that neither option offered categorical avoidance of side effects, but recurrence seems to have been interpreted in terms of the possibility of death as is not uncommon; Reyna, Nelson, et al., 2015.) Survival rates were described as the same for both options. Choice of radiation therapy (or Treatment A) was scored as 1 and chemotherapy (or Treatment B) as 0; participants rarely selected No Treatment, also scored as 0. Results were highly similar omitting the latter responses. Higher scores indicate preference for the treatment option with lower chance of cancer recurrence, but higher side effects (radiotherapy or Treatment A). Order

TABLE 1 Mean proportions choosing avoiding cancer recurrence for Tasks 1 and 2 and higher relative risk in Tasks 3 and 4: Studies 1 and 2

Tasks	Study 1		Study 2	
	M	SD	M	SD
Avoid recurrence: Avoiding cancer recurrence by choosing the treatment (radiotherapy) with lower recurrence rate (5%) but higher side effects versus chemotherapy (11% recurrence rate).	0.23	0.42	0.23	0.42
Avoid recurrence: Avoiding cancer recurrence by choosing Treatment A with lower recurrence rate (5%) but higher side effects versus Treatment B (11% recurrence rate).	0.28	0.45	0.27	0.45
Ratio judgment: Judging the risk of getting skin cancer for a lifeguard (1 in 20) as 5 times greater than the risk for the general population (1 In 100).	0.76	0.43	0.76	0.42
Ratio and class inclusion judgment: Judging the chances of a woman with a genetic BRCA mutation to have breast cancer (5 times 12.2%) as greater than her risk of ovarian cancer (15 times 1.4%) or both breast and ovarian cancer.	0.56	0.50	0.57	0.50

Note: M = Mean; SD = Standard deviation.

of presentation of Tasks 1 and 2 was counterbalanced across participants with a 30-min delay in between.

For Task 3, we indicated that a beach lifeguard who did not wear sunscreen had a 1 in 20 risk of getting skin cancer compared to a 1 in 100 risk for the average person, and asked whether the risk was five times greater risk (scored as 1, correct), 1/5 times greater risk (scored as 0, incorrect), or 20,000 times greater risk (rarely selected, and scored as 0). For Task 4, we indicated that the base rate of breast cancer was 12.2% (and of ovarian cancer was 1.4%) among women in general, and that breast cancer risk increased five times (and ovarian cancer risk increased 15 times) for a woman with an inherited genetic mutation. The question asked, for a woman who has inherited the genetic mutation, which of the following was most likely to occur: breast cancer (scored as 1, correct), breast cancer and ovarian cancer (scored as 0, incorrect), and ovarian cancer (rarely selected and scored as 0).

3 | RESULTS

Overall, for the health risks tasks in Studies 1 and 2, about a quarter of each sample chose avoiding cancer recurrence (as opposed to avoiding side effects) in Tasks 1 and 2, about three quarters correctly identified a lifeguard's 1 in 20 risk of skin cancer as greater than the average risk of 1 in 100 (Task 3), and a little over half correctly judged that a woman with a genetic mutation had a higher risk of developing breast cancer ($5 \times 12.2\%$) than of developing ovarian cancer ($15 \times 1.4\%$) or both breast and ovarian cancer (Table 1). These dichotomized outcome variables, scored as indicated above, were input to logistic regression analyses.

Predictors in the logistic regression analyses were drawn from measures of categorical gist, ordinal gist, objective numeracy, and intelligence used in Reyna and Brust-Renck (2020). Each of these four scales was reasonably reliable and did not deviate significantly from normality. Because the measures that involved numerical processing were expected to correlate with one another, we conducted a principal component analysis to derive orthogonal factor scores for input as predictors into regression analyses. The component tasks described above loaded as expected onto the dimensions of categorical gist, ordinal gist, and objective numeracy. Intelligence was treated as a separate dimension, not included in the principal component analysis but added as a predictor in regressions. Results for the base models with the three types of numerical processing as predictors are shown in the top halves of Tables 2–5 and results adding Intelligence as a predictor are shown in the bottom halves of Tables 2–5. Results using composite scores by combining raw measures of subscales separately for categorical gist, ordinal gist, and objective numeracy were similar to the ones using factor scores as predictors (Supporting Information).

