Decision

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An intriguing finding in the decision-making literature is that, when people have to choose between sure and risky options of equal expected value, they typically take more risks when decisions are framed as losses instead of gains (Tversky & Kahneman, 1981). This framing effect is robust and has important implications for health, finance, and politics. However, theoretical debate exists on the origins of this effect. Moreover, pronounced task-related, individual, and developmental differences exist in the magnitude of the effect. These two issues—theoretical debate and differential framing effects—can be solved together, as an adequate theory of the framing effect should both describe the effect itself and describe differences therein. Therefore, we compare four theories on their capacity to describe differential framing effects: cumulative prospect theory (CPT), fuzzy trace theory (FTT), dual process theory, and a hybrid theory (HT) incorporating elements from lexicographic theory and fuzzy trace theory. First, in a theoretical analysis and empirical review, we build on recent advances in the fields of decision making, brain–behavior relationships, and cognitive development. Second, in an empirical study, we directly compare these theories by using a new experimental task and new analytic approach in which we use hierarchical Bayesian model-based mixture analysis of theories. Taken together, results indicate that differential framing effects are best described by the notion that the majority of decision makers decide according to the hybrid theory, and a sizable minority according to cumulative prospect theory and fuzzy trace theory. We discuss implications of these results for our understanding of the framing effect, and for decision making in general.

Keywords: framing effect, cumulative prospect theory, fuzzy trace theory, lexicographic theory, hierarchical Bayesian model-based mixture analysis

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An intriguing finding in the literature on risky decision making is that, when people have to choose between sure and risky options of equal expected value, they typically take more risks when decisions are framed as losses instead of gains (Kahneman & Tversky, 1984; Tversky & Kahneman, 1981). An example of this framing effect is illustrated in Figure 1a. Decision makers are asked to imagine they are given 10 dollars. In the *gain frame*, they are then asked whether they would prefer the sure option of keeping 2 dollars, or the risky option of keeping the 10 dollars with .2 probability and thus losing the 10 dollars with .8 probability. In this *gain frame*, people typically choose the sure option. In the *loss frame*, they are asked whether they would prefer the sure option of losing 8 dollars, or the risky option of keeping the 10 dollars with .2 probability and thus losing the 10 dollars with .8 probability. In this *loss frame*, people typically choose the risky option.

This so-called framing effect[1] in risky choice has important implications for decision making in several domains, such as health (Edwards et al., 2001; Gallagher & Updegraff, 2012; Jefferies-Sewell et al., 2015; McNeil et al., 2004; Rothman & Salovey, 1997; Veldwijk et al., 2016), finance (Brown et al., 2008; Olsen, 1997; Roszkowski & Snelbecker, 1990), or politics (Boettcher, 2004; Kuehnhanss et al., 2015). It is therefore not surprising that the framing effect is among the most investigated phenomena in the decision-making literature. Meta-analyses on this extensive literature have indicated that the framing effect is robust (Gallagher & Updegraff, 2012; Kühberger, 1998; O'Keefe & Jensen, 2009; Piñon & Gambara, 2005) and a large-scale replication project indicated a medium effect size (Klein et al., 2014).

Although it has been shown that the effect is robust, two issues remain. First, the origin of the framing effect is still subject to debate, with different accounts proposed by cumulative prospect theory (CPT; Kahneman & Tversky, 1979; Tversky & Kahneman, 1981, 1992), fuzzy trace theory (FTT; Reyna & Brainerd, 2011; Reyna & Ellis, 1994; Reyna et al., 2011), and dual process theory (DPT; Kahneman & Frederick, 2007). Second, the framing effect is subject to pronounced task-related, individual, and developmental differences. One task-related effect is the truncation effect (Figure 1b): The framing effect is often absent in the truncated formulation in which frame-inconsistent information is omitted (Reyna & Brainerd, 1991), that is, when information on risky losses is omitted in the gain frame, and information on risky gains is omitted in the loss frame (Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna & Brainerd, 1991; Reyna et al., 2014). Another task-related effect is what we will coin the probability effect: The framing effect increases with the probability of risky gains (De Martino et al., 2006; Kühberger et al., 1999).[2] In addition to these task-related differences, there are pronounced individual differences in the magnitude of the framing effect, which may to some

[1] This is a framing effect, and not a reflection effect, as expected values of gain and loss framed items are the same, and consequently sure gain and sure loss amounts differ in their absolute value (Fagley, 1993).

[2] De Martino et al. (2006) reported this probability effect in their supplementary online materials, but did not discuss it any further. Kühberger et al. (1999) speculated that the probability effect might originate in a confound of probability with gain amounts or loss amounts. In the empirical study of the current article, we eliminate this confound.

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Additional publication materials can be found on the Open Science Framework (Huizenga et al., 2022).

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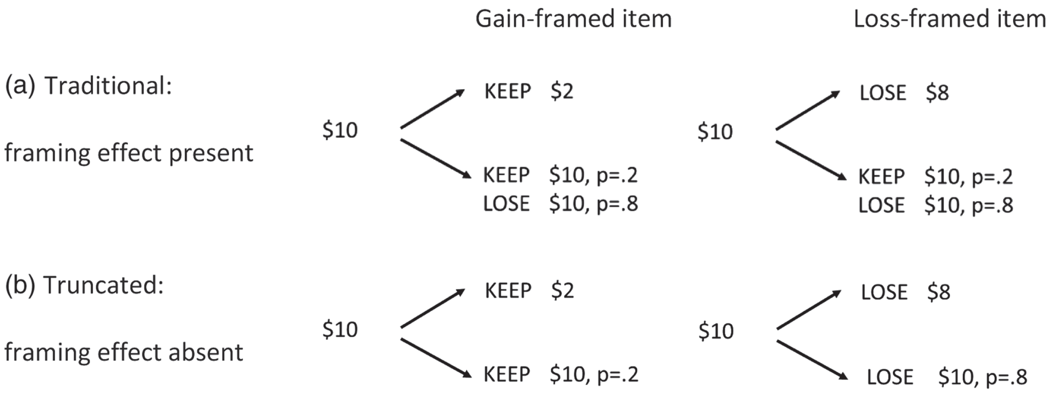
Figure 1
Traditional and Truncated Formulation of Gain and Loss Framed Items



Note. Note that the problem contains an endowment, that is, the 10 dollars (De Martino et al., 2006; McNeil et al., 2004; Reyna & Brainerd, 2011; Reyna et al., 2018; Tversky & Kahneman, 1981, 1986; Zhen & Yu, 2016). Other variants of framing problems do not include this endowment. See the online Supplemental Materials 1, for further details.

extent correlate with a variety of individual differences variables (e.g., Chandler et al., 2009; Corbin et al., 2010; De Martino et al., 2006; Fagley & Miller, 1987; Kahneman & Frederick, 2007; Kam & Simas, 2010; Roiser et al., 2009; Shiloh et al., 2002; Simon et al., 2004; Smith & Levin, 1996; Zickar & Highhouse, 1998). Finally, there are developmental differences: The framing effect increases from childhood to adulthood (Reyna & Ellis, 1994; Reyna et al., 2011; Schlottmann & Tring, 2005, but see Levin et al., 2014).

These two issues—theoretical debate and differential framing effects—can be solved together: An adequate theory of the framing effect should not only describe the effect itself, but should also be able to describe task-related, individual, and developmental differences in this effect. For example, it was argued that CPT cannot adequately describe the probability effect (Kühberger et al., 1999). As another example, Reyna and Brainerd (1991) showed that FTT can describe, and even predicts, the truncation effect, whereas CPT cannot (see also Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna et al., 2014). Moreover, Reyna and Brainerd (2011) argued that FTT, a developmental theory, can describe, and even predicts, the developmental increase in the framing effect, whereas CPT cannot. Finally, Kahneman and Frederick (2007) suggested that DPT may better describe individual differences in brain-related indices of the framing effect than CPT can.

In the current article we therefore systematically compare CPT, FTT, and DPT on their capacity to describe each of the four differential framing effects. We also propose a hybrid theory (HT), inspired by lexicographic theories proposed in the decision making (Bröder & Schiffer, 2006; Kelly et al., 1973; Luce, 1978; Payne et al., 1988; Rieskamp, 2008; Su et al., 2013; Tversky et al., 1988) and the developmental (Piaget & Inhelder, 1969; Siegler et al., 1981) literature.[3] In this HT, we incorporate the concept of "gist," which figures prominently in FTT's explanation of the framing effect. We chose these four theories as each of them was previously mentioned in the decision making as well as in the developmental literature. In the general discussion, we show how these theories relate to decision making and linguistic theories specifically developed to describe framing effects, that is the lexical ambiguity hypothesis (Mandel, 2014; Teigen & Nikolaisen, 2009), information leakage theory (Kühberger & Gradl, 2013; Kühberger & Tanner, 2010; Sher & McKenzie, 2006), and the explicated valence account (Tombu & Mandel, 2015).

This article is organized as follows. In the *theoretical analysis*, we analyze how each theory describes the framing effect and derive the formal model for each theory's description. We then

[3] Note that in this developmental literature it is assumed that children progress from one attribute to two attribute lexicographic decision making, after which they base their decisions on an integration of these attributes. If we thus refer to lexicographic decision making in the developmental literature, we only refer to the lexicographic process and not to the integration process.

analyze how each theory could describe the aforementioned four differential framing effects. In the *empirical review*, we assess whether these theoretical descriptions of differential framing effects are actually supported by existing empirical evidence. We show that, although the existing empirical evidence is informative, it is by no means conclusive. We therefore argue that a new type of empirical study is needed, allowing for more conclusive evidence on which theory best describes differential framing effects. In the *empirical study*, we report such a study, featuring a new experimental task and analytic approach. Our new experimental task was designed so that modeled choice patterns differ between theories, thereby allowing the possibility to discriminate between theories. Our analytic approach allowed us to compare theories by means of formal model comparison. That is, we formulated each theory as a formal, mathematical model and fitted these models to the data after which the best-fitting model for each individual was selected by means of a hierarchical Bayesian model-based mixture analysis (Lee, 2011; Nilsson et al., 2011; Pachur et al., 2017; Steingroever et al., 2018). In the *discussion*, we integrate the theoretical analysis, empirical review, and empirical study, and discuss implications for our understanding of the framing effect, as well as for our understanding of decision making in general.

Theoretical Analysis

Cumulative Prospect Theory

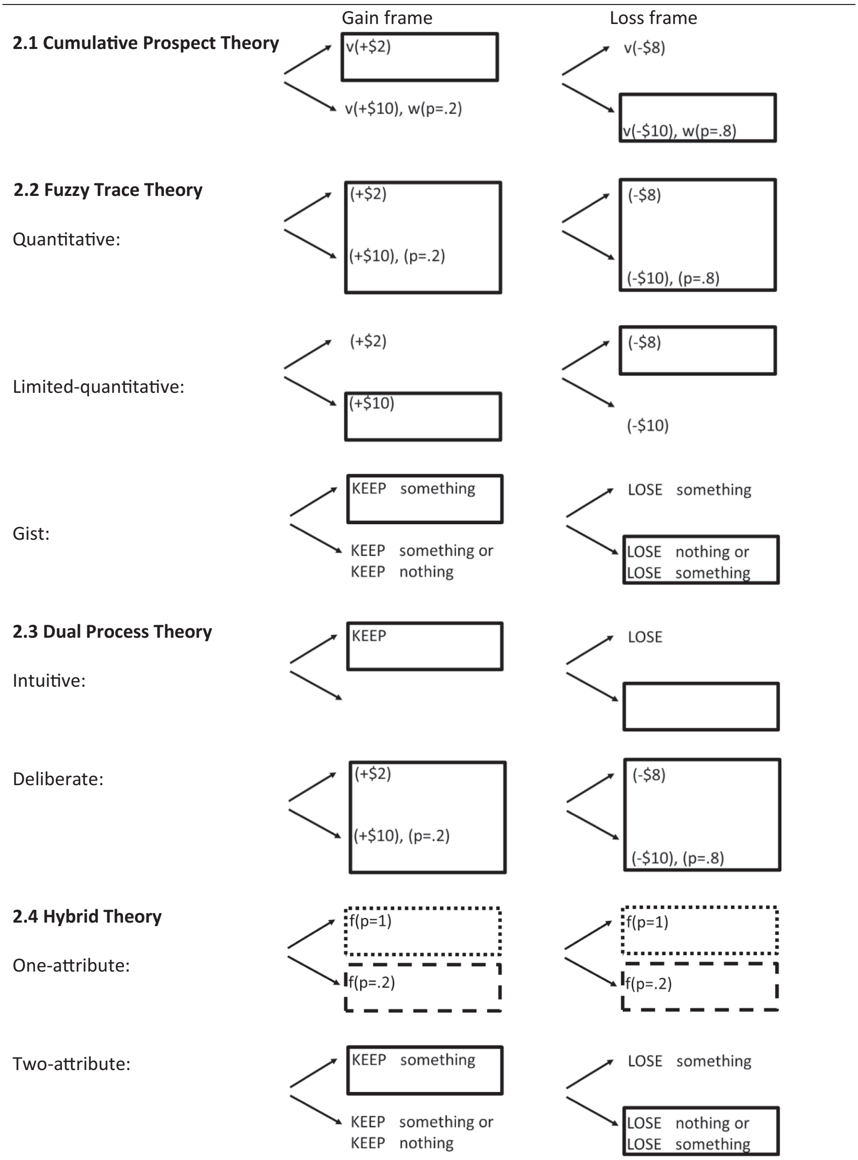
The framing effect is often described by referring to the basic principles of CPT (Tversky & Kahneman, 1992). According to CPT, decision makers, being asked to choose between two options, (a) may edit the two options, (b) subjectively evaluate attributes characterizing the two edited options, and (c) integrate each option's subjective attributes into an overall index of subjective utility, and subsequently choose the option with the highest utility. According to CPT, subjective evaluation of attributes (Step 2) is the key ingredient generating the framing effect (Tversky & Kahneman, 1981).

First, although CPT proposes that decision problems are often edited (Kahneman & Tversky, 1979), it has to our knowledge never been stated explicitly how decision makers edit the framing problem.[4] We propose they do so in the following way. In the editing phase, the endowment, in the example 10 dollars, is set as a reference point, and therefore is omitted (Figure 2.1; Kahneman & Tversky, 1979, refer to this as "coding"). We argue that it is also necessary that frame-inconsistent information, that is, information on risky losses in the gain frame and information on risky gains in the loss frame, is omitted (Figure 2.1). This is necessary because CPT's explanation of the framing effect by means of subjective evaluation is not required to obtain a framing effect if decision makers do not remove frame-inconsistent information, whereas it is required if decision makers do remove this information. We illustrate this with the example in Figure 1a, on the understanding that the endowment has already been omitted. First, consider what happens if decision makers do *not* remove frame-inconsistent information (for our argument's sake, we use objective probabilities and amounts): In the gain frame, the expected value is 2 for the sure option and $10 \times .2–10\times.8 = -6$ for the risky option. Therefore, the sure option will be chosen. In the loss frame, the expected value is -8 for the sure option and $10 \times .2–10 \times .8 = -6$ for the risky option. Therefore, the risky option will be chosen. Hence, a framing effect will be present, subjective evaluation is not required to obtain it. Now consider what happens if frame-inconsistent information *is* omitted. In the gain frame, the expected value is 2 for the sure option and $10 \times .2 = 2$ for the risky option, hence decision makers are indifferent. In the loss frame, the expected value of the sure option is -8 and the expected value of the risky option is $-10 \times .8 = -8$, again decision makers are indifferent. Thus, a framing effect is *not* present and CPT's subjective evaluation is required to obtain the framing effect. For these reasons, we argue that the editing phase also consists of removal of frame-inconsistent information, an additional way of editing next to coding, combination, segregation, cancelation, simplification, and the detection of dominance (Kahneman & Tversky, 1979).

Second, this edited decision problem is subjectively evaluated. The subjective evaluation phase is formalized by nonlinear functions, transforming objective gain and loss amounts and gain and loss probabilities into their subjective counterparts (Figure 2.1, functions v and w). A commonly used probability weighting function (Gonzalez & Wu, 1999; Lattimore et al., 1992) models the observation that low probabilities are overweighted, whereas

[4] In online Supplemental Material 1, we show that this editing is not required in problems that do not include an endowment.

Figure 2
Schematic Representation of Theories

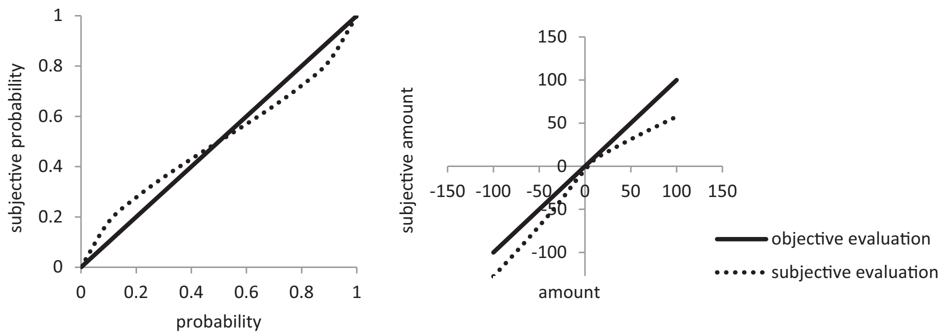


Note. If a box encloses one option, there is a preference for that option, if the box encloses two options, people are indifferent. In hybrid theory's one-attribute strategy, some people may choose risky (- - -) and others sure (…). See text, for further details.

high probabilities are underweighted (Figure 3 left-hand panel). A commonly used value function (Tversky & Kahneman, 1992) models the observation that losses are overweighted compared to gains ("loss aversion"), and that high absolute gain and loss amounts are underweighted as compared to low ones (Figure 3 right-hand panel).

Third, each option's subjective utility is derived by multiplying subjective gain amount or loss amount by its subjective probability,

Figure 3
Subjective Evaluation of Probability and Amount



Note. Probability weighting function (left-hand panel) and value function (right-hand panel) for the objective decision maker and for the subjective decision maker given the often cited (e.g., Trepel et al., 2005) CPT parameter estimates $\gamma = .69$ and $\delta = 1.00$ for the probability weighting function and $\alpha = .88$ and $\lambda = 2.22$ for the value function. Please refer to the text for interpretation of parameters. CPT = cumulative prospect theory.

and the option with the highest subjective utility is chosen.

The aforementioned underweighting of high absolute gain and loss amounts has been suggested as the key ingredient of CPT's account of the framing effect. More specifically, in the gain frame, requiring a choice between a sure small gain amount and a risky large gain amount, decision makers underweight the large gain amount and therefore prefer the sure option. In the loss frame, requiring a choice between a sure small loss amount and a risky large loss amount, decision makers underweight the large loss and therefore prefer the risky option.