3.1 | Tasks 1 and 2—Cancer recurrence versus side effects in rectal cancer

Tasks 1 and 2 were analyzed separately, but results were highly similar (Tables 2 and 3). Participants with higher scores in categorical gist were significantly more likely to choose the treatment option with lower recurrence rates and higher side effects in both Study 1 and Study 2, controlling for ordinal gist and objective numeracy (which were not significant). Categorical gist remained significant when intelligence was added as a predictor.

3.2 | Task 3—Ratio comparison of the risk of skin cancer

Results for Task 3 are shown in Table 4. In Study 1, categorical gist, ordinal gist, and objective numeracy all contributed positively and uniquely to correctly judging the ratio comparisons between risks. Participants with higher scores were more likely to choose the option with the correct ratio comparison, that the risk of getting skin cancer for a lifeguard (1 in 20) is 5 times greater than the risk for the general population (1 in 100). These predictors remained significant controlling for Intelligence in Study 1.

In Study 2, ordinal gist and objective numeracy remained significant, each contributing independently to correctly

TABLE 2 Logistic regression to predict choice of lower recurrence treatment (radiotherapy) for rectal cancer with factor scores of gist numeracy tasks of categorical gist and ordinal gist, objective numeracy, and controlling for intelligence

	Study 1				Study 2			
	B	**SE**	**Wald**	**OR**	**B**	**SE**	**Wald**	**OR**
Constant	−1.15	0.09	173.34**	0.32	−1.19	0.09	175.37**	0.30
GN Categorical gist	0.21	0.09	5.50*	1.24	0.21	0.10	4.84*	1.23
GN Ordinal gist	−0.03	0.09	0.10	0.97	0.17	0.10	3.03†	1.19
Objective numeracy	−0.05	0.09	0.34	0.95	0.12	0.10	1.66	1.13
Constant	−1.26	0.23	30.60**	0.28	−1.23	0.24	27.45**	0.29
GN Categorical gist	0.21	0.09	5.34*	1.24	0.21	0.10	4.87*	1.24
GN Ordinal gist	−0.05	0.10	0.26	0.95	0.11	0.11	0.97	1.12
Objective numeracy	−0.07	0.10	0.57	0.93	0.16	0.11	2.14	1.18
Intelligence	0.02	0.04	0.24	1.02	0.01	0.03	0.04	1.01

Note: GN = Gist numeracy; OR = odds ratio. Higher scores mean choosing the treatment with lower recurrence rates, but higher side effects (Radiotherapy) instead of the treatment with higher recurrence rates, but lower side effects (Chemotherapy) even though survival rate was the same.
†$p < 0.10$. * $p < 0.05$. ** $p < 0.01$.

TABLE 3 Logistic regression to predict choice of lower recurrence treatment (treatment a) for rectal cancer with factor scores of gist numeracy tasks of categorical gist and ordinal gist, objective numeracy, and controlling for intelligence

	Study 1				Study 2			
	B	**SE**	**Wald**	**OR**	**B**	**SE**	**Wald**	**OR**
Constant	−0.92	0.08	123.47**	0.40	−0.94	0.08	125.26**	0.39
GN Categorical gist	0.19	0.08	5.19*	1.21	0.24	0.09	6.87*	1.27
GN Ordinal gist	−0.09	0.08	1.20	0.92	−0.03	0.09	0.09	0.97
Objective numeracy	−0.05	0.08	0.33	0.95	0.03	0.09	0.10	1.03
Constant	−0.88	0.21	17.28**	0.41	−0.61	0.22	7.82*	0.55
GN Categorical gist	0.19	0.09	5.22*	1.21	0.22	0.09	6.17*	1.25
GN Ordinal gist	−0.08	0.09	0.76	0.92	0.12	0.10	1.28	1.12
Objective numeracy	−0.04	0.09	0.16	0.96	0.04	0.10	0.21	1.05
Intelligence	−0.01	0.03	0.04	0.99	−0.05	0.03	2.81†	0.95

Note: GN = Gist numeracy; OR = odds ratio. Higher scores mean choosing the treatment with lower recurrence rates, but higher side effects (Treatment A) instead of the treatment with higher recurrence rates, but lower side effects (Treatment B) even though survival rate was the same.
†$p < 0.10$. * $p < 0.05$. ** $p < 0.01$.

judging relative risk, but categorical gist was no longer a significant predictor. Again, controlling for Intelligence did not change results; ordinal gist and objective numeracy remained significant.