CPT: Formal Model

In this section, we give the formal CPT model for the likelihood of a risky choice in the framing paradigm. Formalization requires assumptions, which we make explicit.[5] Let x denote an amount and let p denote its probability. Subjective utility (su) of an option is then defined as:

$$\mathrm{su} = [\mathrm{w}(\mathrm{p})][\mathrm{v}(\mathrm{x})]. \quad (1)$$

In this equation, w and v refer to the probability weighting and value functions, respectively. As the decision problems are edited, in the gain frame, x and p refer to amount and probability of gains only, whereas in the loss frame, they refer to losses only. The probability weighting function w is often defined as (Gonzalez & Wu, 1999; Lattimore et al., 1992; Figure 3, left-hand panel):

$$\mathrm{w}(\mathrm{p}) = \frac{\delta \mathrm{p}^{\gamma}}{\delta \mathrm{p}^{\gamma} + (1 - \mathrm{p})^{\gamma}}. \quad (2)$$

The parameter γ models overweighting of low probabilities and underweighting of high probabilities, it varies between zero and one, an often cited estimate is .69 (Tversky & Fox, 1995). The parameter δ models a general underestimation ($0 < \delta < 1$) or overestimation ($\delta > 1$) of probability. The value function v is often defined as (Tversky & Kahneman, 1992; Figure 3 right-hand panel):

$$\mathrm{v}(\mathrm{x}) = \begin{cases} x^{\alpha} & x > 0 \\ -\lambda(-x)^{\alpha} & x \leq 0 \end{cases}. \quad (3)$$

The parameter λ models loss aversion, it typically exceeds one: An often cited estimate is 2.22 (Tversky & Kahneman, 1992). The parameter α models the observation that high absolute amounts are underweighted compared to low amounts, the parameter varies between zero and one; an often cited estimate is .88 (Tversky & Kahneman, 1992). Finally, the logit choice rule (Stott, 2006) models the likelihood of a risky choice as a function of the difference in subjective utility (Equation 1) of the risky and sure options:

$$\mathrm{p}(\text{risky choice}) = \frac{1}{1 + \exp\{-\phi[\mathrm{su}(\mathrm{r}) - \mathrm{su}(\mathrm{s})]\}}. \quad (4)$$

[5] "formulating models forces one to be very precise about what is being said, which, all too often, is not true of informally stated theories. This fact is important in making theories falsifiable." (Luce, 1999), see also (Fum et al., 2007).

$$\text{Loss frame}: \text{p(risky choice)} = \frac{1}{1 + \exp\{-\phi \times -\lambda[w(p(r)) \times (-x(r))^{\alpha} - w(p(s)) \times (-x(s))^{\alpha}]\}},$$

$$\text{Gain frame}: \text{p(risky choice)} = \frac{1}{1 + \exp\{-\phi[w(p(r)) \times (x(r))^{\alpha} - w(p(s)) \times (x(s))^{\alpha}]\}}. \quad (5)$$

The weighting parameter ϕ indexes to what extent choices are guided by differences in subjective utility. A positive ϕ indicates that options with the highest subjective utility are chosen. If ϕ is zero, choices are based on guessing.[6] In total, CPT is thus characterized by seven strategy parameters. Substitution of Equations 1 and 3 into 4 yields the following likelihood to choose risky:

(See above)

Note that loss-framed items alone do not contain sufficient information to estimate ϕ and λ separately, they are not identified as they are contained in the product $-\phi \times -\lambda$. However, if gain- and loss-framed items are modeled together, these two parameters are identified. One might argue that the loss aversion parameter is not required since overweighting of losses may only be present if items contain both gains and losses, and not when they only contain losses. However, we consider this unlikely, as overweighting of losses has also been shown to occur in situations featuring losses only (Baumeister et al., 2001; Yechiam & Hochman, 2012). We therefore do incorporate the loss aversion parameter.

CPT: Differential Framing Effects

In this theoretical section, we analyze whether CPT could potentially describe the four differential framing effects. The results of this analysis are summarized in Table 1. That is, although CPT was not designed to theoretically predict all of these differential effects, we can analyze whether it potentially can be used to describe them. For example, CPT is not a developmental theory and therefore does not predict developmental differences. However it may potentially describe developmental differences in framing effects by developmental differences in the parameters governing CPT. In Table 1, we therefore also make explicit whether a theory only can describe effects, or even can predict them.

In the Empirical Review section, we determine whether there is actually empirical evidence for these descriptions. This evidence is also summarized in Table 1. For example, in the current section, we show that CPT could potentially describe a developmental increase in the framing effect if there would be a developmental increase in underweighting of high gain and loss amounts. In the Empirical Review section, we then show that the evidence for such a developmental increase in underweighting of high gain and loss amounts is mixed.

First, could CPT describe the truncation effect, that is, the absence of the framing effect if frame-inconsistent information is omitted? Several authors convincingly argued it cannot in problems that do not include an endowment (Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna & Brainerd, 1991; Reyna et al., 2014). The same is true for problems that do include an endowment. As indicated earlier, the CPT description of the framing effect requires that decision makers *themselves* edit the decision problem in such a manner that frame-inconsistent information is omitted (Figure 2.1, information on risky losses is omitted in the gain frame and information on risky gains is omitted in the loss frame). Thus the absence or presence of frame-inconsistent information (the truncation effect) cannot be of any influence. Hence CPT cannot describe the truncation effect. Second, could CPT describe the probability effect, that is, the observation that the framing effect increases with risky gain

[6] Note that in the original formulation of CPT, choices are deterministically driven by differences in subjective value, that is, ϕ is arbitrarily large. In studies in which CPT models are fitted to the data, ϕ is estimated and thus can also be low (e.g. Nilsson et al., 2011; Pachur et al., 2017; for a review also refer to Stott, 2006).

Table 1

Summary of Potential Theoretical Descriptions of Differential Framing Effects

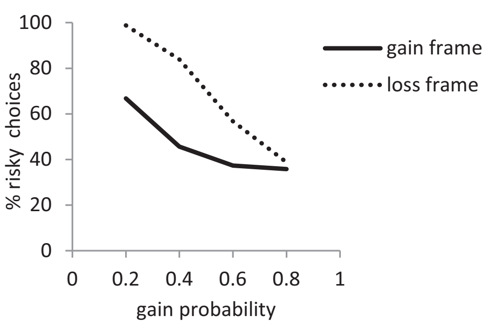
Differential framing effects	CPT	FTT	DPT	HT
Framing absent if frame-inconsistent information is omitted ("truncation effect")		P+		P+
Framing increases with risky gain probability ("probability effect")				P?
Individual differences	D±	D±	D±	D±
Developmental differences: framing effect increases with age	D−	P±	D−	D±

Note. If a theory can describe a differential framing effect, we indicate this by a D, if it even predicts it we indicate this by a P. We also indicate whether potential descriptions are supported by empirical evidence: (? = evidence is lacking; + = supporting evidence; ± = mixed evidence; − = contradictory evidence). See text, for more details. CPT = cumulative prospect theory; FTT = fuzzy trace theory; DPT = dual process theory; HT = hybrid theory.

probabilities? We consider this to be unlikely, as the often cited CPT parameters yield a framing effect that decreases instead of increases with risky gain probability, as illustrated in Figure 4. Third, underweighting of large amounts, captured by $\alpha < 1$, constitutes the key ingredient of CPT's explanation of the framing effect. Therefore, CPT could describe individual differences in the framing effect if there would exist individual differences in the magnitude of this parameter. Finally, and in a similar vein, a developmental increase in the framing effect could be described, if there would exist a developmental increase in underweighting of large amounts.

Figure 4

The CPT-Predicted Percentage of Risky Choices as a Function of Frame and Risky Gain Probability: The Framing Effect Decreases—Instead of Increases—With Risky Gain Probability



Note. The Figure is based on the often cited parameter estimates γ=.69, δ = 1.00, α=.88, and λ = 2.22 ($\gamma_{\_g} = \gamma_{\_l}$, $\delta_{\_g} = \delta_{\_l}$). The attributes of the decision items used to generate this Figure are given in Table 2 (the "Constant Sure Gain" items). CPT = cumulative prospect theory.

Fuzzy Trace Theory

According to FTT (Reyna & Ellis, 1994; Reyna et al., 2011), people code three strategies in parallel, and predominantly rely on one—a quantitative, a limited-quantitative, or a gist strategy—each resulting in a different effect of frame.[7] First, people may use a quantitative strategy that does not yield a framing effect (Reyna, 2012; Reyna & Brainerd, 2011; Reyna et al., 2014; Figure 2.2). In this strategy, options are compared on expected value, it is thus equal to the CPT strategy as discussed in the previous section (including CPT's editing phase), with the important difference that probabilities and amounts are objectively, and not subjectively, evaluated. In the gain frame, expected values of sure and risky options are equal, therefore sure and risky options will be chosen equally often. As the same applies to the loss frame, decision makers using this strategy will not show the framing effect. The second strategy proposed by FTT is a limited-quantitative strategy that yields a so-called reverse framing effect (e.g., Reyna et al., 2011); see Figure 2.2. According to FTT, the only information that remains after editing is information on sure and risky gain *amounts* in the gain frame, and on sure and risky loss *amounts* in the loss frame. The endowment is omitted, as well as all information incongruent with frame and information related to probability. Let us consider the example

[7] In a recent paper, another type of FTT has also been proposed, according to which decisions are based on both a weighted sum of multiple strategies and on reward sensitivity (Broniatowski & Reyna, 2018).

in Figure 2.2. After this editing, in the gain frame, decision makers will gain 2 dollars in the sure option, whereas they will gain 10 in the risky option; therefore they will choose risky. In the loss frame, they will lose 8 dollars in the sure option, whereas they will lose 10 in the risky option; therefore they will choose sure. Consequently, this strategy will result in a reverse framing effect: More risks are taken in the gain than in the loss frame. The third strategy proposed by FTT is a gist strategy that yields a framing effect (Figure 2.2). In this strategy, amounts and probabilities are transformed to nominal variables. That is, amounts are transformed to "something" versus "nothing." Probabilities are transformed to "certain," in that one event occurs, versus "uncertain," in that either of two events may occur (Reyna, 2012; Reyna & Brainerd, 2011; Reyna & Ellis, 1994; Reyna et al., 2014; Rivers et al., 2008). Therefore, in the gain frame, the decision problem is transformed to a choice between "keeping something" versus "keeping something or keeping nothing," therefore the sure option is preferred. In the loss frame, the problem is transformed to "losing something" versus "losing something or losing nothing," therefore the risky option is preferred. Consequently, this gist strategy results in the framing effect.

FTT: Formal Model

In this section, we propose formal models for FTT's strategies in the framing paradigm, while again making the assumptions required for this formalization explicit. Again, x denotes a gain or loss amount and p its associated probability. The quantitative strategy mimics the CPT strategy with the important exception that amounts and probabilities are objectively evaluated. So, in the quantitative strategy, decision makers edit the choice problem (Figure 2.2) and compare options on expected value (ev):

$$\mathrm{ev} = [\mathrm{p}][\mathrm{x}]. \tag{6}$$

As decision problems are edited, in the gain frame, these amounts and probabilities refer to gains only, whereas in the loss frame, they refer to losses only. The logit choice rule (Equation 4), with subjective utility replaced by expected value, yields the likelihood of a risky choice:

$$\mathrm{p(risky\ choice)} = \frac{1}{1 + \exp\{-\phi[\mathrm{ev(r)} - \mathrm{ev(s)}]\}}. \tag{7}$$

A positive ϕ in Equation 7 again indicates that decision makers choose options with optimal expected values. As expected values of sure and risky options are equal, the likelihood to choose risky is 50%, both in gain and in loss frames. The quantitative strategy will thus not give rise to the framing effect.

In the limited-quantitative strategy, problems are also edited (Figure 2.2): In the gain frame, only sure and risky gain amounts, and, in the loss frame, only sure and risky loss amounts remain. Decision makers compare options on these amounts (x). That is, in the gain frame they compare options on gains, whereas in the loss frame they do so for losses. The logit choice rule (Equation 4), with subjective utility replaced by amount (x), will yield the likelihood to choose the risky option:

$$\mathrm{p(risky\ choice)} = \frac{1}{1 + \exp\{-\phi[x(\mathrm{r}) - \mathrm{x(s)}]\}}. \tag{8}$$

A positive ϕ in Equation 8 indicates that decision makers choose options with optimal amounts, that is, with high gains in the gain frame (i.e., the risky option) and with low losses in the loss frame (i.e., the sure option). This strategy thus will yield the reverse framing effect.

In the gist strategy, options are compared on gist. In the gain frame, the gist of risky and sure options is "keep something or keep nothing" and "keep something," respectively. Replacing the operation "or" by addition, the gist difference becomes "keep nothing," which we quantify by the dummy code $d = -1$. Analogously, in the loss frame, the gist difference between risky ("lose something or lose nothing") and sure ("lose something") options will be "lose nothing," which we quantify by the dummy code $d = 1$. The likelihood to choose risky can then be obtained from Equation 4, on the understanding that differences in subjective utility are replaced by dummy-coded differences in gist, that is by $d = -1$ in gain frame, and by $d = 1$ in the loss frame.

$$\text{p(risky choice)} = \frac{1}{1 + \exp\{-\phi d\}}. \quad (9)$$

The parameter ϕ then indicates to what extent decisions are based on the gist difference, with a positive parameter indicating that more risk is taken in the loss than in the gain frame. This strategy thus will yield the regular framing effect. Finally, note that each FTT strategy is characterized by one strategy parameter.

FTT: Differential Framing Effects

In this section, we discuss whether FTT could describe differential framing effects, this analysis is summarized in Table 1. In the Empirical Review section, we review whether there is empirical evidence for these theoretical descriptions (also summarized in Table 1).

First, Reyna and Brainerd (1991) proposed to study the truncation effect as an elegant way to test FTT. It was found that FTT's gist strategy can describe, and even predicts, the truncation effect (Kühberger & Tanner, 2010; Reyna & Brainerd, 1991). This is because in the truncated formulation, the gist of sure and risky options will become the same (Figures 1b and 2.2). It becomes "gain something" in both gain frame options, resulting in 50% risky choices, and "lose something" in both loss frame options, again resulting in 50% risky choices. Consequently, the framing effect will be absent (see also Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna et al., 2014). Second, the probability effect cannot be described by FTT's gist strategy, as it is independent of gain probability. Third, FTT proposes that the reliance on one over the other strategies may differ between individuals (Reyna, 2012; Reyna & Brainerd, 2011; Rivers et al., 2008), although they are available to all (Reyna & Brainerd, 1994; Reyna et al., 2003). Therefore FTT could describe individual differences in the framing effect if there would exist individual differences in the preference for quantitative (framing effect absent) versus limited-quantitative (reverse-framing effect) versus gist-based (framing effect present) strategy use. Finally, FTT is a developmental theory, which predicts counterintuitive developmental findings, among them, the observation that framing effects increase with age (Reyna & Brainerd, 1995, 2011). FTT states that young children rely more on the quantitative strategy, yielding no framing effects, whereas adults rely more on the gist strategy, yielding framing effects (Reyna & Brainerd, 1995; Reyna & Ellis, 1994; Reyna et al., 2011; Reyna & Farley, 2006; Rivers et al., 2008). Therefore FTT would be supported by empirical evidence in favor of such a developmental shift from reliance on quantitative to gist-based processing.

Dual Proces Theory

According to DPT, decisions are based on an intuitive response that may be inhibited and subsequently overridden by a deliberate one (Kahneman, 2003). In the context of the framing of decisions, Kahneman and Frederick (2007) proposed that decision makers are characterized by an intuitive response to the emotionally loaded phrasing of the sure options. More specifically (Figure 2.3), in the gain frame, the sure option is characterized by "keep," whereas in the loss frame, it is characterized by "lose." This would result in a liking of the sure option in the gain frame, and in a disliking of the sure option in the loss frame, and thus in a framing effect. However, this intuitive response may be inhibited, and decision makers may resort to a deliberate process that does not result in the framing effect. As it does not result in a framing effect, we assume that this deliberate process is based on comparing expected value, just as in FTT's quantitative strategy, although this has not been specified in such detail by Kahneman and Frederick (2007).

DPT: Formal Model

Here we give formalizations of the intuitive and deliberative strategies in the framing paradigm, making our assumptions explicit. In the intuitive strategy, the phrasing of sure options evokes affect, which then guides the decisions (Kahneman & Frederick, 2007). In the gain frame, we quantify the affective response triggered by "keep" by the dummy code $d = -1$. In the loss frame, we quantify the affective response triggered by "lose" by the dummy code $d = 1$.

The likelihood to choose risky is then obtained from Equation 4, on the understanding that the difference in subjective utility is replaced by the dummy-coded affective response:

$$p(\text{risky choice}) = \frac{1}{1 + \exp\{-\phi d\}}. \quad (10)$$

The parameter ϕ indexes to what extent decisions are based on this affective response, with a positive parameter indicating that more risk is taken in the loss than in the gain frame. Note that the structure of the model mimics that of FTT's gist strategy (Equation 9); therefore, we use the same dummy-coded variable d. Note however that the interpretations of these models differ in an important way: Whereas in DPT's intuitive strategy the framing effect is triggered by the phrasing of the sure option, in FTT's gist strategy it is triggered by a difference in phrasing between risky and sure options.

Finally, the deliberate strategy is assumed to be similar to FTT's quantitative strategy in which options are compared on expected value, which was formalized in Equations 6 and 7. Note that each DPT strategy is thus characterized by one strategy parameter.

DPT: Differential Framing Effects

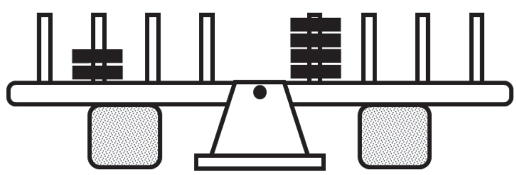
Could DPT be used to describe differential framing effects? Our answer is summarized in Table 1. Note again that we review later whether these theoretical descriptions are actually supported by empirical evidence. First, we argue that DPT cannot describe the truncation effect. This is due to the fact that decision makers using DPT's intuitive strategy do not consider information on the risky option at all (Figure 2.3). Therefore, omitting part of this information cannot be of any influence. Second, we argue that the probability effect also cannot be described by DPT, as decision makers using DPT's intuitive strategy do not consider information on the risky option, and therefore their decisions are independent of gain probability. Third, according to DPT, individual differences in the framing effect could be described if there would be individual differences in the capacity to inhibit intuitive responses and in the capacity to use deliberate processing (Kahneman & Frederick, 2007). Finally, in a similar way, DPT could describe a developmental increase in the framing effect if there would be a developmental *decrease* in the capacity to inhibit and in the capacity to use deliberate processing. Note however that this contradicts dual-process theories in the developmental field, which assume a developmental *increase* in both inhibition and deliberate processing (e.g., Bjorklund & Harnishfeger, 1990; Steinberg, 2010).