3.3 | Task 4—Processing of class inclusion illusions in estimating breast cancer genetic risk

Results for Task 4 are shown in Table 5. As in Task 3, ordinal gist and objective numeracy predicted correct responses in Study 1 and this result replicated in Study 2. Also, as observed for all tasks, the same predictors were significant when controlling for Intelligence in both Study 1 and Study 2. Participants with higher scores were more likely to correctly identify the probability of a woman with a genetic mutation to have breast cancer as greater than the probability of ovarian cancer or both breast and ovarian cancer (i.e., having both cancers is less probable than having either cancer by itself). In particular, correctly choosing breast cancer over ovarian cancer involves appreciating that, although the increase in risk is lower for breast cancer than ovarian cancer (increases by 5 times vs. by 15 times), the higher base rate of breast cancer than ovarian cancer (12.2% vs. 1.4%) more than compensates for that in determining overall risk.

TABLE 4 Logistic regression to predict correct choice in a ratio comparison task involving risk of skin cancer with factor scores of gist numeracy tasks of categorical gist and ordinal gist, objective numeracy, and controlling for intelligence

	Study 1				Study 2			
	B	**SE**	**Wald**	**OR**	**B**	**SE**	**Wald**	**OR**
Constant	1.45	0.11	182.31**	4.25	1.35	0.10	180.79**	3.87
GN Categorical gist	0.28	0.10	8.35*	1.33	0.01	0.10	0.02	1.01
GN Ordinal gist	0.67	0.10	46.18**	1.96	0.69	0.10	50.29**	1.99
Objective numeracy	0.98	0.10	95.45**	2.68	0.63	0.10	43.47**	1.88
Constant	1.22	0.25	24.30**	3.38	1.03	0.24	18.54**	2.80
GN Categorical gist	0.27	0.10	7.79*	1.32	0.03	0.10	0.07	1.03
GN Ordinal gist	0.62	0.11	31.88**	1.86	0.54	0.11	24.02**	1.72
Objective numeracy	0.93	0.11	69.18**	2.54	0.63	0.11	34.86**	1.87
Intelligence	0.04	0.04	1.04	1.04	0.05	0.04	2.17	1.05

Note: GN = Gist numeracy; OR = odds ratio. Higher scores mean correctly identifying that the risk of getting skin cancer for a lifeguard (1 in 20) is 5 times greater than the risk for the general population (1 in 100).
† $p < 0.10$. * $p < 0.05$. ** $p < 0.01$.

TABLE 5 Logistic regression to predict correct choice in a ratio judgment class inclusion problem in estimating breast cancer genetic risk with factor scores of gist numeracy tasks of categorical gist and ordinal gist, objective numeracy, and controlling for intelligence

	Study 1				Study 2			
	B	**SE**	**Wald**	**OR**	**B**	**SE**	**Wald**	**OR**
Constant	0.35	0.08	18.02**	1.41	0.29	0.08	12.72**	1.34
GN Categorical gist	0.06	0.08	0.45	1.06	0.09	0.08	1.10	1.09
GN Ordinal gist	0.43	0.09	24.88**	1.54	0.61	0.10	41.82**	1.85
Objective numeracy	0.72	0.09	61.49**	2.06	0.55	0.09	38.10**	1.74
Constant	0.02	0.20	0.01	1.02	−0.03	0.21	0.02	0.97
GN Categorical gist	0.04	0.08	0.29	1.05	0.10	0.08	1.34	1.10
GN Ordinal gist	0.35	0.10	12.83**	1.42	0.46	0.10	19.54**	1.59
Objective numeracy	0.64	0.10	39.34**	1.90	0.54	0.10	27.11**	1.72
Intelligence	0.06	0.03	3.03†	1.06	0.05	0.03	2.76†	1.05

Note: GN = Gist numeracy; OR = odds ratio. Higher scores mean correctly identifying that it is more likely that a woman with a genetic BRCA mutation would have breast cancer (5 × 12.2%) than either ovarian cancer (15 × 1.4%) or both breast and ovarian cancer.
† $p < 0.10$. * $p < 0.05$. ** $p < 0.01$.