Hybrid Theory

The aforementioned three theories describe the framing effect, and could describe some, but not every differential framing effect (Table 1). In order to potentially describe all differential framing effects, we also consider lexicographic theory, which has been proposed in the decision-making literature (Bröder & Schiffer, 2006; Kelly et al., 1973; Luce, 1978; Payne et al., 1988; Rieskamp, 2008; Su et al., 2013; Tversky et al., 1988) and in the developmental literature (Piaget & Inhelder, 1969; Siegler et al., 1981). In this lexicographic theory, we also incorporate FTT's idea of "gist," hence we coin this Hybrid Theory incorporating elements from lexicographic theory and FTT.

In lexicographic decision making, options are sequentially compared on their attributes. That is, these decision makers first compare options on one attribute, if they consider differences on this first attribute to be large, they base their choice on it. If they consider differences on the first attribute to be small, they proceed to a second attribute, and base their decision on that. We first illustrate this, not in a decision-making task but, in a classic developmental paradigm, the balance scale task (e.g., Siegler & Chen, 2002). In this task, participants have to decide to which side a balance scale will tip, depending on the number and distance of weights on each side of the fulcrum (Figure 5). A wide variety of strategies can be used in this task (Jansen & van der Maas, 1997;

Figure 5
The Balance Scale Task



Note. Participants have to decide to which side the balance scale will tip after the supporting blocks have been removed. Image created by Brenda Jansen.

Wilkening & Anderson, 1982). For example, some participants, using an integrative strategy, multiply attributes, that is, number of weights and their distance, into a single concept and compare options on it. However, others, using a lexicographic strategy, do not. More specifically, they first assess one attribute, often the number of weights. If they consider differences on the number of weights to be large, they base their choice on it. If they consider differences to be small, they proceed to a second attribute, often distance, and base their decision on that. In decision-making tasks, similar processes apply, but in this case attributes refer to the attributes of decision-making options (Bröder & Schiffer, 2006; Kelly et al., 1973; Luce, 1978; Pachur et al., 2017; Payne et al., 1988; Rieskamp, 2008; Su et al., 2013; Tversky et al., 1988).

Some lexicographic decision makers may always base their decisions on the first attribute, even if the attribute differences between options are small. Several explanations have been put forward for such a one-attribute strategy. In the developmental literature, it has been suggested that a one-attribute strategy is used by decision makers who cannot suppress an impulsive response to small differences on the first attribute (Bjorklund & Harnishfeger, 1990; Borst et al., 2012; Houdé, 2000; Poirel et al., 2012). For example young children, characterized by immature inhibition (Chevalier, 2015; Durston et al., 2002; Huizinga et al., 2006), often use a one-attribute strategy (Jansen & van der Maas, 1997, 2001, 2002; Raijmakers et al., 2004), but see (Schlottmann, 2001; Schlottmann & Anderson, 1994). Moreover, adolescents with mild to borderline intellectual disability, characterized by immature inhibition (Bexkens et al., 2014), also use a one-attribute strategy (Bexkens et al., 2016). In the decision-making literature, it has been suggested that, if options are approximately equivalent and if participants are forced to choose, all decision makers, not only children, may use a one-attribute strategy. They do so to simply break the tie between two nearly equivalent options (Tversky et al., 1988), for a similar line of reasoning, see (Wang, 2008; Wang et al., 2017). To summarize, a one-attribute strategy may be used if decision makers cannot inhibit impulsive responses to the first attribute, or if they use the first attribute to break the tie between nearly equivalent options.

Before we provide a lexicographic account of the framing effect, it should be acknowledged that this theory is not without criticism. First, it has been argued, in the decision making as well as in the developmental literature, that data often do not offer the possibility to distinguish between lexicographic and other decision strategies (Huizenga et al., 2014; Johnson et al., 2008; Wilkening & Anderson, 1982). Therefore, it is important to design experimental tasks offering the possibility to delineate strategies (Rieskamp, 2008). Second, it has been stated that lexicographic decision making may not be used in every situation, but may be restricted to situations in which options are nearly equivalent (Leland, 1994; Shafir et al., 1993; Tversky et al., 1988), as lexicographic decision making then is characterized by a favorable balance between the outcome of a decision and the time required to obtain it (Lieder & Griffiths, 2017; Payne et al., 1988). The framing paradigm arguably satisfies this requirement of near equivalence, as sure and risky options have equal expected values.

Which attributes, and in what order, are considered in the framing task? We propose that the first attribute is gain probability and the second attribute is FTT's gist. This proposition is motivated by three reasons. First, previous studies, also in developmental samples, have shown that probability, and not gain or loss amounts, often is considered to be the most important attribute (Aïte et al., 2012; Hasher & Zacks, 1984; Huizenga et al., 2007; Jansen et al., 2012; Kwak et al., 2015; Payne, 2005; Payne et al., 1988; Slovic, 1995; Slovic & Lichtenstein, 1983; Van Duijvenvoorde et al., 2016; Venkatraman et al., 2009; Venkatraman et al., 2014, but see, e.g., Brandstätter et al., 2006; Rieskamp, 2008). Second, the importance of the gist attribute is exemplified by the fact that FTT, in which gist is a crucial attribute, can describe more differential framing effects than CPT and DPT (Table 1). Third, this order of attributes, probability first and gist second, can predict both the truncation effect and the probability effect, as we show later in the section HT: Differential framing effects.

So, according to HT, decision makers first assess gain probability, and therefore the decision problem is edited such that only information on gain probability remains. If decision makers base their decision on gain probability, they may either choose sure or risky (Figure 2.4). As editing has resulted in equivalent gain and loss framed items (Figure 2.4), no framing effect will be present.[8]

Decision makers may, however, not base their decision on gain probability, but move on to the second attribute, gist. The decision problem is reedited just as in FTT's gist strategy. Deciding given this second attribute will result in a framing effect, just as in FTT's gist-based strategy (Figure 2.4). The risky gain probability threshold at which decision makers base their decision on the second instead of the first attribute may for example, be .6. In this case, decision makers are *not* affected by frame at low risky gain probabilities, but are affected at high risky gain probabilities.

HT: Formal Model

In this section, we derive the formal model and our associated assumptions for the two-attribute strategy; the one-attribute strategy is shown to be a special case of it. Decision makers base their decisions on a quantity q, which may either be a difference in gain probability or a difference in gist. The risky gain probability threshold parameter at which decision makers jump from gain probability- to gist-based decisions is denoted by the parameter ψ. Formally:

$$q = \begin{cases} \beta_0 + \beta_1(p(r) - p(s)) & p(r) \leq \psi \\ \theta d & p(r) > \psi \end{cases}. \quad (11)$$

As the gain probability of the sure option is always one, we omit it without loss of generality:

$$q = \begin{cases} \beta_0 + \beta_1 p(r) & p(r) \leq \psi \\ \theta d & p(r) > \psi \end{cases}, \quad (12)$$

$$p(\text{risky choice}) = \frac{1}{1 + \exp\{-q\}}. \quad (13)$$

In Equation 12, risky gain probability is again denoted by p(r). The parameter β_0 is an intercept. A positive β_0 indexes that if risky gain probability is zero, people prefer the risky option; a negative parameter indicates that they then prefer the sure option. The parameter β_1 quantifies how decisions are based on risky gain probability. A positive β_1 indicates an increasing preference for risky options if risky gain probability increases, whereas a negative parameter indicates a decreasing preference. The difference in gist (i.e., the second attribute) is coded by $d = 1$ in the loss frame and $d = -1$ in the gain frame, just as in FTT's gist strategy. The parameter θ quantifies to what extent decisions are based on the difference in gist; a positive θ indicates that more risk is taken in the loss than in the gain frame. Note that if the threshold parameter ψ exceeds the maximum risky gain probability in a task, decision makers always base their decision on the first attribute. In total the HT strategy is thus characterized by four strategy parameters.

HT: Differential Framing Effects

Again we first analyze whether HT could describe differential framing effects, in the Empirical Review section, we then discuss whether such a description is actually supported by empirical evidence. First, and as summarized in Table 1, HT can describe and even predicts the truncation effect. That is, just as in FTT's gist strategy, the framing effect originates in gist differences, which will disappear when frame-inconsistent information is omitted. Second, HT can describe and even predicts the probability effect. More specifically, at low risky gain probabilities, the difference between risky versus sure gain probabilities is large. Therefore, people may consider only gain probability and thus will not be affected by frame. However, with increasing probability of risky gains, the probability difference between sure and risky options decreases. As a consequence, decision makers will have an increasing tendency to consider the second attribute, gist, which will introduce a framing effect. Third, HT could describe individual differences in the framing effect if only some decision makers would consider the second attribute, gist. As argued earlier, they may do so if they are able to inhibit an impulsive response to the first attribute, gain probability, or if they do not use gain probability to break the tie between nearly equivalent options (Tversky et al., 1988). Finally, and in a similar way, HT could describe a developmental increase in the framing effect if there would exist a developmental increase in inhibition or a developmental increase in the tendency to use probability to break the tie between nearly equivalent options, or in both underlying processes.

[8] Note this was also noticed by Reyna and Ellis (1994) whom stated that "[…] children might focus on the risk dimension, […]. This trend would not differ across frames, […].".

Empirical Review

In the previous section, we analyzed whether differential framing effects could be described by each of the four theories. We showed that FTT and HT could describe the truncation effect, that HT could describe the probability effect, and that all theories could describe individual and developmental differences in the framing effect if individual and developmental differences in explanatory constructs are present. In the current section, we review whether such descriptions are actually supported by empirical evidence.

We showed that both FTT and HT could describe, and even predict, the truncation effect as truncation removes gist differences. These FTT and HT descriptions of the truncation effect are indeed supported by empirical evidence (Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna & Brainerd, 1991; Reyna et al., 2014). We also showed that HT could describe, and even predict, the probability effect since the second attribute, gist, is only considered at high gain probabilities. However, there is to our knowledge no empirical evidence addressing this suggestion. Kühberger even speculated that the probability effect may originate in a confound of probability with gain or loss amounts (Kühberger et al., 1999). If found to be true, this would provide evidence against HT's account of the probability effect. In the current empirical study, we therefore remove this confound.

Finally, we showed that all theories could describe individual and developmental differences if there would exist individual and developmental differences in a variety of constructs. That is, CPT requires differences in underweighting of large amounts, FTT differences in the reliance on gist versus quantitative strategies, DPT differences in inhibition and deliberation, and HT differences in inhibition and differences in a preference for using probability to break the tie between nearly equivalent options. We will refer to these as differences in *explanatory constructs*. We now review whether individual and developmental differences in the framing effect are related to individual and developmental differences in these explanatory constructs. For example, let us consider CPT, which proposes that increased underweighting of large amounts increases the framing effect. Supporting evidence would then be that individuals scoring high on indices related to underweighting would show a more pronounced framing effect. Evidence on developmental differences would preferably be derived from a mediation analysis. In the CPT example, the effect of age (independent variable) on the framing effect (dependent variable) should then be mediated by indices related to underweighting. However, as such mediational evidence is lacking for all theories, we can only discuss studies on age-related changes in explanatory constructs. For example, in CPT, we only discuss evidence on the development of indices related to underweighting of large amounts. To foreshadow the results, the conclusion of this empirical review is that evidence on individual and developmental differences is far from unequivocal. We therefore argue that a new type of empirical study is needed, which we then report in the remainder of the article.

Individual Differences

In CPT, the explaining construct is underweighting of large amounts. To our knowledge, and surprisingly, no studies directly tested associations between individual differences in the framing effect and individual differences in underweighting. However, as underweighting is generally interpreted as an indication of subjectivity (Tversky & Kahneman, 1992), indirect empirical evidence can be obtained from studies investigating the relationship between the framing effect on the one hand and a wide variety of subjectivity/objectivity indices on the other. Many studies investigated this association, and CPT can thus be considered as supported by studies showing that the framing effect is associated with high scores on a presumed subjectivity index, experiential processing (Stark et al., 2017), and by studies showing that the framing effect is associated with low scores on presumed objectivity indices, like SAT scores (West et al., 2008), analytic versus holistic thinking style (McElroy & Seta, 2003), and need for cognition (Simon et al., 2004; Smith & Levin, 1996), and by studies showing that a reduced framing effect is observed in individuals with autism spectrum disorders, known to be characterized by objective processing (De Martino et al., 2008). However, other studies have shown that the framing effect is *not* associated with indices like need for cognition (LeBoeuf & Shafir, 2003), rationality (Shiloh et al., 2002), rational thinking (Mahoney et al., 2011), SAT scores (Stanovich & West, 2008), conscientiousness (Appelt et al., 2010), rational processing (Stark et al., 2017), analytic thinking (Miller et al., 2009), cognitive reflection (Toplak et al., 2014), and a variety of decision-making styles (Bruine de Bruin et al., 2007).[10] Moreover, contradicting the CPT description, one study indicated that the framing effect is increased, instead of decreased, in individuals scoring high on working memory capacity (Corbin et al., 2010).

In FTT, the explanatory construct is reliance on gist versus quantitative strategies. Again, to our knowledge, no studies directly tested a relationship between this preference and the framing effect. However, this preference may be related to the aforementioned subjectivity/objectivity indices, where gist-based processing would be associated with indices of subjectivity whereas quantitative strategies would be associated with indices of objectivity. As indicated in the previous CPT paragraph, the evidence for such a relationship is mixed.

In DPT, the explanatory constructs are the capacity to inhibit intuitive responses and the capacity to use deliberate processing. Kahneman and Frederick (2007) argued that the role of inhibition may be supported by the observation that individuals with a diminished framing effect are characterized by enhanced responses in the orbitomedial prefrontal cortex (OMPFC; De Martino et al., 2006; Roiser et al., 2009), which has been implicated in the inhibition of intuitive responses (Etkin et al., 2011; Ochsner et al., 2004). Inhibition as an explaining construct is also supported by a study showing that some, but not all, indices of inhibition are associated with a diminished framing effect (Sütterlin et al., 2011). Kahneman and Frederick argued that the role of deliberation may also be supported by enhanced responses in the OMPFC (De Martino et al., 2006; Roiser et al., 2009) as OMPFC activity may reflect the integration of several sources of information. However, assuming that deliberation can be assessed by the aforementioned behavioral subjectivity/objectivity indices, the evidence in favor of the deliberation construct is, as indicated in CPT paragraph, mixed.

Finally, HT's explanatory constructs are inhibition and using probability to break the tie between nearly equivalent options. The empirical evidence related to inhibition contradicts HT's description that increased inhibition is related to an *increased* framing effect, as it has been shown to be unassociated, or even associated with a *decreased* framing effect (Sütterlin et al., 2011). Moreover, it is unclear how to operationalize the construct "probability to break the tie between nearly equivalent options''. Arguably, such a focus on probability may be supported by the observation that OMPFC activity is associated with a decreased framing effect (De Martino et al., 2006; Roiser et al., 2009). OMPFC activity, implicated in the coding of a common currency (Levy & Glimcher, 2011; Sescousse et al., 2013), would then reflect probability coding. However, to our knowledge, no studies tested whether OMPFC activity in the framing task scales with probability.

Developmental Differences

A CPT description of a developmental increase in the framing effect would be supported by empirical evidence showing that underweighting of large amounts increases with age. To our knowledge no study tested this, however, some studies did test other forms of subjective weighting. These studies contradict the CPT description: One study found a developmental decrease in subjective probability weighting (Harbaugh et al., 2002), and others an age related increase in objective number representation (for an overview: Siegler et al., 2009). Indirect evidence, again based on the assumption that subjective weighting is related to subjectivity/objectivity indices, also contradicts a CPT description, as there is an age-related decrease in subjectivity (Kokis et al., 2002; Stanovich et al., 2008).

FTT can describe and even predicts a developmental increase in the framing effect. This prediction would be supported by empirical evidence showing an age-related increase in reliance on gist strategies. Indeed, in the domain of decision making, reasoning, and memory, it has been shown that reliance on heuristic processing increases with age (Brainerd & Reyna, 2015; Davidson, 1991; De Neys & Vanderputte, 2011; Furlan et al., 2013; Jacobs & Klaczynski, 2002; Morsanyi & Handley, 2008). However, if one assumes that a preference for gist strategies is related to subjectivity indices,

[10] Some have argued that associations are more likely to be observed in within-subjects designs. That is, people scoring high, as compared to low, on objectivity indices may be better able to recognize that problems are equivalent and thus will be less affected by frame (Broniatowski & Reyna, 2018; LeBoeuf & Shafir, 2003; Stanovich & West, 2008).

the evidence contradicts the FTT description, as several studies report a developmental decrease in subjectivity indices (Kokis et al., 2002; Stanovich et al., 2008).

A DPT description of a developmental increase in the framing effect would require empirical evidence showing a developmental decrease in both inhibition and deliberate processing. However, there is a developmental *increase* in inhibition (e.g., Best & Miller, 2010; Crone, 2009; Durston et al., 2002; Huizinga et al., 2006; Steinbeis & Crone, 2016) and in deliberate processing as operationalized by subjectivity/objectivity indices (Kokis et al., 2002; Stanovich et al., 2008).

A HT description of a developmental increase in the framing effect would require empirical evidence showing a developmental increase in inhibition or using probability to break the tie between nearly equivalent options. Indeed there is a developmental increase in inhibition (e.g., Best & Miller, 2010; Crone, 2009; Durston et al., 2002; Huizinga et al., 2006; Steinbeis & Crone, 2016). However, we are not aware of any studies addressing development in the construct of using probability to break the tie between nearly equivalent options.

Conclusion and Discussion Theoretical Analysis and Empirical Review

An adequate theory of the framing effect should not only describe the framing effect itself, but also should describe differential framing effects, that is, task-related, individual, and developmental differences in this effect. Therefore, we analyzed for each of the four theories whether it could describe these differential framing effects. The general conclusion is that CPT, FTT, and DPT could describe some, but not every differential effect, whereas HT, incorporating elements from lexicographic theory and FTT, could describe every effect. However, the empirical evidence regarding these descriptions is not conclusive, as can be seen in the summary in Table 1. Although FTT's and HT's description of the truncation effect is supported by empirical evidence, there is no evidence pertaining to HT's description of the probability effect. Moreover, the empirical evidence on the CPT, FTT, DPT, and HT descriptions of individual and developmental differences contradicts these descriptions or is inconclusive.

Therefore, the empirical evidence does not offer the opportunity to unequivocally decide which theory best describes differential framing effects. For these reasons, we aimed to gather additional evidence in an empirical study in which we implemented a new experimental and data analytic approach. This new approach allowed us to directly pit theories against each other, as is further outlined in the next section.

Empirical Study

The purpose of the empirical study was to determine which theory best describes differential framing effects. In the theoretical section, we showed that each theory of the framing effect can be rewritten as a formal model. This offers the unique opportunity to compare theories directly by testing which formal model best describes data on differential framing effects. In doing so, two issues deserve special consideration.