4 | DISCUSSION

We investigated how individual differences in gist-based thinking about numbers and computational abilities are associated with making preference-sensitive decisions about tradeoffs between cancer recurrence and side effects and in judging the relative risks of skin cancer (due to sun exposure) and breast cancer (due to genetic mutations) in scenarios that mimic those in public health and medicine (e.g., Reyna, Nelson, et al., 2015; Wolfe et al., 2015). Broadly consistent with fuzzy-trace theory (e.g., Reyna & Brust-Renck, 2020) and other approaches to numeracy (e.g., Peters, 2020) and approximate numeracy (Sobkow et al., 2020), we found that multiple types of numerical processing independently predicted choices and judgments (even when controlling for fluid intelligence). This is the first extension of scales that distinguish categorical gist of numbers, ordinal gist of numbers, and objective numeracy beyond basic paradoxes in judgment and decision making to other domains, specifically, health and medicine.

With the increasing emphasis on evidence-based and shared decision making, people who are not health professionals and who lack mathematical expertise are called upon to make serious health decisions involving numerical ratios, risks, and tradeoffs. However, representative surveys suggest that the average person's ability to accomplish these kinds of numerical processing tasks is limited (Reyna et al., 2009). Although we studied college students, their average scores on items that could be evaluated as correct or incorrect only ranged from 56% to 76% correct, a percentage that would earn an F and a C, respectively according to standard grading rubrics. In addition, we recruited two large samples that encompassed a wide range of numerical abilities and proclivities.

As we discussed in the introduction, objective numeracy has been studied extensively and has been shown to be an important factor in the quality of health judgments and decisions. Our results are consistent with the role of objective numeracy in facilitating judgments about relative health risks and these results replicated across tasks and samples (see also Patalano et al., 2015; Peters, 2012). However, our results indicate that this is only one perspective on numerical information. Consistent with core assumptions of fuzzy-trace theory, there was also evidence that individuals extract multiple representations of numerical information that vary in precision, including qualitative interpretations of numbers that are vague, subjective, and approximate. The evidence for this was that task responses tended to vary across individuals in concert with their scores on valid and reliable measures of categorical and ordinal gist, as well as objective numeracy, and these effects were independent of one another (because factor scores were orthogonal). Each of these contributors to health judgments and decisions accounted for unique variance beyond differences in general intelligence (measured with a well-validated scale). These effects echo those of a formal model of decision making that also distinguished categorical gist, ordinal gist, and objective (verbatim) representations of numbers that accounted for 16 different effects in a literature review on decision making (Broniatowski & Reyna, 2018).

Drilling down to which kinds of representations were predictive in different tasks, categorical gist was related to preference-sensitive decisions about cancer recurrence versus side effects. This decision was described as a tradeoff in which numbers pulled in opposite directions: No one wants cancer to recur or to experience side effects that compromise quality of life, but the treatments described a common dilemma in which one option was superior to the other along these countervailing dimensions offering either a lower recurrence rate or a lower rate of side effects. On its face, this decision does not offer options that differ categorically, as ordinarily used in fuzzy-trace theory to elicit decision preferences that pivot on categorical gist (e.g., Reyna et al., 2014). However, the result that categorical gist was consistently related to preferences to avoid cancer recurrence across versions of the task and across samples suggests that some respondents viewed these options as differing categorically. The more likely that people were to think categorically, the more likely they were to choose avoiding recurrence, suggesting that they viewed the options as differing categorically, for example, as low versus high chance of death from cancer recurrence.

A similar conclusion can tentatively be drawn for at least one of the two samples for skin cancer for which categorical gist was also predictive despite the lack of categorical contrasts across options, too. This pattern of responses is consistent with categorizing the rates of skin cancer as differing qualitatively, again, perhaps as low versus high. Such a categorization of continuous quantities is analogous to results for jurors' mental representations of civil damage awards (e.g., sums awarded to redress pain and suffering), which appear to be classified as low versus high (Reyna, Hans et al., 2015).

There are three reasons why the association with categorical gist measures goes beyond reflecting mere risk aversion by itself. First, options in our problems were all risky, for example, the risk of cancer recurring or the risk of side effects. Thus, categorical gist representations characterize how people tended to interpret the numbers, rather than how the numbers varied objectively. Second, prior research has shown that these categorical gist measures differ from measures of "pure" risk aversion in the sense of preferences for lower versus higher variability in outcomes (Reyna & Brust-Renck, 2020). Third, measures of categorical gist include whether, for example, Russian roulette should be played for any amount of money (regardless of how large the amount is) and other outcomes that do not involve money or death, which assess rejection of trading off itself (under specific circumstances) rather than the degree to which one prefers to trade off risk for reward.

Ordinal gist representations figured in both risk comparison tasks, including a more complicated task that also tapped class-inclusion reasoning (Reyna & Brainerd, 2008). The latter ability is to recognize that when a class of objects or events is subsumed in another class of objects or events—as in the relationship between feminist bank tellers and bank tellers or between developing both breast and ovarian cancer and developing breast cancer—it must be less frequent or less probable. This kind of ordinal relationship of relative magnitude can assist judgments of relative risk regardless of the specific numbers involved and does not require computation. Our results that ordinal gist was distinct from objective numeracy is also reminiscent of findings separating approximate number sense, the intuitive number system, from the analytical system, although both are related to numerical processing (e.g., Brannon, 2006; Peters & Bjalkebring, 2015; Thompson & Opfer, 2010).

It is worth noting that these participants were less likely to have experienced side effects, compared with older patients although young people can and do develop cancer. Individuals who have experienced adverse effects of medical treatment might make different decisions on average, in particular, they might be more tolerant of side effects because of hedonic adaptation (e.g., Ubel et al., 2003).

In summary, in our zeal to encourage high levels of numeracy to facilitate health judgments and decisions, it is important to not overlook the theoretically and empirically grounded arguments that individuals represent numerical information in multiple ways and that individuals vary in the degree to which they rely on these distinct representations. Moreover, people rely on imprecise representations of numbers, even as adults and even with advanced training. These gist representations capture approximate relative magnitudes or, at the crudest but most meaningful level, the categorical gist of *qualitatively* different options. Such qualitative distinctions are often, but not always, necessary to take action in the real world when partial action is not an option.

ACKNOWLEDGMENTS

Preparation of this manuscript was supported in part by a doctoral fellowship to the first author from the CAPES Foundation, Ministry of Education of Brazil (BEX 0412/12-0), and grants to the second author from the National Science Foundation (1536238), National Cancer Institute (R21CA149796), and the National Institute of Nursing Research (R01NR014368-01).

ORCID

Priscila G. Brust-Renck https://orcid.org/0000-0001-9891-510X
Valerie F. Reyna https://orcid.org/0000-0003-2851-5797

REFERENCES

Apter, A. J., Wang, X., Bogen, D., Bennett, I. M., Jennings, R. M., Garcia, L., Sharpe, T., Frazier, C., & Have, T. T. (2009). Linking numeracy and asthma-related quality of life. *Patient Education and Counseling*, *75*(3), 386–391. https://doi.org/10.1016/j.pec.2009.01.003

Arthur, W., & Day, D. (1994). Development of a short form for the Raven advanced progressive matrices test. *Educational and Psychological Measurement*, *54*(2), 394–403. https://doi.org/10.1177/0013164494054002013

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology*, *41*, 189–201. https://doi.org/10.1037/0012-1649.41.6.189

Bostrom, A. (2017). Mental models of risk. In J. F. Nussbaum, *The Oxford Encyclopedia of Health and Risk Message Design and Processing*. Oxford Research Encyclopedia of Communication, Oxford University Press. https://doi.org/10.1093/acrefore/9780190228613.013.533

Brainerd, C. J., & Gordon, L. L. (1994). Development of verbatim and gist memory for numbers. *Developmental Psychology*, *30*(2), 163–177. http://doi.org/10.1037/0012-1649.30.2.163

Brannon, E. M. (2006). The representation of numerical magnitude. *Current Opinion in Neurobiology*, *16*(2), 222–229. https://doi.org/10.1016/j.conb.2006.03.002.