The first issue to be considered is the experimental paradigm's sensitivity to distinguish between theories. A sensitive paradigm should satisfy two requirements. First, its items should vary in risky gain probability, as effects of risky gain probability are *not* described by FTT and DPT, whereas they are described by CPT and LT. Second, items of a sensitive paradigm should differ in gain amounts and loss amounts, as effects of these attributes are not described by DPT and HT, whereas they are described by CPT and FTT. In the empirical study, we therefore tested the four theories against each other by employing a sensitive experimental paradigm, consisting of multiple items that differ in gain probabilities and in gain and loss amounts.

The second issue relates to the fact that there may exist individual and developmental differences in strategy use (Bexkens et al., 2016; Glöckner & Pachur, 2012; Horstmann et al., 2012; Huizenga et al., 2007; Jansen et al., 2012; Lang & Betsch, 2018; Mata & Von Helversen, 2011; Pachur & Olsson, 2012; Pachur et al., 2017; Steingroever et al., 2014; Zadelaar et al., 2019). In accordance, FTT, DPT, and HT all propose that people may differ in their strategy use. For example, according to FTT people may use a quantitative, a limited-quantitative, or a gist strategy. Moreover, although not proposed as such by either of these theories, some decision makers may use a strategy proposed by one theory, whereas others may use a strategy proposed by another theory.

Therefore, a traditional analysis of averaged data may mask important individual and developmental differences, or may even result in erroneous conclusions on strategy use. For example, let us suppose that decision making is governed by the laws of FTT, and that half of the participants uses the limited-quantitative strategy, yielding the reverse-framing effect, whereas the other half uses a gist strategy, yielding the regular framing effect. In this case, average data will show no framing effect at all, which will then be incorrectly interpreted as being indicative of usage of FTT's quantitative strategy. For these reasons, we used a hierarchical Bayesian model-based mixture analysis, that is very well suited to identify such strategy differences.

Method

Participants

To investigate individual and developmental differences in the framing effect, we studied a large and developmentally diverse sample. Children and adolescents were recruited through schools for primary and secondary education in the Netherlands; adults were psychology students from the University of Amsterdam. The total sample consisted of 294 participants in several age groups: 6–8 years ($N = 50$; $M_{\text{age}} = 6.8$; 54% male), 8–10 years ($N = 50$; $\text{M}_{\text{age}} = 8.6$; 41% male); 10–12 years ($N = 50$; $M_{\text{age}} = 10.9$; 54% male), 12–13 years ($N = 51$; $M_{\text{age}} = 12.3$; 35% male), 14–16 years ($N = 49$; $M_{\text{age}} = 14.3$; 37% male), and 18–57 years ($N = 44$; $M_{\text{age}} = 23.6$; 36% male).[11] For children and adolescents, primary caretakers were informed about the experiment and were provided with the opportunity to exempt their child from participating. Adults gave written informed consent. All procedures were approved by the local ethics committee of the University of Amsterdam.

Materials and Experimental Design

The framing task was a paper-and-pencil task, coined "The Money Game." The task consisted of two booklets, one containing 32 regular gain-framed items, and the other containing 32 matching regular loss-framed items. Each participant filled in both booklets. In these regular items, risky and sure options had the same expected value (see Table 2). Both booklets also contained four catch items in which risky and sure options markedly differed in their expected value (Table 2). These catch items allowed us to determine whether participants understood the task and paid attention to it (De Martino et al., 2006), which is especially important in the present study, as it included young children. In each item, participants were presented with an endowment and were asked to make a choice between a sure and a risky option (Figure 6). Probabilities were presented graphically (De Martino et al., 2006), to increase understanding of the probability concept, especially by children (Reyna & Farley, 2006).

To study the framing effect, we included the within-subjects factor frame with two levels: gain frame and loss frame. To study the probability effect, we included the within-subjects factor probability of a risky gain, with levels .2, .4, .6, and .8. To check for the potential effect of gain and loss amounts, we included the factor scenario with two levels: constant sure gain (CSG) or constant sure loss (CSL; Table 2). Note that due to the requirement of equal expected values of sure and risky options, probability differences might be confounded with gain or loss amount differences (Table 2, final two columns; Kühberger et al., 1999). That is, in the CSL items, probability differences are confounded with loss amount differences, whereas in the CSG items, probability differences are confounded with gain amount differences. Administering both sets of items however eliminates these confounds. That is, if we find a probability effect in both sets of items, we can attribute it to probability differences and not to gain or loss amount differences. Similarly, if we find effects of Scenario, we can attribute it to gain and loss amount differences and not to probability differences.

Each of the 2 (frame) $\times$ 4 (probability) $\times$ 2 (scenario) = 16 item types was repeated in four blocks; twice with the sure option in the upper position, and the risky option in the lower position, and twice vice versa. Within the gain and loss frame version of the booklet, each of the four blocks contained all eight item types, the order of item types within a block was random, half of the participants received this order and the other half received the reversed order. Each item was presented on a separate page.

[11] The initial sample contained more participants in the three youngest age groups. To prevent results to be dominated by these age groups, we randomly selected 50 participants.

Table 2
Characteristics of Item Types

Endowment	Risky gain amount	Risky gain probability	Risky loss amount	Risky loss probability	Sure gain amount	Sure gain probability	Sure loss amount	Sure loss probability	Gain probability dif.	Gain amount dif.	Loss amount dif.
Scenario: constant sure loss (CSL)											
22.5	22.5	.2	−22.5	.8	4.5	1	−18.0	1	−.8	18.0	−4.5
30.0	30.0	.4	−30.0	.6	12.0	1	−18.0	1	−.6	18.0	−12.0
45.0	45.0	.6	−45.0	.4	27.0	1	−18.0	1	−.4	18.0	−27.0
90.0	90.0	.8	−90.0	.2	72.0	1	−18.0	1	−.2	18.0	−72.0
Scenario: constant sure gain (CSG)											
30.0	30.0	.2	−30.0	.8	6.0	1	−24.0	1	−.8	24.0	−6.0
15.0	15.0	.4	−15.0	.6	6.0	1	−9.0	1	−.6	9.0	−6.0
10.0	10.0	.6	−10.0	.4	6.0	1	−4.0	1	−.4	4.0	−6.0
7.5	7.5	.8	−7.5	.2	6.0	1	−1.5	1	−.2	1.5	−6.0
Catch											
50.0	50.0	.05	−50.0	.95	45.0	1	−5.0	1	−.95	5.0	−45.0
50.0	50.0	.95	−50.0	.05	5.0	1	−45.0	1	−.05	45.0	−5.0

Note. dif. = difference.

Procedure

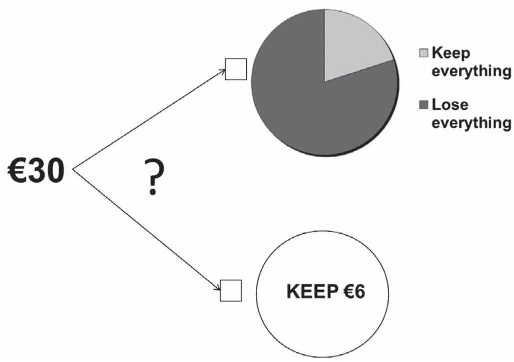
The Paper-and-Pencil test was administered groupwise. Participants were handed the gain and loss frame booklets; both booklets contained an instruction including two example items. As the three youngest age groups received groupwise verbal instruction, order of booklets was not counterbalanced between participants, but between classes of the same age. So for example, if 8–10 year olds were sampled from two classes, one class received the gain–loss order, and the other class the loss–gain order. In the three older age groups, order of booklets was counterbalanced between participants.

In the three youngest age groups, the experimenter and the participants went through the instructions together, and instructions were illustrated by a spinning wheel. The instructions concerned two examples in which expected values of sure and risky options differed to a large extent. In one example the sure option was clearly superior, in the other example the risky option was clearly superior. In this manner, we did not bias participants to either sure or risky options. Participants were then asked to quietly fill in all items in the gain frame booklet. After completion of the gain frame booklet, the experimenter read out aloud a brief unrelated story from a children's book. Thereafter, the experimenter went through the loss frame instruction, which was equivalent to the gain frame instruction, except that the wording of the sure option was adapted to the loss frame. Subsequently, participants were asked to quietly fill in all items in the loss frame booklet. In the three older age groups, instructions were similar, yet were not read aloud and were not illustrated by a spinning wheel. In addition, participants did not pause in between the two booklets. All children and adolescents received a small present after completing the test; adults obtained course credit and received a candy bar. Incentives did not depend on performance.

Data Analysis

Analysis of Missing Values on Regular Items. On nearly all of the 16 regular item types, maximally two out of 294 participants had one or more missing values. However, three participants had one or more missing values on the loss-framed item with an endowment of 45, and 18 participants one or more missing values on the

Figure 6
An Example of a Gain-Framed Item



loss-framed item with an endowment of 22.5. As the number of missing values was thus very low, we computed per participant the percentage of risky choices over available repetitions, in general thus four, but in a few cases less than four.

Analysis of Catch Items. The percentage of correct responses on the catch items was very high in every age group (8–10 years: 90%, 10–12 years: 99%, 12–13 years: 96%, 14–16 years: 96%, 18–57 years: 95%), except in the youngest age group of 6–8 years (72%). This suggests that about a quarter of the children in this age group did not understand the task or did not pay attention to it. Lack of understanding or lack of attention may lead to random choice, that is, 50% risky choices in gain and loss frames, which then mistakenly may be interpreted as objective (CPT), quantitative (FTT), or deliberate (DPT) strategy use (Stanovich et al., 2011). Therefore, we omitted this age group from further analyses, leaving $294 - 50 = 244$ participants for further analyses.

Traditional Analysis of Group-Averaged Data. To offer the possibility to compare our results to those obtained from traditional frequentist analyses on group-averaged data, the type of choice (risky or safe) on an item type[12] served as a dependent variable in a mixed model logistic regression analysis using traditional null hypothesis testing. The independent variables were the between-subjects variable age group (coded as 1, 2, 3, 4, 5; continuous), and the within-subjects variables frame (gain, loss; coded as −1 and 1; nominal), probability (.2, .4, .6, .8; continuous), and scenario (CSL and CSG; coded as −1 and 1; nominal). As random effects we included the variances and covariances of all main and interaction effects of the within variables, these effects were thus allowed to vary over participants. All independent variables were standardized (Dalal & Zickar, 2012; Jaccard et al., 1990). Analyses were performed with the glmer function (family binomial) from the R-package lme4 (Bates et al., 2015). Test on fixed effects were obtained by a Likelihood Ratio Test. Only main and interaction effects with frame are reported.

Hierarchical Bayesian Model-Based Mixture Analysis. This was used to assign each individual simultaneously to its most likely strategy and to estimate the corresponding strategy parameters. The five possible strategies were CPT, HT, FTT gist/DPT intuitive, FTT limited-quantitative, and FTT quantitative/DPT deliberate. The FTT gist and DPT intuitive strategy, as well as the FTT quantitative and DPT deliberate strategy are mathematically identical, if conceptually distinct (cf. Theoretical Analysis section). In the following, we describe the analysis conceptually, for details and a graphical model, please refer to online Supplemental Materials 3.

The strategy index parameter was categorically distributed so that all five strategies had equal prior probabilities: Cat(.2,.2,.2,.2,.2). The strategy parameters, the parameters defining each strategy, had a hierarchical structure: individual-level strategy parameters and group-level strategy parameters (i.e., the mean and standard deviation of the overarching distributions from which individual parameters were drawn). The prior on the shape of the overarching distribution was a truncated normal distribution, reflecting the assumption that individual differences in strategy parameters are normally distributed. The priors on the mean of the overarching distributions were uniform and their range reflected theory-based assumptions, as outlined in the next paragraph. The priors on the standard deviation of the overarching distribution allowed very tight to very wide distributions. That is, they were uniform distributions ranging from 0 to .25 times the range of the prior on the mean. So for example, if the prior on the mean ranged from 0 to 1, the prior on the standard deviation ranged from 0 to .25. The analysis was performed by a

[12] The dependent variable was thus averaged over the responses on four identical replicates of each item type. See online Supplemental Material 2, for a further motivation of the choice for this dependent variable.

latent-mixture model (Lodewyckx et al., 2011) and assignment of each individual to a strategy was based on the posterior odds. Please refer to online Supplemental Materials 3 for more details.

The priors on the mean of the overarching distributions are given in Table 3. For CPT, the priors were defined such that they "excluded theoretically impossible values but included parameter values found in previous research" (Pachur et al., 2017, p. 68). Note that as the CPT model is often considered to be the standard model accounting for framing effects, it is important to use its full potential to fit the data. Therefore we allowed δ and γ to differ between gains and losses (e.g., Lattimore et al., 1992). The parameter α was not allowed to vary between gain and loss domains, as this may lead to underestimation of λ (Nilsson et al., 2011).

DPT's impulsive and deliberate strategies, and FTT's gist, limited-quantitative, and quantitative strategies each required only one parameter: ϕ. The prior was wide, (0, 10), allowing the likelihood to choose risky to vary between 0 and 1. The HT model contained four parameters: ψ, β_0, β_1, and θ. The range of the probability threshold ψ should be (0, 1), as risky gain probability varied between 0 and 1. The range of β_0 was set to (−10, 10). In this manner, the likelihood to choose risky at a zero gain probability varied between 0 and 1. The range of β_1 was set to (−40, 40), thereby allowing both decreasing and increasing preferences for the risky option with increasing risky gain probability. The range of θ was set to (0, 10). The lower bound for θ should be zero, as HT models only the regular framing effect and not the reverse-framing effect; the upper bound of 10 followed the same rationale as that for β_0.

Publication materials, including analysis code, will be made publicly available on the Open Science Framework (Huizenga et al., 2022).

Results

Traditional Analysis of Group-Averaged Data

Figure 7 depicts the percentage of risky choices as a function of frame, probability, scenario, and age group. The Likelihood Ratio Test shows the typical main effect of frame (b = .25, $\chi[1]$ = 28.99, $p < .001$), in that more risk was taken in the loss compared to the gain frame. The frame-by-age group interaction (b = .21, $\chi[1]$ = 22.36, $p <$ .001) indicated that the framing effect increased with age. The frame-by-probability interaction (b = .26, $\chi[1]$ = 17.70, $p < .001$) indicated that the framing effect increased with increasing risky gain probability. A frame-by-scenario interaction was also present (b = .06, $\chi[1]$ = 4.34, p = .037): The framing effect was more pronounced in CSG than in CSL items. Both interactions were included in a three-way interaction between frame, probability, and scenario (b = −.08, $\chi[1]$ = 4.92, p = .027): The probability-dependent increase in the framing effect was more pronounced in CSL than in CSG items. Finally, a frame-by-scenario-by-age interaction (b = .09, $\chi[1]$ = 8.22, p = .004) indicated that the age-related increase in the framing effect was more pronounced in CSG than in CSL items. The other three- and four-way interactions with frame were not significant (frame by probability by age p = .61; frame by scenario by probability by age: p = .080).

Taken together, this group-averaged analysis provides some evidence for each of the theories. First, the framing effect increases with risky gain probability (De Martino et al., 2006; Kühberger et al., 1999), which could only be described by HT. Second, scenario moderates the framing effect. This moderation by scenario could only be described by CPT and FTT, as the other theories are independent of gain and loss amounts. Third, the framing effect increases with age (Reyna & Ellis, 1994; Reyna et al., 2011; Schlottmann & Tring, 2005), which could be described by all theories. Note, however that this group-averaged analysis can give rise to biased conclusions if strategy differences are present. We therefore now proceed to the results of the hierarchical Bayesian model-based mixture analysis.

Hierarchical Bayesian Model-Based Mixture Analysis

As can be seen in final row of Table 4, 22% of the individuals were assigned to CPT, 9% to FTT gist/DPT intuitive, none to FTT limited quantitative, 9% to FTT quantitative/DPT deliberate, and 60% to HT (see Supplemental Figure S3, for a classification plot, and Supplemental Table S1, for information on the assignment of each individual).

According to CPT, framing effects originate in an underweighting of large amounts, captured by an α below 1.00, an often cited estimate being .88

Table 3

Priors and Posteriors of Overarching Means

Strategy	Parameter	Prior	Estimates mean	Lower bound	Upper bound
CPT	α	$U(0, 1)$	0.58	0.48	0.66
	$\delta_{\_g}$	$U(0, 5)$	2.01	1.65	2.47
	$\delta_{\_1}$	$U(0, 5)$	2.02	1.70	2.48
	$\gamma_{\_g}$	$U(0,1)$	0.91	0.78	1.00
	$\gamma_{\_1}$	$U(0, 1)$	0.97	0.91	1.00
	λ	$U(1, 5)$	1.97	1.00	2.93
	ϕ	$U(0, 5)$	4.72	4.06	4.99
FTT gist/DPT intuitive	ϕ	$U(0, 10)$	0.45	0.02	0.67
FTT limited-quantitative	ϕ	$U(0, 10)$	—	—	—
FTT quantitative/DPT deliberate	ϕ	$U(0, 10)$	4.91	0.01	9.39
HT	β_0	$U(-10, 10)$	−5.81	−7.48	−4.64
	β_1	$U(-40, 40)$	9.41	8.20	10.56
	Ψ	$U(0, 1)$	0.98	0.93	1.00
	θ	$U(0, 10)$	0.42	0.01	0.92

Note. For each parameter, the uniform (*U*) priors on the mean of overarching distribution, the median of the estimated mean of the overarching distribution, and the associated 95% credibility interval. Estimates are only tabulated if at least one individual was assigned to a strategy. CPT = cumulative prospect theory; FTT = fuzzy trace theory; DPT = dual process theory; HT = hybrid theory.

(Tversky & Kahneman, 1992). Indeed, the median of the overarching mean estimate of α was below 1 (see Table 3), which was also true for all individual level estimates (see Supplemental Figure S4). All other CPT parameter estimates showed pronounced individual differences (see Supplemental Figure S4), associated modeled choice patterns also did so: They showed no, reverse or regular framing effects, the latter increased or decreased with probability of risky gains (see Supplemental Figure S5).

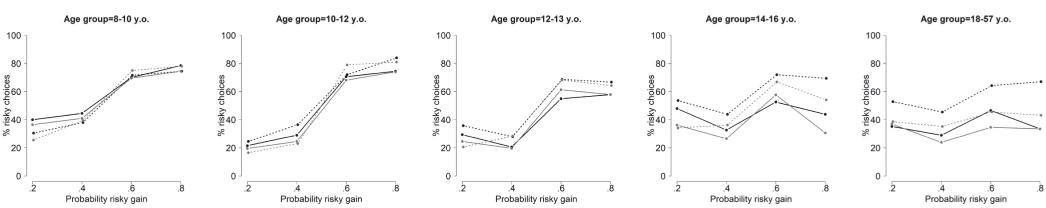
FTT and DPT can describe the presence of framing effects by reliance on an FTT gist/DPT intuitive strategy and their absence by reliance on an FTT quantitative/DPT deliberate strategy. Indeed 9% were assigned to the FTT gist/DPT intuitive strategy, and 9% were assigned to the FTT quantitative/DPT deliberate strategy. Hence modeled choice patterns showed framing effects for those assigned to the former strategy, whereas they did not do so for those assigned to the latter strategy (see Supplemental Figure S5).

According to HT, framing effects are due to a probability threshold ψ below 0.8. The median of the overarching mean estimate of ψ exceeded 0.8 (see Table 3), but the median of the individual estimates was above 0.8 for 47%, whereas it was below 0.8 for 13% of the total sample. Accordingly, modeled choice patterns for the former individuals did not show framing effects, whereas they did so for the latter (see Supplemental Figure S5).

The main conclusion of this analysis therefore is that individual differences in framing effects are best described by the notion that a majority uses the HT strategy, and a sizable minority the CPT

Figure 7

Percentage of Risky Choices (y-Axis), as a Function of Probability of a Risky Gain (x-Axis), Frame (Gain; Loss [dotted]), Scenario (Gray: CSL; Black: CSG), and Age Group



Note. CSL = constant sure loss; CSG = constant sure gain.

Table 4
Number of Individuals Assigned to a Strategy

Age group	CPT	FTT gist/DPT int.	FTT qua/DPT del.	HT	HT1	HT2
8–10 years	12	0	7	31	29	2
10–12 years	5	2	3	40	34	6
12–13 years	11	3	4	33	26	7
14–16 years	10	11	3	25	16	9
18–57 years	17	5	5	17	10	7
Total	55	21	22	146	115	31
Total %	22%	9%	9%	60%	47%	13%

Note. The FTT limited quantitative strategy is not included, as it was never assigned. Final rows: number and percentage aggregated over age groups. In the HT strategy, we also made a distinction between individuals with an estimated probability threshold above .8 (decisions based on one attribute: HT1) and individuals with an estimated threshold below .8 (decisions based on two attributes: HT2). qua = quantitative, int = intuitive, del = deliberative; CPT = cumulative prospect theory; FTT = fuzzy trace theory; DPT = dual process theory; HT = hybrid theory.

strategy or one of the FTT/DPT strategies. One final aspect is worth mentioning: CPT strategy parameters and consequently modeled choice patterns showed marked variations between individuals.

Age Effects

To reiterate, each of the theories can potentially describe a developmental increase in framing effects. CPT by a developmental decrease in α (as an $\alpha < 1$ denotes underweighting of large amounts, which is proposed to generate framing effects); FTT and DPT by a developmental increase in the use of the FTT gist/DPT intuitive strategy and a developmental decrease in the use of the FTT quantitative/DPT deliberate strategy; HT by a developmental increase in the use of the two-attribute HT strategy and a developmental decrease in the use of the one-attribute HT strategy.

To address the CPT description, we tested in a Bayesian regression using the brms package with default priors (Bürkner, 2017), whether α decreased with age (linear effect of age group), which proved not to be the case $b = 0.00$, 95% CI [−0.00, 0.00].

To address the FTT, DPT, and HT descriptions, we first determined for those assigned to HT, whether they adopted a one-attribute strategy (probability threshold >0.8) or a two-attribute strategy (probability threshold <0.8). Table 4 gives the resulting crosstabulation of assigned strategy by Age group. There was an age-related decrease for the one-attribute HT probability-gist strategy, $b = -0.45$, 95% CI [−0.65, −0.26], and there tended to be an age-related increase for the two-attribute HT strategy, $b = 0.29$, 95% CI [0.00, 0.57]. There was also an age-related increase for the FTT gist based/DPT intuitive strategy, $b = 0.60$, 95% CI [0.23, 1.00], but the effect of age on the FFT quantitative/DPT deliberative strategy was small and probably absent (Wagenmakers et al., 2020); $b = -0.08$, 95% CI [−0.41, 0.24].[13] Taken together, these results thus indicate that a developmental increase in framing effects is best described by a developmental *decrease* in the one-attribute HT strategy, a tendency of a developmental *increase* in the two-attribute HT strategy, and a developmental increase in the FTT gist based/DPT intuitive strategy.

Conclusion and Discussion Empirical Study

The results of the empirical study indicate that individual and task-related differences in framing effects are best described by the notion that a majority uses the HT strategy and a sizable minority the CPT or a DPT/FTT strategy. Moreover, pronounced individual differences in the parameters governing CPT strategies also contribute to individual differences in framing effects. With respect to developmental differences, the developmental increase in framing effects is best described by a developmental *decrease* in the one-attribute HT strategy and a developmental *increase* in the FTT gist based/DPT intuitive strategy and the two-attribute HT strategy, although the latter developmental effect was small.

[13] For the record, we performed a similar analysis for CPT: Its use tended to increase with age, $b = 0.22$, 95% CI [0.00, 0.45].

This conclusion is derived given a task and analytic procedure designed to assess strategy use by means of a hierarchical Bayesian model-based mixture analysis. This analysis has several advantages. First, it easily accommodates nonlinear models, such as the CPT model or HT's threshold model. Second, it reflects theoretical assumptions, not only in the structure of a model, but also in the prior on its parameters (Lee & Vanpaemel, 2018), for example, that loss aversion should exceed one. Third, it models individuals simultaneously, thereby improving precision of estimates as compared to the analysis of individual data (Lee, 2011; Nilsson et al., 2011; Steingroever et al., 2018). Fourth, it allows for individual differences in strategy use (Lodewyckx et al., 2011) and for individual differences in strategy parameters (Lee, 2011). Finally and relatedly, it offers a reliable way to assign individuals to strategies by means of the posterior odds.

Several concerns may be raised with respect to the task used in the present study. First, it might be argued that the task, in which participants had to make repeated choices, may have induced heuristic lexicographic decision strategies which may not be present in real life, where single choices have to be made. Note however that in many nonframing studies, participants also have to make multiple choices, yet do use nonheuristic decision strategies (e.g., Glöckner & Betsch, 2011; Glöckner & Pachur, 2012; Van Duijvenvoorde et al., 2016). Therefore, we consider it unlikely that the current finding of lexicographic strategies solely originates in the fact that people had to make multiple choices. Second, graphical presentation of gain probability might have enhanced the saliency of this attribute, which may have induced the use of the HT strategy, yielding the probability effect. Moreover, we used framing problems in which risky options were formulated equivalently in gain and loss frames (see, e.g., De Martino et al., 2006; Roiser et al., 2009). This may have triggered the one attribute HT strategy in which participants focused on a common attribute, risky gain probability. This strategy may be argued to be less likely in formulations in which gain and loss framed risky options are formulated nonequivalently. However, several studies presenting probabilities numerically, and not graphically, also observed the probability effect, the same applies to a variety of formulations of the risky option (for a review Kühberger et al., 1999). Therefore we consider these explanations not very likely. Third, after a numerically presented endowment (e.g., euro 30), we asked participants to choose between a safe option and a risky option in which gain and loss amounts were presented as "keep all or lose all." An alternative formulation of the risky option would be "keep 30 or lose 30." To our knowledge no studies exist on whether the first formulation (also used by e.g., De Martino et al., 2006; Roiser et al., 2009; Sip et al., 2015) results in more pronounced framing effects than the second formulation. Future studies may test potential differences between these two formulations. Fourth, we varied endowment between 7.5 and 90. Higher endowments may induce a preference for the safe option in both frames, and thus no framing effect at all (Wang, 1996, 2002; Wang & Johnson, 2012). Fifth, we manipulated frame within-subjects as this offered the possibility to fit formal models. Within-subjects designs run the risk that some participants try to match their answers between frames, resulting in diminished framing effects (Broniatowski & Reyna, 2018; LeBoeuf & Shafir, 2003; Stanovich & West, 2008). However, gain and loss framed items were presented in separate booklets, therefore we consider it unlikely that participants matched their responses. Moreover, diminished framing effects may not be that likely, as a meta-analysis indicated more pronounced framing effects in within- than between-subjects designs (Kühberger, 1998).

Several concerns might also be raised regarding the formal CPT modeling. First, although the CPT probability weighting function was chosen to be consistent with many CPT modeling studies (Gonzalez & Wu, 1999; Lattimore et al., 1992), alternative functional forms also exist (Prelec, 1998; Stott, 2006). It might therefore be argued that we unnecessarily restricted CPT's flexibility to model the data. Note however that our CPT probability weighting function did contain γ and δ parameters varying between gain and loss domains. Therefore we are quite confident that the probability weighting function was flexible enough. Second, it might be argued that we should not have included a loss aversion parameter as decision makers might only be loss averse in items featuring both gains and losses, and not in items in which, after editing, only losses remain. Note however that the estimated mean of the overarching distribution was about two, which is consistent with previous studies showing overweighting of losses, even in the absence of gains (Baumeister et al., 2001; Verburg et al., 2019;

Yechiam & Hochman, 2012). Third, it might be argued that the current CPT results are unreliable, as the CPT model is well known to yield imprecise parameters if fitted to individual data by means of maximum likelihood (Nilsson et al., 2011). Note however that we estimated parameters by means of hierarchical Bayesian analysis, which can include the theoretical assumption that parameters are normally distributed over individuals and which can include theoretically motivated priors on the overarching mean.[14] These two characteristics have been shown to improve precision (Lee, 2011; Nilsson et al., 2011; Steingroever et al., 2018). Moreover, the observed underweighting of high gain and high loss amounts is exactly what would be predicted by CPT's description of the framing effect (Tversky & Kahneman, 1981), thereby strengthening confidence in the reliability of these estimates.

A concern might also be raised regarding the formal modeling of DPT and FTT strategies. To our knowledge, no formal models have been described for these strategies. How do we then know that we formalized these strategies correctly? We are confident as the formal models match the conceptual descriptions of DPT strategies (Kahneman & Frederick, 2007) and of FTT strategies (Reyna, 2012; Reyna & Brainerd, 2011; Reyna & Ellis, 1994; Reyna et al., 2011, 2014; Rivers et al., 2008). Self-evidently, the current findings may inspire different explications of these strategies in future modeling studies. Relatedly, the present study does not speak to the adequacy of other specifications of FTT and accompanying formal models (Broniatowski & Reyna, 2018; Reyna & Brainerd, 2011).

An HT modeling concern might be that we cannot be sure that gain probability was the first attribute considered by lexicographic decision makers: why not gain or loss amounts? We argue however that it is gain probability, as the design unconfounded gain probability differences on the one hand and gain amount and loss amount differences on the other (Table 2). Another HT modeling concern may be that instead of gist, gain amounts should have served as second attribute. If this would be true, HT predicted framing effects would decrease if the difference between sure and risky gains amounts decreases (i.e., if risky gain probabilities increase). As we observed framing effects increasing, instead of decreasing, with risky gain probabilities, we deem this to be unlikely.

In our modeling, we assigned each individual to its most likely strategy, we thus assumed that behavior of each individual is governed by one strategy. An alternative assumption might be that two or more strategies operate in parallel, each with a different weight. It remains to be tested which of these two assumptions is the most likely.

Finally, note that we adopted priors implementing overarching truncated normal distributions on the individual strategy parameters. This may have forced posterior distributions to be too normally distributed when strategy groups consisted of distinct subgroups characterized by distinct strategy parameters. As a hypothetical example, if some people using a CPT strategy are characterized by no loss aversion and others by pronounced loss aversion, truncated normal priors may have forced a bimodal distribution to become unimodal. To assess robustness of results to potential inadequacy of truncated normal distributions, we also used another approach, in which we first determined "choice subgroups" characterized by homogeneous choice patterns and then performed the hierarchical Bayesian model-based mixture analysis on each choice subgroup separately. Results, reported in the online Supplemental Materials 5 Table S2, are largely consistent with those reported here: Summed over choice subgroups, 30% of the decision makers were assigned to CPT, 4% to FTT gist/DPT intuitive, none to FTT limited quantitative, 4% to FTT quantitative/DPT deliberate, and 62% to HT. Of note, the results of these choice subgroup analyses indicate there exist choice subgroup differences in strategy parameters (see Supplemental Table S3, compare e.g., the CPT parameters of the "NF1" and "NF2" choice subgroups).

In future studies, the hierarchical Bayesian model-based mixture analysis may include distinct subgroups for each strategy, with their own distinct set of priors. To facilitate this, we report credibility intervals in the Supplemental Table S5 for all choice subgroups. In this manner, priors on subgroups within strategy groups are informed by previous research (Lee & Vanpaemel, 2018). An alternative way to assess subgroups within strategy groups is to adopt an exploratory approach

[14] Note that we used parameter ranges consistent with CPT's theoretical assumptions. If parameter ranges would be extended, CPT may also describe heuristics (Pachur et al., 2017).

and identify subgroups by implementing arbitrary order constraints (see, e.g., Villarreal et al., 2019, for such an approach). As a hypothetical example, one may implement that the CPT strategy group consists of two subgroups, A and B, where loss aversion is higher in subgroup A than B, and subsequently test whether a model with these two CPT subgroups provides a better fit than a model with only one CPT subgroup.

Another potential extension in future studies is to analyze postdecisional confidence. Framing studies typically only assess choice, to our knowledge, two studies assessed postdecisional confidence (Reyna et al., 2014; Reyna et al., 2018). Previous studies in other contexts showed that postdecision confidence is higher after noncompensatory than after compensatory decisions (Dhami & Ayton, 2001; Zakay, 1985). In a future framing study, it thus may be determined whether those assigned to noncompensatory strategies, that is the DPT intuitive, FTT gist based or the HT strategy, are characterized by higher postdecisional confidence that those assigned to compensatory strategies, that is the CPT strategy, the DPT deliberate, or the FTT quantitative strategy. In doing so, care should be taken to take into account a wide variety of biases in postdecisional confidence (Navajas et al., 2016; Zakay, 2020), which may also change with development (Jepma et al., 2020).

General Conclusion and Discussion

We argued that theoretical debate on the origin of the framing effect can be solved by determining which theory best describes differential framing effects. More specifically, a theory should describe task-related differences, that is, describe the truncation and the probability effect, describe individual differences, and describe a developmental increase in the framing effect. We therefore compared four theories on their capacity to describe these differential effects; we included CPT (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992), FTT (Reyna & Brainerd, 2011; Reyna & Ellis, 1994; Reyna et al., 2011), dual processing theory (Kahneman & Frederick, 2007), and HT incorporating elements from lexicographic theory and FTTs proposition that the framing effect originates in gist differences (Reyna & Ellis, 1994), see also (Brainerd & Reyna, 2015; Reyna et al., 2011, 2018; Reyna et al., 2015).

Comparisons between theories were made at three levels. First, we analyzed whether theories could describe differential framing effects. Second, we reviewed whether empirical evidence actually supported these theoretical descriptions. Third, we showed that a crucial comparison between theories required an empirical study adopting a new experimental and analytical approach. In the following paragraphs, we first integrate the theoretical analysis, empirical review, and current empirical results. This integration suggests several lines of future research, which are outlined briefly. We then discuss implications for research into the framing effect, and for decision making in general.

In the empirical study, 60% of the participants were best described by HT incorporating elements from lexicographic theory and FTT. HT's description of the framing effect states that decision makers either base their decisions on the first attribute, gain probability, or on the second attribute, FTT's gist. If decision makers base their decision on gain probability, they will *not* be affected by frame. If they base their decision on gist, they will be affected by frame. We evaluated whether this theory could describe the four differential framing effects. First, the theoretical analysis showed that HT can describe the truncation effect, as truncation removes gist differences between sure and risky options (Chick et al., 2016; Kühberger & Tanner, 2010; Mandel, 2001; Reyna & Brainerd, 1991; Reyna et al., 2014). The empirical review also provided supporting evidence for this description. Second, the theoretical analysis showed that HT can describe the probability effect, as decision makers only assess the second attribute, gist, if they consider differences on the first attribute, gain probability, to be too small. The empirical review showed that there are no direct tests of this description. Therefore, we addressed it in the current empirical study, resulting in supporting evidence. That is, the study showed that decision makers considered gist if gain probability differences were small. Third, the theoretical analysis showed that HT could describe individual differences in the framing effect if some decision makers would always choose according to the first attribute, gain probability, whereas others may consider the second attribute, gist. The empirical review provided mixed evidence for such a description, but it was supported in the current empirical study. That is, 47% always based their decision on gain probability and thus were not affected by frame, and 13% considered gist, and thus were affected by frame if gain probability differences were small. In the empirical review, we showed that these individual differences are not likely to be related to individual differences in inhibition, but may be related to individual differences in using the probability attribute to break the tie between nearly equivalent options (Leland, 1994; Shafir et al., 1993; Tversky et al., 1988). To test this prediction, future studies may repeat the current empirical study while adding indices of this tendency to use probability to break the tie. For example, we argued that using probability to break the tie may be reflected in OMPFC activation, as (a) these regions have been shown to be associated with a decreased framing effect (De Martino et al., 2006; Roiser et al., 2009) and (b) these regions have been implicated in coding a common currency (Levy & Glimcher, 2011; Sescousse et al., 2013), which may simply be gain probability. This prediction can be tested in future studies by assessing whether OMPFC activation in the framing task scales with gain probability differences. Fourth, the theoretical analysis indicated that HT could describe a developmental increase in the framing effect if there would exist an age-related decrease in using a one-attribute strategy, yielding no framing effect, and an age-related increase in using a two-attribute strategy, yielding the framing effect. The empirical review provided some evidence for such a description. In the current empirical study, the developmental decrease in the one-attribute strategy was indeed observed, as well as a tendency for a developmental increase in the two-attribute strategy. In the empirical review, we showed that the developmental decrease in using one-attribute strategies is most likely to be related to a developmental increase in inhibition (Best & Miller, 2010; Chevalier, 2015; Crone, 2009; Durston et al., 2002; Huizinga et al., 2006; Steinbeis & Crone, 2016). In future studies, this prediction can be tested by repeating the current empirical study in a developmental sample while adding indices of inhibition as a mediator.