Broniatowski, D. A., & Reyna, V. F. (2018). A formal model of fuzzy-trace theory: Variations on framing effects and the Allais paradox. *Decision*, *5*(4), 205–252. https://doi.org/10.1037/dec0000083

Brust-Renck, P. G., Reyna, V. F., & Corbin, J. C., Royer, C. E., & Weldon, R. B. (2015). The role of numeracy in communication. In H. Cho, T. Reimer, & K. McComas (Eds.), *The SAGE handbook of risk communication* (pp. 134–145). Thousand Oaks, California: SAGE Publications. https://us.sagepub.com/en-us/nam/the-sage-handbook-of-risk-communication/book239298. ISBN: 9781452258683

Brust-Renck, P. G., Reyna, V. F., Wilhelms, E. A., & Lazar, A. N. (2016). A fuzzy-trace theory of judgment and decision-making in health care: Explanation, prediction, and application. In M. A. Diefenbach, S. Miller-Halegoua, & D. J. Bowen (Eds.), *Handbook of health decision science* (pp. 71–86). Springer

Cokely, E. T., Ghazal, S., & Garcia-Retamero, R. (2015). Measuring numeracy. In B. L. Anderson & J. Schulkin (Eds.), *Numerical reasoning in judgments and decision making about health* (pp. 11–38). Cambridge University Press. https://doi.org/10.1017/CBO9781139644358.002

Dehaene, S., & Cohen, L. (1991). Two mental calculation systems: A case study of severe acalculia with preserved approximation. *Neuropsychologia*, *29*(11), 1045–1074. https://doi.org/10.1016/0028-3932(91)90076-K

Dieckmann, N. F., Peters, E., Leon, J., Benavides, M., P Baker, D., & Norris, A. (2015). The role of objective numeracy and fluid intelligence in sex-related protective behaviors. *Current HIV Research*, *13*(5), 337–346. https://doi.org/10.2174/1570162/13666150511123841

Fischhoff, B. (2015). The realities of risk-cost-benefit analysis. *Science*, *350*(6260). https://doi.org/10.1126/science.aaa6516

Fischhoff, B., & Broomell, S. B. (2020). Judgment and decision making. *Annual Review of Psychology*, *71*, 331–355. https://doi.org/10.1146/annurev-psych-010419-050747

Garcia-Retamero, R., Galesic, M., & Gigerenzer, G. (2010). Do icon arrays help reduce denominator neglect? *Medical Decision Making*, *30*(6), 672–684. https://doi.org/10.1177/0272989/10369000

Gärtner, F. R., Portielje, J. E., Langendam, M., Hairwassers, D., Agoritsas, T., Gijsen, B., Liefers, G., Pieterse, A. H., & Stiggelbout, A. M. (2019). Role of patient preferences in clinical practice guidelines: A multiple methods study using guidelines from oncology as a case. *BMJ Open*, *9*(12), e032483. https://doi.org/10.1136/bmjopen-2019-032483

Hanich, L. B., Jordan, N. C., Kaplan, D., Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology*, *93*(3), 615–626. http://doi.org/10.1037/0022-0663.93.3.615

Kleber, J., Dickert, S., Peters, E., & Florack, A. (2013). Same numbers, different meanings: How numeracy influences the importance of numbers for pro-social behavior. *Journal of Experimental Social Psychology*, *49*, 699–705. https://doi.org/10.1016/j.jesp.2013.02.009

Kutner, M., Greenberg, E., Jin, Y., Boyle, B., Hsu, Y., & Dunleavy, E. (2007). *Literacy in everyday life: Results from the 2003 national assessment of adult literacy (NCES 2007–480)*. U.S. Department of Education. Washington, DC: National Center for Education Statistics. https://nces.ed.gov/Pubs2007/2007480_1.pdf

Levy, H., Ubel, P. A., Dillard, A. J., Weir, D. R., & Fagerlin, A. (2014). Health numeracy: The importance of domain in assessing numeracy. *Medical Decision Making*, *34*(1), 107–115. https://doi.org/10.1177/0272989/13493144