In the empirical study, 22% of the participants were best described by CPT. According to CPT, people base their decisions on subjective utility, in which gain and loss amounts and their associated probabilities are subjectively evaluated. Subjective underweighting of large gain and loss amounts is then proposed to be the origin of framing effects (Tversky & Kahneman, 1981). We evaluated whether CPT could describe differential framing effects. First, the theoretical analysis indicated that CPT cannot describe the truncation effect, as decision makers themselves already omit frame-inconsistent information. Second, the theoretical analysis indicated that CPT cannot describe the probability effect (Kühberger et al., 1999), as CPT's often cited parameters only predict a framing effect decreasing, and not increasing, with risky gain probabilities. In the empirical study, some CPT modeled choice patterns were indeed characterized by framing effects decreasing with risky gain probabilities, however others by framing effects increasing with risky gain probabilities. Third, the theoretical analysis showed that CPT could describe individual differences in the framing effect if there would exist individual differences in underweighting of large gain and loss amounts. Since the empirical review indicated that no studies directly tested this relationship, the review focused on the relationship between the framing effect and broad indices of objectivity/subjectivity. The evidence for such a relationship proved to be inconclusive (Chandler et al., 2009; Corbin et al., 2010; De Martino et al., 2006; Fagley & Miller, 1987; Kahneman & Frederick, 2007; Kam & Simas, 2010; Roiser et al., 2009; Shiloh et al., 2002; Simon et al., 2004; Smith & Levin, 1996; Zickar & Highhouse, 1998). The current empirical study was the first to fit the CPT model to framing data, and thus offered the possibility to directly test this CPT description of individual differences. The results of this study show that CPT decision makers were all characterized by underweighting of large gain and loss amounts, however the modeled choice patterns showed either no, regular or reversed framing effects. Therefore, we conclude that CPT's description of individual differences is not convincingly supported by the current empirical study. Fourth, the theoretical analysis showed that CPT could describe a developmental increase in the framing effect if there would be a developmental increase in underweighting of large gain and loss amounts. As there were no empirical studies on developmental differences in amount weighting, the empirical review focused on developmental increases in broad indices of subjectivity. This review provided inconclusive evidence. (De Neys & Vanderputte, 2011; Furlan et al., 2013; Jacobs & Potenza, 1991; Kokis et al., 2002;

Morsanyi & Handley, 2008; Stanovich et al., 2008). The current empirical study indicated no developmental effects on the underweighting of large gain and loss amounts. We therefore conclude that CPT's description of a developmental increase in the framing effect is not supported.

In the empirical study, 18% of the participants were assigned to the FTTs gist and quantitative strategies, matching the intuitive or deliberate strategies of DPT. Our theoretical analysis and empirical review indicated that FTT can describe and even predicts the truncation effect and developmental differences, whereas DPT cannot, we therefore deem the former theory to be more likely. We evaluated whether FTT could describe the four differential framing effects. The theoretical analysis showed that FTT describes and even predicts the truncation effect, which was supported by the empirical review. The analysis also showed that FTT cannot describe the probability effect. The analysis showed that FTT can describe individual differences if some would adopt the gist-based and some the quantitative strategy. The empirical review showed no conclusive evidence on this matter, yet the empirical results did indicate that 9% used the former, and 9% the latter strategy. Finally, the theoretical analysis indicated that FTT describes and even predicts a developmental increase in the framing effect, if there would exist an age-related increase in reliance on the gist-based strategy and an age-related decrease in reliance on the quantitative strategy. The empirical review showed no conclusive evidence on these developmental trends. However, in the empirical study, we found evidence for the former, but not for the latter, effect.

The current findings have several implications for research into the framing effect. First, to our surprise, CPT, FTT, DPT, and HT formal models have never been fitted to framing data. The current empirical study highlights the benefits of such a formal modeling approach, as it (a) requires explicit specification of conceptual assumptions and (b) offers the opportunity to directly pit theories against each other. The methodology, which will be made freely available on Open Science Framework (H.M. Huizenga et al., 2022), may be used to reanalyze existing, or analyze future, data sets, to test which theory provides the best description of differential framing effects.

Second, the present study indicates that the assumption of homogeneous strategy use always needs to be tested (Bouwmeester et al., 2004; Dauvier et al., 2012; Huizenga et al., 2007; Van Der Maas & Straatemeier, 2008). If this assumption is not satisfied, averaging data from individuals using different strategies may give rise to erroneous conclusions (see also Scarpa et al., 2009).

Third, to obtain a robust framing effect, we suggest items with high risky gain probabilities, as this increases the tendency that HT decision makers consider the second attribute, gist. Moreover, these items should be formulated in the traditional, and not in the truncated, way. That is, risky options should provide information on both risky gains and risky losses, as otherwise gist differences disappear (Chick et al., 2016; Kühberger & Tanner, 2010; Kühberger et al., 1999; Mandel, 2001; Reyna et al., 2014). Self-evidently, these two recommendations apply to both scientific studies into the framing effect, and to interventions aimed at promoting sensible decision making in the domains of health, finance, or politics (Boettcher, 2004; Brown et al., 2008; Edwards et al., 2001; Gallagher & Updegraff, 2012; Jefferies-Sewell et al., 2015; Kuehnhanss et al., 2015; McNeil et al., 2004; Olsen, 1997; Roszkowski & Snelbecker, 1990; Rothman & Salovey, 1997; Veldwijk et al., 2016).

Fourth, the present study suggests that the main reason for an absence of the framing effect is that decision makers base their decisions on gain probability, as 47% of the decision makers used a one-attribute lexicographic strategy. The absence of a framing effect is thus not likely due to reliance on objective (CPT), quantitative (FTT), or deliberate (DPT) strategies. This notion is supported by two results of the hierarchical Bayesian model-based mixture analysis. First, in those assigned to CPT, strategy parameters were indicative of subjective, and not objective, decision making. Second, only a few participants (9%) were assigned to the quantitative (FTT)/deliberate (DPT) strategy. Therefore, we suggest to no longer use framing items to assess reliance on objective, quantitative, or deliberate processing. Relatedly, the absence of a framing effect in younger age-groups cannot be taken as support for reliance on quantitative strategies, as was proposed by FTT. That is, the main cause of an absence of a framing effect in children is not that they rely on a quantitative strategy, but that they base their decisions on gain probability (see also Footnote 8).

Finally and relatedly, we suggest to report not only the framing effect, that is, the difference in percentage of risky choices in gain and loss frame, but also the percentage of risky choices in each frame separately. This offers the opportunity to determine whether people use CPT's objective, FTT's quantitative, or DPT's deliberate strategy, generating 50% risky choices in both frames, or simply use a one-attribute HT probability-gist strategy based on gain probability

Care should be taken not to overgeneralize the current conclusions. The observation that HT best modeled behavior of the majority of decision makers in the present study, does not imply that HT strategies are also used in other decision contexts. That is, it has been argued that lexicographic strategies are specifically used in contexts in which options are nearly equivalent (Leland, 1994; Shafir et al., 1993; Tversky et al., 1988; Wang, 2008; Wang et al., 2017), as in the current framing paradigm. In other contexts, other strategies might be more common. Moreover, in samples consisting of only adults, HT strategies might be less, and the CPT strategy, more prominent. For example, the present study indicated an age-related decrease in the one-attribute HT strategy and a weak increase in the CPT strategy (but on the other hand also a weak increase in the two-attribute HT strategy). Moreover, the current findings speak only to differential framing effects in one experimental paradigm involving economic gambles. Future studies are required to test whether the current results replicate in other paradigms, more specifically, to test whether the same theories are favored, or that others provide a better fit. For example, as framing effects may differ between paradigms pertaining to saving money or to saving lives, and even between saving strangers or to saving kin (Wang, 2002; Zheng et al., 2010), it remains to be tested whether current results replicate in such paradigms. Self-evidently, problems then should be developmentally appropriate, for example, they should not concern saving lives but rather inviting friends to a party.

Note that we included four theories previously mentioned both in the decision making and in the developmental literature. The current conclusions thus only pertain to these four theories, future work may include other theories proposed in the decision making but not in the developmental field, or vice versa. With respect to the former, it is interesting to zoom in on decision-making theories specifically proposed for the framing effect, for example, the lexical ambiguity hypothesis (Mandel, 2014; Teigen & Nikolaisen, 2009), information leakage theory (Kühberger & Gradl, 2013; Kühberger & Tanner, 2010; Sher & McKenzie, 2006), and the explicated valence account (Tombu & Mandel, 2015). In pitting theories against each other by means of formal model comparison, it is important to include additional experimental manipulations that distinguish between all theories, as outlined next.

First, the lexical ambiguity hypothesis (Mandel, 2014; Teigen & Nikolaisen, 2009) states that the sure option may be interpreted either as an exact number or as a lower bound. To get back to our example in the introduction, in the gain frame keeping 2 may be interpreted as keeping exactly 2, and in the loss frame losing 8 may be interpreted as losing exactly 8 dollars. This then should lead to no framing effect in rational decision makers, that is, in those adopting an objective CPT, a rational DPT, or a quantitative CPT strategy (cf. Figure 2). However, the sure option can also be interpreted as at least keeping 2 in the gain frame and at least losing 8 dollars in the loss frame, which then should lead to a framing effect in aforementioned rational decision makers. As the current experimental paradigm was not setup to check which of the two interpretations was adopted, we refer the reader to studies that included experimental manipulations to test this explanation of differential framing effects. For example, one study showed that manipulating the wording of the sure option as "exactly" versus "at least" decreased and increased framing effects respectively, thus providing evidence for the lexical ambiguity hypothesis (Mandel, 2014). However, another study showed that even if the sure option was stated unambiguously, framing effects still occurred (Chick et al., 2016). For a more elaborate discussion, see (Fisher, 2022; Fisher & Mandel, 2021; Reyna et al., 2021).

Second, information leakage theory, proposed for attribute framing (Sher & McKenzie, 2006), and extended to risky choice framing (Kühberger & Gradl, 2013; Kühberger & Tanner, 2010), states that decision makers infer that the sure option provides an increase to the endowment in the gain frame and a decrease to it in the loss frame; therefore they choose the sure and risky option respectively. This strategy would in the current task yield the same formal model and descriptions as DPT's intuitive strategy (see Figure 2; only focus on gain and loss wording of the sure option).[15] The current result that the intuitive strategy was the best fitting model for only 9% of the participants may at first sight be taken as evidence against information leakage theory. Such a conclusion is however too strong as different mechanisms may operate in attribute versus risky choice framing; moreover, the current task was not specifically designed to disentangle DPT's intuitive and the information leakage strategy.

Third, according to the explicated valence account (Tombu & Mandel, 2015), decision makers compare the explicated valence of sure and risky options. In the current task, this yields the same formal model and predictions as FTT's gist-based strategy, as the explicated valence of sure and risky options is positive versus mixed positive and negative in the gain frame, and negative versus mixed positive and negative in the loss frame (cf. Figure 2). Again, the current result that FTT's gist-based strategy was only the best fitting model for 9% of the sample may be taken against the explicated valence account. But note that the current task was not designed to disentangle the explicated valence account and FTT's gist-based strategy. We refer to Wallin et al. (2016) on how to do so.

Two broader implications arise from the present study. First, the study highlights that individual differences in decision making may not only be quantitative, but also qualitative, in nature. That is, individual differences are not only always due to variations in for example, CPT's amount weighting, but also due to the use of qualitatively different decision strategies. For example, even in adults, both one- and two-attribute lexicographic strategies were observed in addition to the CPT strategy (about a half decided according to HT and a half according to CPT). The notion of qualitative individual differences in decision making is common in the behavioral decision-making literature (Bröder & Schiffer, 2006; Fischbacher et al., 2013; Heck & Erdfelder, 2017; Lagarde, 2013; Luce, 1978; Payne et al., 1988; Rieskamp, 2008; Tversky et al., 1988), yet has received less attention in the neuro-imaging literature, with a few exceptions (Gluth et al., 2014; Hunt et al., 2012; Rao et al., 2011; Van Duijvenvoorde et al., 2016; Venkatraman et al., 2009; Zadelaar et al., 2019). Therefore, it is still largely unknown how various decision strategies are implemented in the brain (Schonberg et al., 2011; Vlaev et al., 2011).

Second, and relatedly, developmental differences in decision making may be qualitative, instead of quantitative. For example, in the present study, there was a developmental shift from a one-attribute HT strategy to a two-attribute HT strategy. Qualitative developmental differences in decision making have received little interest, the only exceptions being studies inspired by FTT (Reyna & Brainerd, 2011; Reyna & Ellis, 1994; Reyna et al., 2011) and a few other studies (Huizenga et al., 2007; Jansen et al., 2012; Jepma et al., 2020; Lang & Betsch, 2018; Mata & Von Helversen, 2011; Pol Van de & Langeheine, 1990; Steingroever et al., 2019; Van Duijvenvoorde et al., 2014). Moreover, neuroimaging studies on qualitative developmental differences in decision making are lacking (van den Bos et al., 2018). An increased interest in qualitative developmental differences in decision making is pertinent, as it has been shown that other capacities, like proportional reasoning, transitive reasoning, categorization, and feedback learning are all subject to pronounced qualitative developmental changes (Andersen et al., 2014; Bouwmeester & Sijtsma, 2007; Bouwmeester et al., 2004; Jansen & van der Maas, 2002; Johansen & Palmeri, 2002; Lee & Sarnecka, 2011; Peters et al., 2014; Schmittmann et al., 2012).

To conclude, the present study shows that task-related, individual, and developmental differences in the framing effect are best described by the notion that the majority of decision makers decides according to HT incorporating elements from lexicographic theory and FTT's concept of gist, whereas a sizable minority decides according to CPT and strategies derived from FTT. The main implications of the present study are threefold: (a) careful construction of tasks and formal modeling of theories offer the possibility for theoretical arbitration; (b) an absence of the framing effect is not due to reliance on objective, quantitative, or deliberate processing; and (c) individual and developmental differences in

[15] In a similar vein, query theory (Johnson et al., 2007) proposes that attributes are considered in a particular order, where the first attribute influences decisions more than others. A query theory account of the framing effect (Wall et al., 2020) states that decision makers first focus on the wording of sure options, therefore predictions boil down to those of DPT's intuitive strategy.

decision making can be qualitative instead of quantitative in nature.

References

Aïte, A., Cassotti, M., Rossi, S., Poirel, N., Lubin, A., Houdé, O., & Moutier, S. (2012). Is human decision making under ambiguity guided by loss frequency regardless of the costs? A developmental study using the Soochow Gambling Task. *Journal of Experimental Child Psychology*, *113*(2), 286–294. https://doi.org/10.1016/j.jecp.2012.05.008

Andersen, L. M., Visser, I., Crone, E. A., Koolschijn, P. C. M. P., & Raijmakers, M. E. J. (2014). Cognitive strategy use as an index of developmental differences in neural responses to feedback. *Developmental Psychology*, *50*(12), 2686–2696. https://doi.org/10.1037/a0038106

Appelt, K., Milch, K., Hangraaf, M., & Weber, E. (2010). *Much ado about very Little (so far)? The role of individual differences in decision making* [Manuscript submitted for publication]. http://kirstinappelt.com/downloads/papers/AppeltMilchHandgraafWeber-2010-MuchAdoAboutVeryLittleSoFar.pdf

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Baumeister, R. F., Bratslavsky, E., Finkenauer, C., & Vohs, K. D. (2001). Bad is stronger than good. *Review of General Psychology*, *5*(4), 323–370. https://doi.org/10.1037//1089-2680.5.4.323

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Bexkens, A., Jansen, B. R. J., van der Molen, M. W., & Huizenga, H. M. (2016). Cool decision-making in adolescents with behavior disorder and/or mild-to-borderline intellectual disability. *Journal of Abnormal Child Psychology*, *44*(2), 357–367. https://doi.org/10.1007/s10802-015-9996-8

Bexkens, A., Ruzzano, L., Collot d' Escury-Koenigs, A. M. L., van der Molen, M. W., & Huizenga, H. M. (2014). Inhibition deficits in individuals with intellectual disability: A meta-regression analysis. *Journal of Intellectual Disability Research*, *58*(1), 3–16. https://doi.org/10.1111/jir.12068

Bjorklund, D., & Harnishfeger, K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review*, *71*(10), 48–71. https://doi.org/10.1016/0273-2297(90)90004-N

Boettcher, W. A. I. (2004). The prospects for prospect theory: An empirical evaluation of international of relations applications framing and loss aversion. *Political Psychology*, *25*(3), 331–362. https://doi.org/10.1111/j.1467-9221.2004.00375.x

Borst, G., Poirel, N., Pineau, A., Cassotti, M., & Houdé, O. (2012). Inhibitory control in number-conservation and class-inclusion tasks: A neo-Piagetian inter-task priming study. *Cognitive Development*, *27*(3), 283–298. https://doi.org/10.1016/j.cogdev.2012.02.004

Bouwmeester, S., & Sijtsma, K. (2007). Latent class modeling of phases in the development of transitive reasoning. *Multivariate Behavioral Research*, *42*(3), 457–480. https://doi.org/10.1080/00273170701384324

Bouwmeester, S., Sijtsma, K., & Vermunt, J. K. (2004). Latent class regression analysis for describing cognitive developmental phenomena: An application to transitive reasoning. *European Journal of Developmental Psychology*, *1*(1), 67–86. https://doi.org/10.1080/17405620344000031

Brainerd, C. J., & Reyna, V. F. (2015). Fuzzy-trace theory and lifespan cognitive development. *Developmental Review*, *38*, 89–121. https://doi.org/10.1016/j.dr.2015.07.006

Brandstätter, E., Gigerenzer, G., & Hertwig, R. (2006). The priority heuristic: Making choices without trade-offs. *Psychological Review*, *113*(2), 409–432. https://doi.org/10.1037/0033-295X.113.2.409

Bröder, A., & Schiffer, S. (2006). Stimulus format and working memory in fast and frugal strategy selection. *Journal of Behavioral Decision Making*, *19*(4), 361–380. https://doi.org/10.1002/bdm.533

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

Brown, J. R., Kling, J. R., Mullainathan, S., & Wrobel, M. V. (2008). Why don't people choose annuities? A framing explanation. *The American Economic Review*, *98*(2), 304–309. https://doi.org/10.1257/aer.98.2.304

Bruine de Bruin, W., Parker, A. M., & Fischhoff, B. (2007). Individual differences in adult decision-making competence. *Journal of Personality and Social Psychology*, *92*(5), 938–956. https://doi.org/10.1037/0022-3514.92.5.938

Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01

Chandler, R. A., Wakeley, J., Goodwin, G. M., & Rogers, R. D. (2009). Altered risk-aversion and risk-seeking behavior in bipolar disorder. *Biological Psychiatry*, *66*(9), 840–846. https://doi.org/10.1016/j.biopsych.2009.05.011

Chevalier, N. (2015). The development of executive function: Toward more optimal coordination of control with age. *Child Development Perspectives*, *9*(4), 239–244. https://doi.org/10.1111/cdep.12138

Chick, C. F., Reyna, V. F., & Corbin, J. C. (2016). Framing effects are robust to linguistic disambiguation: A critical test of contemporary theory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(2), 238–256. https://doi.org/10.1037/xlm0000158

Corbin, J. C., Mcelroy, T., & Black, C. (2010). Memory reflected in our decisions: Higher working memory capacity predicts greater bias in risky choice. *Judgment and Decision Making*, *5*(2), 110–115.