Liberali, J. M., Reyna, V. F., Furlan, S., Stein, L. M., & Pardo, S. T. (2012). Individual differences in numeracy and implications for biases and fallacies in probability judgment. *Journal of Behavioral Decision Making*, *25*(4), 361–381. https://doi.org/10.1002/bdm.752

Lyons, I. M., & Beilock, S. L. (2013). Ordinality and the nature of symbolic numbers. *The Journal of Neuroscience*, *33*(43), 17052–17061. https://doi.org/10.1523/JNEUROSCI.1775-13.2013

Patalano, A. L., Saltiel, J. R., Machlin, L., & Barth, H. (2015). The role of numeracy and approximate number system acuity in predicting value and probability distortion. *Psychonomic Bulletin & Review*, *22*(6), 1820–1829. https://doi.org/10.3758/s13423-015-0849-9

Peters, E. (2012). Beyond Comprehension: The Role of Numeracy in Judgments and Decisions. *Current Directions in Psychological Science*, *21*(1), 31–35. http://doi.org/10.1177/0963721411429960

Peters, E. (2020). *Innumeracy in the wild: Misunderstanding and misusing numbers*. Oxford University Press. https://doi.org/10.1093/oso/9780190861094.001.0001

Peters, E., & Bjalkebring, P. (2015). Multiple numeric competencies: When a number is not just a number. *Journal of Personality and Social Psychology*, *108*(5), 802–822. https://doi.org/10.1037/pspp0000019

Peters, E., Dieckmann, N., Dixon, A., Hibbard, J. H., & Mertz, C. K. (2007). Less is more in presenting quality information to consumers. *Medical Care Research and Review*, *64*(2), 169–190. https://doi.org/10.1177/1077558706298290

Peters, E., Slovic, P., Västfjäll, D., & Mertz, C. K. (2008). Intuitive numbers guide decisions. *Judgment and Decision-making*, *3*(8), 619–635. http://journal.sjdm.org/8827/jdm8827.html

Peters, E., Fennema, M. G., & Tiede, K. E. (2019). The loss-bet paradox: Actuaries, accountants, and other numerate people rate numerically inferior gambles as superior. *Journal of Behavioral Decision Making*, *32*(1), 15–29. https://doi.org/10.1002/bdm.2085

Petrova, D., Garcia-Retamero, R., Catena, A., Cokely, E., Heredia Carrasco, A., Arrebola Moreno, A., & Ramírez Hernández, J. A. (2017). Numeracy predicts risk of pre-hospital decision delay: A retrospective study of acute coronary syndrome survival. *Annals of Behavioral Medicine*, *51*(2), 292–306. https://doi.org/10.1007/s12160-016-9853-1

Raven, J., Raven, J. C., & Court, J. H. (1985). *Manual for Raven's Progressive Matrices and Vocabulary Scale*. Oxford, UK: Oxford Pyschologists Press.

Reyna, V. F. (2008). A theory of medical decision making and health: Fuzzy trace theory. *Medical Decision Making*, *28*(6), 850–865. https://doi.org/10.1177/0272989/08327066

Reyna, V. F. (2012). A new intuitionism: Meaning, memory, and development in fuzzy-trace theory. *Judgment and Decision Making*, *7*(3), 332–359. http://journal.sjdm.org/11/111031/jdm111031.html

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). Hoboken, NJ: John Wiley & Sons. https://psycnet.apa.org/record/1994-98730-011

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

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. https://doi.org/10.1016/j.lindif.2007.03.011

Reyna, V. R., & Brust-Renck, P. G. (2015). A review of theories of numeracy: Psychological mechanisms and implications for medical decision making. In B. L. Anderson & J. Schulkin (Eds.), *Numerical reasoning in judgments and decision making about health* (pp. 215–251). Cambridge University Press. https://doi.org/10.1017/CBO9781139644358.011

Reyna, V. F., & Brust-Renck, P. G. (2020). How representations of number and numeracy predict decision paradoxes: A fuzzy-trace theory approach. *Journal of Behavioral Decision Making*, https://doi.org/10.1002/bdm.2179

Reyna, V. R., 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. https://doi.org/10.1177/0956797613497022

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. https://doi.org/10.1037/a0023943

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision-making: Implications for theory, practice, and public policy. *Psychological Science in the Public Interest*, *7*(1), 1–44. https://doi.org/10.1111/j.1529-1006.2006.00026.x