Crone, E. A. (2009). Executive functions in adolescence: Inferences from brain and behavior. *Developmental Science*, *12*(6), 825–830. https://doi.org/10.1111/j.1467-7687.2009.00918.x

Dalal, D. K., & Zickar, M. J. (2012). Some common myths about centering predictor variables in moderated multiple regression and polynomial regression. *Organizational Research Methods*, *15*(3), 339–362. https://doi.org/10.1177/1094428111430540

Dauvier, B., Chevalier, N., & Blaye, A. (2012). Using finite mixture of GLMs to explore variability in children's flexibility in a task-switching paradigm. *Cognitive Development*, *27*(4), 440–454. https://doi.org/10.1016/j.cogdev.2012.07.004

Davidson, D. (1991). Children's decision-making examined with an information-board procedure. *Cognitive Development*, *6*(1), 77–90. https://doi.org/10.1016/0885-2014(91)90007-Z

De Martino, B., Harrison, N. A., Knafo, S., Bird, G., & Dolan, R. J. (2008). Explaining enhanced logical consistency during decision making in autism. *Journal of Neuroscience*, *28*(42), 10746–10750. https://doi.org/10.1523/JNEUROSCI.2895-08.2008

De Martino, B., Kumaran, D., Seymour, B., & Dolan, R. J. (2006). Frames, biases, and rational decision-making in the human brain. *Science*, *313*(5787), 684–687. https://doi.org/10.1126/science.1128356

De Neys, W., & Vanderputte, K. (2011). When less is not always more: Stereotype knowledge and reasoning development. *Developmental Psychology*, *47*(2), 432–441. https://doi.org/10.1037/a0021313

Dhami, M. K., & Ayton, P. (2001). Bailing and jailing the fast and frugal way. *Journal of Behavioral Decision Making*, *14*(2), 141–168. https://doi.org/10.1002/bdm.371

Durston, S., Thomas, K. M., Yang, Y., Ulug, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science*, *5*(4), F9–F16. https://doi.org/10.1111/1467-7687.00235

Edwards, A., Elwyn, G., Covey, J., Matthews, E., & Pill, R. (2001). Presenting risk information–a review of the effects of "framing" and other manipulations on patient outcomes. *Journal of Health Communication*, *6*, 61–82. https://doi.org/10.1080/10810730150501413

Etkin, A., Egner, T., & Kalisch, R. (2011). Emotional processing in anterior cingulate and medial prefrontal cortex. *Trends in Cognitive Sciences*, *15*(2), 85–93. https://doi.org/10.1016/j.tics.2010.11.004

Fagley, N. S. (1993). A note concerning reflection effects versus framing effects. *Psychological Bulletin*, *113*(2), 451–452. https://doi.org/10.1037/0033-2909.113.3.451

Fagley, N. S., & Miller, P. M. (1987). The effects of decision framing on choice of risky vs certain options. *Organizational Behavior and Human Decision Processes*, *39*(2), 264–277. https://doi.org/10.1016/0749-5978(87)90041-0

Fischbacher, U., Hertwig, R., & Bruhin, A. (2013). How to model heterogeneity in costly punishment: Insight for responders'response times. *The Journal of Behavioral Decision Making*, *26*, 462–476. https://doi.org/10.1002/bdm

Fisher, S. A. (2022). Framing effects and fuzzy traces: 'Some' observations. *Review of Philosophy and Psychology*, *13*, 719–733. https://doi.org/10.1007/s13164-021-00556-3

Fisher, S. A., & Mandel, D. R. (2021). Risky-choice framing and rational decision-making. *Philosophy Compass*, *16*(8), Article e12763. https://doi.org/10.1111/phc3.12763

Fum, D., Del Missier, F., & Stocco, A. (2007). The cognitive modeling of human behavior: Why a model is (sometimes) better than 10,000 words. *Cognitive Systems Research*, *8*(3), 135–142. https://doi.org/10.1016/j.cogsys.2007.07.001

Furlan, S., Agnoli, F., & Reyna, V. F. (2013). Children's competence or adults' incompetence: Different developmental trajectories in different tasks. *Developmental Psychology*, *49*(8), 1466–1480. https://doi.org/10.1037/a0030509

Gallagher, K. M., & Updegraff, J. A. (2012). Health message framing effects on attitudes, intentions, and behavior: A meta-analytic review. *Annals of Behavioral Medicine*, *43*(1), 101–116. https://doi.org/10.1007/s12160-011-9308-7

Glöckner, A., & Betsch, T. (2011). The empirical content of theories in judgment and decision making: Shortcomings and remedies. *Judgment and Decision Making*, *6*(8), 711–721. https://doi.org/10.1017/S1930297500004149

Glöckner, A., & Pachur, T. (2012). Cognitive models of risky choice: Parameter stability and predictive accuracy of prospect theory. *Cognition*, *123*(1), 21–32. https://doi.org/10.1016/j.cognition.2011.12.002

Gluth, S., Rieskamp, J., & Büchel, C. (2014). Neural evidence for adaptive strategy selection in value-based decision-making. *Cerebral Cortex*, *24*(8), 2009–2021. https://doi.org/10.1093/cercor/bht049

Gonzalez, R., & Wu, G. (1999). On the shape of the probability weighting function. *Cognitive Psychology*, *38*, 129–166. https://doi.org/10.1006/cogp.1998.0710

Harbaugh, W. T., Krause, K., & Vesterlund, L. (2002). Risk attitudes of children and adults: Choices over small and large probability gains and losses. *Experimental Economics*, *5*, 53–84. https://doi.org/10.1023/A:1016316725855

Hasher, L., & Zacks, R. T. (1984). Automatic processing of fundamental information: The case of frequency of occurrence. *The American Psychologist*, *39*(12), 1372–1388. https://doi.org/10.1037/0003-066X.39.12.1372

Heck, D. W., & Erdfelder, E. (2017). Linking process and measurement models of recognition-based decisions. *Psychological Review*, *124*(4), 442–471. https://doi.org/10.1037/rev0000063

Horstmann, A., Villringer, A., & Neumann, J. (2012). Iowa Gambling Task: There is more to consider than long-term outcome. Using a linear equation model to disentangle the impact of outcome and frequency of gains and losses. *Frontiers in Neuroscience*, *6*, Article 61. https://doi.org/10.3389/fnins.2012.00061

Houdé, O. (2000). Inhibition and cognitive development: Object, number, categorization, and reasoning. *Cognitive Development*, *15*(1), 63–73. https://doi.org/10.1016/S0885-2014(00)00015-0

Huizenga, H. M., Zadelaar, J. N., Jansen, B. R. J., Olthof, M. C., Steingroever, H., Dekkers, L. M. S., van Duijvenvoorde, A. C. K., Figner, B., & Agelink van Rentergem, J. (2022). *Formal models of differential framing effects in decision making under risk: Publication materials*. OSF. https://doi.org/10.17605/OSF.IO/W62HA

Huizenga, Hilde M, Crone, E. A., & Jansen, B. R. J. (2007). Decision-making in healthy children, adolescents and adults explained by the use of increasingly complex proportional reasoning rules. *Developmental Science*, *10*(6), 814–825. https://doi.org/10.1111/j.1467-7687.2007.00621.x

Huizenga, Hilde M, Van Duijvenvoorde, A. C. K., van Ravenzwaaij, D., Wetzels, R., & Jansen, B. R. J. (2014). Is the unconscious, if it exists, a superior decision maker? *Behavioral and Brain Sciences*, *37*(1), 32–33. https://doi.org/10.1017/S0140525X13000769

Huizinga, M., Dolan, C. V, & Van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*(11), 2017–2036. https://doi.org/10.1016/j.neuropsychologia.2006.01.010

Hunt, L. T., Kolling, N., Soltani, A., Woolrich, M. W., Rushworth, M. F. S., & Behrens, T. E. J. (2012). Mechanisms underlying cortical activity during value-guided choice. *Nature Neuroscience*, *15*(3), 470–476. https://doi.org/10.1038/nn.3017

Jaccard, J., Wan, C. K., & Turrisi, R. (1990). The detection and interpretation of interaction effects between continuous variables in multiple regression. *Multivariate Behavioral Research*, *25*(4), 467–478. https://doi.org/10.1207/s15327906mbr2504_4

Jacobs, J., & Klaczynski, P. A. (2002). The development of judgment and decision making during childhood and adolescence. *Current Directions in Psychological Science*, *11*(4), 145–149. https://doi.org/10.1111/1467-8721.00188

Jacobs, J., & Potenza, M. (1991). The use of judgement heuristics to make social and object decisions: A developmental perspective. *Child Development*, *62*(1), 166–178. https://doi.org/10.2307/1130712

Jansen, B. R. J., & van der Maas, H. L. J. (1997). Statistical test of the rule assessment methodology by latent class analysis. *Developmental Review*, *17*, 321–357. https://doi.org/10.1006/drev.1997.0437

Jansen, B. R. J., & van der Maas, H. L. J. (2001). Evidence for the phase transition from rule I to rule II on the balance scale task. *Developmental Review*, *21*(4), 450–494. https://doi.org/10.1006/drev.2001.0530

Jansen, B. R. J., & van der Maas, H. L. J. (2002). The development of children's rule use on the balance scale task. *Journal of Experimental Child Psychology*, *81*(4), 383–416. https://doi.org/10.1006/jecp.2002.2664

Jansen, B. R. J., Van Duijvenvoorde, A. C. K., & Huizenga, H. M. (2012). Development of decision making: Sequential versus integrative rules. *Journal of Experimental Child Psychology*, *111*(1), 87–100. https://doi.org/10.1016/j.jecp.2011.07.006

Jefferies-Sewell, K., Sharma, S., Gale, T. M., Hawley, C. J., Georgiou, G. J., & Laws, K. R. (2015). To admit or not to admit? The effect of framing on risk assessment decision making in psychiatrists. *Journal of Mental Health*, *24*(1), 20–23. https://doi.org/10.3109/09638237.2014.951477

Jepma, M., Schaaf, J. V., Visser, I., & Huizenga, H. M. (2020). Uncertainty-driven regulation of learning and exploration in adolescents: A computational account. *PLoS Computational Biology*, *16*(9), Article e1008276. https://doi.org/10.1371/journal.pcbi.1008276

Johansen, M. K., & Palmeri, T. J. (2002). Are there representational shifts during category learning? *Cognitive Psychology*, *45*(4), 482–553. https://doi.org/10.1016/S0010-0285(02)00505-4

Johnson, E. J., Haubl, G., & Keinan, A. (2007). Aspects of endowment: A query theory of value construction. *Journal of Experimental Psychology: Learning Memory and Cognition*, *33*(3), 461–474. https://doi.org/10.1037/0278-7393.33.3.461

Johnson, E. J., Schulte-Mecklenbeck, M., & Willemsen, M. C. (2008). Process models deserve process data: Comment on Brandstätter, Gigerenzer, and Hertwig (2006). *Psychological Review*, *115*(1), 263–273. https://doi.org/10.1037/0033-295X.115.1.263

Kahneman, D. (2003). A perspective on judgment and choice: Mapping bounded rationality. *The American Psychologist*, *58*(9), 697–720. https://doi.org/10.1037/0003-066X.58.9.697

Kahneman, D., & Frederick, S. (2007). Frames and brains: Elicitation and control of response tendencies. *Trends in Cognitive Sciences*, *11*(2), 45–46. https://doi.org/10.1016/j.tics.2006.11.007

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica*, *47*(2), 263–292. https://doi.org/10.2307/1914185

Kahneman, D., & Tversky, A. (1984). Choices, values, and frames. *American Psychologist*, *39*(4), 341–350. https://doi.org/10.1037/0003-066X.39.4.341

Kam, C. D., & Simas, E. N. (2010). Risk orientations and policy frames. *The Journal of Politics*, *72*(2), 381–396. https://doi.org/10.1017/S0022381609990806

Kelly, F., McNeil, K., & Newman, I. (1973). Suggested inferential statistical models for research in behavior modification. *The Journal of Experimental Education*, *41*(4), 54–63. https://doi.org/10.1080/00220973.1973.11011427

Klein, R. A., Ratliff, K. A., Vianello, M., Adams, R. B., Bahnik, S., Bernstein, M. J., Bocian, K., Brandt, M., Brooks, B., Brumbaugh, C., & Nosek, B. A. (2014). Investigating variation in replicability: A "many labs" replication project. *Social Psychology*, *45*(3), 142–152. https://doi.org/10.1027/1864-9335/a000178

Kokis, J. V, Macpherson, R., Toplak, M. E., West, R. F., & Stanovich, K. E. (2002). Heuristic and analytic processing: Age trends and associations with cognitive ability and cognitive styles. *Journal of Experimental Child Psychology*, *83*(1), 26–52. https://doi.org/10.1016/S0022-0965(02)00121-2

Kuehnhanss, C. R., Heyndels, B., & Hilken, K. (2015). Choice in politics: Equivalency framing in economic policy decisions and the influence of expertise. *European Journal of Political Economy*, *40*, 360–374. https://doi.org/10.1016/j.ejpoleco.2015.06.001

Kühberger, A. (1998). The influence of framing on risky decisions: A meta-analysis. *Organizational Behavior and Human Decision Processes*, *75*(1), 23–55. https://doi.org/10.1006/obhd.1998.2781

Kühberger, A., & Gradl, P. (2013). Choice, rating, and ranking: Framing effects with different response modes. *Journal of Behavioral Decision Making*, *26*(2), 109–117. https://doi.org/10.1002/bdm.764

Kühberger, A., Schulte-Mecklenbeck, M., & Perner, J. (1999). The effects of framing, reflection, probability, and payoff on risk preference in choice tasks. *Organizational Behavior and Human Decision Processes*, *78*(3), 204–231. https://doi.org/10.1006/obhd.1999.2830

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*, 314–329. https://doi.org/10.1002/bdm

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. https://doi.org/10.1016/j.cogdev.2015.08.001

Lagarde, M. (2013). Investigating attribute non-attendance and its consequences in chouce expriments with latent class models. *Health Economics*, *22*, 554–567. https://doi.org/10.1002/hec

Lang, A., & Betsch, T. (2018). Children's neglect of probabilities in decision making with and without feedback. *Frontiers in Psychology*, *9*, Article 191. https://doi.org/10.3389/fpsyg.2018.00191

Lattimore, P., Baker, J., & Witte, A. (1992). The influence of probability on risky choice: A parametric examination. *Journal of Economic Behavior and Organization*, *17*, 377–400. https://doi.org/10.1016/S0167-2681(95)90015-2

LeBoeuf, R. A., & Shafir, E. (2003). Deep thoughts and shallow frames: On the susceptibility to framing effects. *Journal of Behavioral Decision Making*, *16*(2), 77–92. https://doi.org/10.1002/bdm.433

Lee, M. D. (2011). How cognitive modeling can benefit from hierarchical Bayesian models. *Journal of Mathematical Psychology*, *55*(1), 1–7. https://doi.org/10.1016/j.jmp.2010.08.013

Lee, M. D., & Sarnecka, B. W. (2011). Number-knower levels in young children: Insights from Bayesian modeling. *Cognition*, *120*(3), 391–402. https://doi.org/10.1016/j.cognition.2010.10.003

Lee, M. D., & Vanpaemel, W. (2018). Determining informative priors for cognitive models. *Psychonomic Bulletin and Review*, *25*(1), 114–127. https://doi.org/10.3758/s13423-017-1238-3

Leland, J. (1994). Generalized similarity judgments: An alternative explanation for choice anomalies. *Journal of Risk and Uncertainty*, *9*, 151–172. http://link.springer.com/article/10.1007/BF01064183

Levin, I. P., Bossard, E. A., Gaeth, G. J., & Yan, H. (2014). The combined role of task, child's age and individual differences in understanding decision processes. *Judgment and Decision Making*, *9*(3), 274–286. https://doi.org/10.1017/CBO9781107415324.004

Levy, D. J., & Glimcher, P. W. (2011). Comparing apples and oranges: Using reward-specific and reward-general subjective value representation in the brain. *The Journal of Neuroscience*, *31*(41), 14693–14707. https://doi.org/10.1523/JNEUROSCI.2218-11.2011

Lieder, F., & Griffiths, T. L. (2017). Strategy selection as rational metareasoning. *Psychological Review*, *124*(6), 762–794. https://doi.org/10.18565/aig.2017.6.35-40

Lodewyckx, T., Kim, W., Lee, M. D., Tuerlinckx, F., & Kuppens, P. (2011). A tutorial on Bayes factor estimation with the product space method. *Journal of Mathematical Psychology*, *55*(5), 331–347. https://doi.org/10.1016/j.jmp.2011.06.001

Luce, R. D. (1978). Lexicographic trade-off structures. *Theory and Decision*, *9*(6), 187–193.

Luce, R. D. (1999). Where is Mathemaical Modeling in Psychology Headed? *Theory & Psychology*, *9*(6), 723–737.