Reyna, V. F., Hans, V. P., Corbin, J. C., Yeh, R., Lin, K., & Royer, C. (2015). The gist of juries: Testing a model of damage award decision making. *Psychology, Public Policy, and Law*, *21*(3), 280–294. https://doi.org/10.1037/law0000048

Reyna, V. F., Lloyd, F. J., & Brainerd, C. J. (2003). Memory, development, and rationality: An integrative theory of judgment and decision-making. In S. L. Schneider & J. Shanteau (Eds.), *Emerging perspectives on judgment and decision research* (pp. 201–245). Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511609978.009

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. https://doi.org/10.1037/a0017327

Reyna, V. F., Nelson, W. L., Han, P. K., Pignone, M. P. (2015). Decision making and cancer. *American Psychologist*, *70*(2), 105–118. http://doi.org/10.1037/a0036834

Scherer, L. D., Yates, J. F., Baker, S. G., & Valentine, K. D. (2017). The influence of effortful thought and cognitive proficiencies on the conjunction fallacy: Implications for dual-process theories of reasoning and judgment. *Personality and Social Psychology Bulletin*, *43*(6), 874–887. https://doi.org/10.1177/0146167217700607

Schley, D. R., & Peters, E. (2014). Assessing "economic value": Symbolic-number mappings predict risky and riskless valuations. *Psychological Science*, *25*(3), 753–761. https://doi.org/10.1177/0956797613515485

Schneider, M., Siegler, R. S. (2010). Representations of the magnitudes of fractions. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(5), 1227–1238. http://doi.org/10.1037/a0018170

Siegler, R. S., & Opfer, J. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, *14*, 237–243. https://doi.org/10.1111/1467-9280.02438

Siegler, R. S., Thompson, C. A., & Schneider, M. (2011). An integrated theory of whole number and fractions development. *Cognitive Psychology*, *62*, 273–296. https://doi.org/10.1016/j.cogpsych.2011.03.001

Smith, S. G., Curtis, L. M., O'Conor, R., Federman, A. D., & Wolf, M. S. (2015). ABCs or 123s? The independent contributions of literacy and numeracy skills on health task performance among older adults. *Patient Education and Counseling*, *98*(8), 991–997. https://doi.org/10.1016/j.pec.2015.04.007

Sobkow, A., Olszewska, A., & Traczyk, J. (2020). Multiple numeric competencies predict decision outcomes beyond fluid intelligence and cognitive reflection. *Intelligence*, *80*, 101452. https://doi.org/10.1016/j.intell.2020.101452

Stevens, J. R. (2016). Intertemporal similarity: Discounting as a last resort. *Journal of Behavioral Decision Making*, *29*, 12–24. https://doi.org/10.1002/bdm.1870

Thompson, C. A., & Opfer, J. E. (2010). How 15 hundred is like 15 cherries: Effect of progressive alignment on representational changes in numerical cognition. *Child Development*, *81*(6), 1768–1786. 0009-3920/2010/8106-0012

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

Tversky Al, & Kahneman D. (1983). Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review*, *90*(4), 293–315. http://doi.org/10.1037/0033-295x.90.4.293

Ubel, P. A., Loewenstein, G., Jepson, C. (2003). Whose quality of life? A commentary exploring discrepancies between health state evaluations of patients and the general public. *Quality of Life Research*, *12*(6), 599–607. http://doi.org/10.1023/a:1025119931010

Wolfe, C. R., & Fisher, C. R. (2013). Individual differences in base rate neglect: A fuzzy processing preference index. *Learning and Individual Differences*, *25*, 1–11. https://doi.org/10.1016/j.lindif.2013.03.003

Wolfe, C. R., & Reyna, V. F. (2010). Semantic coherence and fallacies in estimating joint probabilities. *Journal of Behavioral Decision Making*, *23*(2), 203–223. https://doi.org/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*(1), 46–59. https://doi.org/10.1177/0272989/14535983

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Brust-Renck, P. G., & Reyna, V. F. (2022). Individual differences in numerical representations of risk in health decision making: A fuzzy-trace theory approach. *Risk Analysis*, 1–10. https://doi.org/10.1111/risa.13914