Mahoney, K. T., Buboltz, W., Levin, I. P., Doverspike, D., & Svyantek, D. J. (2011). Individual differences in a within-subjects risky-choice framing study. *Personality and Individual Differences*, *51*(3), 248–257. https://doi.org/10.1016/j.paid.2010.03.035

Mandel, D. R. (2001). Gain—Loss framing and choice: Separating outcome formulations from descriptor formulations. *Organizational Behavior and Human Decision Processes*, *85*(1), 56–76. https://doi.org/10.1006/obhd.2000.2932

Mandel, D. R. (2014). Do framing effects reveal irrational choice? *Journal of Experimental Psychology: General*, *143*(3), 1185–1198. https://doi.org/10.1037/a0034207

Mata, R., & Von Helversen, B. (2011). When easy comes hard: The development of adaptive strategy selection. *Child Development*, *82*(2), 687–700. https://doi.org/10.1111/j.1467-8624.2010.01535.x

McElroy, T., & Seta, J. J. (2003). Framing effects: An analytic–holistic perspective. *Journal of Experimental Social Psychology*, *39*(6), 610–617. https://doi.org/10.1016/S0022-1031(03)00036-2

McNeil, B. J., Pauker, S. G., Sox, H. C. J., & Tversky, A. (2004). On the elicitation of preferences for alternative therapies. In E. Shafir (Ed.), *Preference, belief, and similarity: Selected writings Amos Tversky* (pp. 583–591). MIT Press. https://doi.org/10.1348/000711005X38690

Miller, P. M., Fagley, N. S., & Casella, N. E. (2009). Effects of problem frame and gender on principals' decision making. *Social Psychology of Education*, *12*(3), 397–413. https://doi.org/10.1007/s11218-008-9087-6

Morsanyi, K., & Handley, S. J. (2008). How smart do you need to be to get it wrong? The role of cognitive capacity in the development of heuristic-based judgment. *Journal of Experimental Child Psychology*, *99*(1), 18–36. https://doi.org/10.1016/j.jecp.2007.08.003

Navajas, J., Bahrami, B., & Latham, P. E. (2016). Post-decisional accounts of biases in confidence. *Current Opinion in Behavioral Sciences*, *11*, 55–60. https://doi.org/10.1016/j.cobeha.2016.05.005

Nilsson, H., Rieskamp, J., & Wagenmakers, E. J. (2011). Hierarchical Bayesian parameter estimation for cumulative prospect theory. *Journal of Mathematical Psychology*, *55*(1), 84–93. https://doi.org/10.1016/j.jmp.2010.08.006

O'Keefe, D. J., & Jensen, J. D. (2009). The relative persuasiveness of Gain-Framed and Loss-Framed Messages for encouraging disease detection behaviors: A meta-analytic review. *Journal of Communication*, *59*(2), 296–316. https://doi.org/10.1111/j.1460-2466.2009.01417.x

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D. E., & Gross, J. J. (2004). For better or for worse: Neural systems supporting the cognitive down- and up-regulation of negative emotion. *NeuroImage*, *23*(2), 483–499. https://doi.org/10.1016/j.neuroimage.2004.06.030

Olsen, R. A. (1997). Prospect theory as an explanation of risky choice by professional investors: Some evidence. *Review of Financial Economics*, *6*(2), 225–232. https://doi.org/10.1016/S1058-3300(97)90008-2

Pachur, T., & Olsson, H. (2012). Type of learning task impacts performance and strategy selection in decision making. *Cognitive Psychology*, *65*(2), 207–240. https://doi.org/10.1016/j.cogpsych.2012.03.003

Pachur, T., Suter, R. S., & Hertwig, R. (2017). How the twain can meet: Prospect theory and models of heuristics in risky choice. *Cognitive Psychology*, *93*, 44–73. https://doi.org/10.1016/j.cogpsych.2017.01.001

Payne, J. W. (2005). It is whether you win or lose: The importance of the overall probabilities of winning or losing in risky choice. *Journal of Risk and Uncertainty*, *30*(1), 5–19. https://doi.org/10.1007/s11166-005-5831-x

Payne, J. W., Bettman, J. R., & Johnson, E. (1988). Adaptive Strategy Selection in Decision Making. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(3), 534–552. https://doi.org/10.1037/0278-7393.14.3.534

Peters, S., Koolschijn, P. C. M. P., Crone, E. A., van Duijvenvoorde, A. C. K., & Raijmakers, M. E. J. (2014). Strategies influence neural activity for feedback learning across child and adolescent development. *Neuropsychologia*, *62*, 365–374. https://doi.org/10.1016/j.neuropsychologia.2014.07.006

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. Basic Books.

Piñon, A., & Gambara, H. (2005). A meta-analytic review of framming effect: Risky, attribute and goal framing. *Psicothema*, *17*(2), 325–331.

Poirel, N., Borst, G., Simon, G., Rossi, S., Cassotti, M., Pineau, A., & Houdé, O. (2012). Number conservation is related to children's prefrontal inhibitory control: An fMRI study of a piagetian task. *PloS ONE*, *7*(7), Article e40802. https://doi.org/10.1371/journal.pone.0040802

Pol Van de, F., & Langeheine, R. (1990). Mixed Markov latent class models. *Social Methodology*, *20*, 213–247. https://doi.org/10.2307/271087

Prelec, D. (1998). The probability weighting function. *Econometrica*, *66*(3), 497–527. https://doi.org/10.2307/2998573

Raijmakers, M. E. J., Jansen, B. R. J., & van der Maas, H. L. J. (2004). Rules and development in triad classification task performance. *Developmental Review*, *24*(3), 289–321. https://doi.org/10.1016/j.dr.2004.06.002

Rao, L.-L., Zhou, Y., Xu, L., Liang, Z.-Y., Jiang, T., & Li, S. (2011). Are risky choices actually guided by a compensatory process? New insights from FMRI. *PloS ONE*, *6*(3), Article e14756. https://doi.org/10.1371/journal.pone.0014756

Reyna, V. F. (2012). A new intuitionism: Meaning, memory, and development in Fuzzy-Trace Theory. *Judgment & Decision Making*, *7*(3), 332–359. https://doi.org/10.1017/S1930297500002291

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. https://doi.org/10.1002/bdm.3960040403

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

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

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

Reyna, V. F., Brainerd, C. J., Chen, Z., & Bookbinder, S. H. (2021). Explaining risky choices with judgments: Framing, the zero effect, and the contextual relativity of gist. *Journal of Experimental Psychology: Learning Memory and Cognition*, *47*(7), 1037–1053. https://doi.org/10.1037/xlm0001016

Reyna, V. F., Chick, C. F., Corbin, J. C., & Hsia, A. N. (2014). Developmental reversals in risky decision making. *Psychological Science*, *25*(1), 76–84. https://doi.org/10.1177/0956797613497022

Reyna, V. F., & Ellis, S. C. (1994). Fuzzy-trace theory and framing effects in children's risky decision making. *Psychological Science*, *5*(5), 275–279. https://doi.org/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. https://doi.org/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. https://doi.org/10.1111/j.1529-1006.2006.00026.x

Reyna, V. F., Helm, R. K., Weldon, R. B., Shah, P. D., Turpin, A. G., & Govindgari, S. (2018). Brain activation covaries with reported criminal behaviors when making risky choices: A fuzzy-trace theory approach. *Journal of Experimental Psychology. General*, *147*(7), 1094–1109. https://doi.org/10.1037/xge0000434

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*. Cambridge Universty Press.

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. https://doi.org/10.1111/cdep.12117

Rieskamp, J. (2008). The probabilistic nature of preferential choice. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(6), 1446–1465. https://doi.org/10.1037/a0013646

Rivers, S. E., Reyna, V. F., & Mills, B. (2008). Risk taking under the influence: A fuzzy-trace theory of emotion in adolescence. *Developmental Review*, *28*, 107–144. https://doi.org/10.1016/j.dr.2007.11.002

Roiser, J. P., de Martino, B., Tan, G. C. Y., Kumaran, D., Seymour, B., Wood, N. W., & Dolan, R. J. (2009). A genetically mediated bias in decision making driven by failure of amygdala control. *The Journal of Neuroscience*, *29*(18), 5985–5991. https://doi.org/10.1523/JNEUROSCI.0407-09.2009

Roszkowski, M. J., & Snelbecker, G. E. (1990). Effects of "Framing" on measures of risk tolerance: Financial planners are not immune. *Journal of Behavioral Economics*, *19*(3), 237–246. https://doi.org/10.1016/0090-5720(90)90029-7

Rothman, A. J., & Salovey, P. (1997). Shaping perceptions to motivate healthy behavior: The role of message framing. *Psychological Bulletinulletin*, *121*(1), 3–19. https://doi.org/10.1037/0033-2909.121.1.3

Scarpa, R., Gilbride, T. J., Campbell, D., & Hensher, D. A. (2009). Modelling attribute non-attendance in choice experiments for rural landscape valuation. *European Review of Agricultural Economics*, *36*(2), 151–174. https://doi.org/10.1093/erae/jbp012

Schlottmann, A. (2001). Children's probability intuitions: Understanding the expected value of complex gambles. *Child Development*, *72*(1), 103–122. http://onlinelibrary.wiley.com/doi/10.1111/1467-8624.00268/abstract

Schlottmann, A., & Anderson, N. H. (1994). Children's judgments of expected value. *Developmental Psychology*, *30*(1), 56–66. https://doi.org/10.1037//0012-1649.30.1.56

Schlottmann, A., & Tring, J. (2005). How children reason about Gains and Losses: Framing effects in judgement and choice. *Swiss Journal of Psychology*, *64*(3), 153–171. https://doi.org/10.1024/1421-0185.64.3.153

Schmittmann, V. D., van der Maas, H. L. J., & Raijmakers, M. E. J. (2012). Distinct discrimination learning strategies and their relation with spatial memory and attentional control in 4- to 14-year-olds. *Journal of Experimental Child Psychology*, *111*(4), 644–662. https://doi.org/10.1016/j.jecp.2011.10.010

Schonberg, T., Fox, C. R., & Poldrack, R. A. (2011). Mind the gap: Bridging economic and naturalistic risk-taking with cognitive neuroscience. *Trends in Cognitive Sciences*, *15*(1), 11–19. https://doi.org/10.1016/j.tics.2010.10.002

Sescousse, G., Caldú, X., Segura, B., & Dreher, J.-C. (2013). Processing of primary and secondary rewards: A quantitative meta-analysis and review of human functional neuroimaging studies. *Neuroscience and Biobehavioral Reviews*, *37*(4), 681–696. https://doi.org/10.1016/j.neubiorev.2013.02.002

Shafir, E., Simonson, I., & Tversky, A. (1993). Reason-based choice. *Cognition*, *49*, 11–36. https://doi.org/10.1016/0010-0277(93)90034-S

Sher, S., & McKenzie, C. R. M. (2006). Information leakage from logically equivalent frames. *Cognition*, *101*(3), 467–494. https://doi.org/10.1016/j.cognition.2005.11.001

Shiloh, S., Salton, E., & Sharabi, D. (2002). Individual differences in rational and intuitive thinking styles as predictors of heuristic responses and framing effects. *Personality and Individual Differences*, *32*, 415–429. https://doi.org/10.1016/S0191-8869(01)00034-4

Siegler, R. S., & Chen, Z. (2002). Development of rules and strategies: Balancing the old and the new. *Journal of Experimental Child Psychology*, *81*, 446–457. https://doi.org/10.1006/jecp.2002.2666

Siegler, R. S., Strauss, S., & Levin, I. (1981). Developmental Sequences within and between Concepts. *Monographs of the Society for Research in Child Development*, *46*(2), 1–84. https://doi.org/10.2307/1165995

Siegler, R. S., Thompson, C. A., & Opfer, J. E. (2009). The logarithmic-to-linear shift: One learning sequence, many tasks, many time scales. *Mind, Brain, and Education*, *3*(3), 143–150. https://doi.org/10.1111/j.1751-228X.2009.01064.x

Simon, A. F., Fagley, N. S., & Halleran, J. G. (2004). Decision framing: Moderating effects of individual differences and cognitive processing. *Journal of Behavioral Decision Making*, *17*(2), 77–93. https://doi.org/10.1002/bdm.463

Sip, K. E., Smith, D. V., Porcelli, A. J., Kar, K., & Delgado, M. R. (2015). Social closeness and feedback modulate susceptibility to the framing effect. *Social Neuroscience*, *10*(1), 35–45. https://doi.org/10.1080/17470919.2014.944316

Slovic, P. (1995). The construction of preference. *American Psychologist*, *50*(5), 364–371. https://doi.org/10.1037//0003-066X.50.5.364

Slovic, P., & Lichtenstein, S. (1983). Preference reversals: A broader perspective. *American Economic Review*, *73*(4), 596–605. https://librarysearch.lse.ac.uk/primo-explore/fulldisplay?docid=TN_proquest233045062&context=PC&vid=44LSE_VU1&lang=en_US&search_scope=CSCOP_ALL&adaptor=primo_central_multiple_fe&tab=default_tab&query=any,contains,Slovic P, Lichtenstein S. 1983. Preference

Smith, S. M., & Levin, I. P. (1996). Need for cognition and choice framing effects. *Journal of Behavioral Decision Making*, *9*, 283–290. https://doi.org/10.1002/(SICI)1099-0771(199612)9:4%3C283::AID-BDM241%3E3.0.CO;2-7

Stanovich, K. E., Toplak, M. E., & West, R. F. (2008). The development of rational thought: A taxonomy of heuristics and biases. In R. V. Kail (Ed.), *Advances in child development and behavior* (pp. 251–285). Elsevier Academic 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. https://doi.org/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*, 103–118. https://doi.org/10.1016/j.dr.2011.07.003

Stark, E., Baldwin, A. S., Hertel, A. W., & Rothman, A. J. (2017). The role of rational and experiential processing in influencing the framing effect. *Journal of Social Psychology*, *157*(3), 308–321. https://doi.org/10.1080/00224545.2016.1198301

Steinbeis, N., & Crone, E. A. (2016). The link between cognitive control and decision-making across child and adolescent development. *Current Opinion in Behavioral Sciences*, *10*, 28–32. https://doi.org/10.1016/j.cobeha.2016.04.009

Steinberg, L. (2010). A dual systems model of adolescent risk-taking. *Developmental Psychobiology*, *52*(3), 216–224. https://doi.org/10.1002/dev.20445

Steingroever, H., Jepma, M., Lee, M. D., Jansen, B. R. J., & Huizenga, H. M. (2019). Detecting strategies in developmental psychology. *Computational Brain & Behavior*, *2*(2), 128–140. https://doi.org/10.1007/s42113-019-0024-x

Steingroever, H., Pachur, T., Šmíra, M., & Lee, M. D. (2018). Bayesian techniques for analyzing group differences in the Iowa Gambling Task: A case study of intuitive and deliberate decision-makers. *Psychonomic Bulletin & Review*, *25*, 951–970. https://doi.org/10.3758/s13423-017-1331-7

Steingroever, H., Wetzels, R., & Wagenmakers, E.-J. (2014). Absolute performance of reinforcement-learning models for the Iowa Gambling Task. *Decision*, *1*(3), 161–183. https://doi.org/10.1037/dec0000005

Stott, H. P. (2006). Cumulative prospect theory's functional menagerie. *Journal of Risk and Uncertainty*, *32*(2), 101–130. https://doi.org/10.1007/s11166-006-8289-6

Su, Y., Rao, L.-L., Sun, H.-Y., Du, X.-L., Li, X., & Li, S. (2013). Is making a risky choice based on a weighting and adding process? An eye-tracking investigation. *Journal of Experimental Psychology:*

Learning, Memory, and Cognition, *39*(6), 1765–1780. https://doi.org/10.1037/a0032861

Sütterlin, S., Herbert, C., Schmitt, M., Kübler, A., & Vögele, C. (2011). Frames, decisions, and cardiac-autonomic control. *Social Neuroscience*, *6*(2), 169–177. https://doi.org/10.1080/17470919.2010.495883

Teigen, K. H., & Nikolaisen, M. I. (2009). Incorrect estimates and false reports: How framing modifies truth. *Thinking and Reasoning*, *15*(3), 268–293. https://doi.org/10.1080/13546780903020999

Tombu, M., & Mandel, D. R. (2015). When does framing influence preferences, risk perceptions, and risk attitudes? The explicated valence account. *Journal of Behavioral Decision Making*, *28*(5), 464–476. https://doi.org/10.1002/bdm.1863

Toplak, M. E., West, R. F., & Stanovich, K. E. (2014). Assessing miserly information processing: An expansion of the Cognitive Reflection Test. *Thinking and Reasoning*, *20*(2), 147–168. https://doi.org/10.1080/13546783.2013.844729

Trepel, C., Fox, C. R., & Poldrack, R. A. (2005). Prospect theory on the brain? Toward a cognitive neuroscience of decision under risk. *Brain Research. Cognitive Brain Research*, *23*(1), 34–50. https://doi.org/10.1016/j.cogbrainres.2005.01.016

Tversky, A., & Fox, C. R. (1995). Weighting risk and uncertainty. *Psychological Review*, *102*(2), 269–283. https://doi.org/10.1037/0033-295X.102.2.269

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453–458. https://doi.org/10.1126/science.7455683

Tversky, A., & Kahneman, D. (1986). Rational choice and the framing of decisions. *The Journal of Business*, *59*(4), S251–S278. https://doi.org/10.1080/03057240802227486

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, *5*(4), 297–323. https://doi.org/10.1007/BF00122574

Tversky, A., Sattath, S., & Slovic, P. (1988). Contingent weighting in judgment and choice. *Psychological Review*, *95*(3), 371–384. https://doi.org/10.1037/0033-295X.95.3.371

van den Bos, W., Bruckner, R., Nassar, M. R., Mata, R., & Eppinger, B. (2018). Computational neuroscience across the lifespan: Promises and pitfalls. *Developmental Cognitive Neuroscience*, *33*, 42–53. https://doi.org/10.1016/j.dcn.2017.09.008

Van Der Maas, H. L. J., & Straatemeier, M. (2008). How to detect cognitive strategies: Commentary on "Differentiation and integration: Guiding principles for analyzing cognitive change." *Developmental Science*, *11*(4), 449–453. https://doi.org/10.1111/j.1467-7687.2008.00690.x

Van Duijvenvoorde, A. C. K., Figner, B., Weeda, W. D., van der Molen, M. W., Jansen, B. R. J., & Huizenga, H. M. (2016). Neural mechanisms underlying compensatory and noncompensatory strategies in risky choice. *Journal of Cogntive Neuroscience*, *28*(9), 1358–1373. https://doi.org/10.1162/jocn

Van Duijvenvoorde, Anna C K, Huizenga, H. M., & Jansen, B. R. J. (2014). What is and what could have been: Experiencing regret and relief across childhood. *Cognition & Emotion*, *28*(5), 926–935. https://doi.org/10.1080/02699931.2013.861800

Veldwijk, J., Essers, B. A. B., Lambooij, M. S., Dirksen, C. D., Smit, H. A., & De Wit, G. A. (2016). Survival or mortality: Does risk attribute framing influence decision-making behavior in a discrete choice experiment? *Value in Health*, *19*(2), 202–209. https://doi.org/10.1016/j.jval.2015.11.004

Venkatraman, V., Payne, J. W., Bettman, J. R., Luce, M. F., & Huettel, S. A. (2009). Separate neural mechanisms underlie choices and strategic preferences in risky decision making. *Neuron*, *62*(4), 593–602. https://doi.org/10.1016/j.neuron.2009.04.007

Venkatraman, V., Payne, J. W., & Huettel, S. A. (2014). An overall probability of winning heuristic for complex risky decisions: Choice and eye fixation evidence. *Organizational Behavior and Human Decision Processes*, *125*(2), 73–87. https://doi.org/10.1016/j.obhdp.2014.06.003

Verburg, M., Snellings, P., Zeguers, M. H. T., & Huizenga, H. M. (2019). Positive-blank versus negative-blank feedback learning in children and adults. *Quarterly Journal of Experimental Psychology*, *72*(4), 753–763. https://doi.org/10.1177/1747021818769038

Villarreal, M., Velázquez, C., Baroja, J. L., Segura, A., Bouzas, A., & Lee, M. D. (2019). Bayesian methods applied to the generalized matching law. *Journal of the Experimental Analysis of Behavior*, *111*(2), 252–273. https://doi.org/10.1002/jeab.506

Vlaev, I., Chater, N., Stewart, N., & Brown, G. D. A. (2011). Does the brain calculate value? *Trends in Cognitive Sciences*, *15*(11), 546–554. https://doi.org/10.1016/j.tics.2011.09.008

Wagenmakers, E.-J., Lee, M. D., Rouder, J. N., & Morey, R. D. (2020). The principle of predictive irrelevance or why intervals should not be used for model comparison featuring a point null hypothesis. *The Theory of Statistics in Psychology*, *3*, 111–129. https://doi.org/10.1007/978-3-030-48043-1_8

Wall, D., Crookes, R. D., Johnson, E. J., & Weber, E. U. (2020). Risky choice frames shift the structure and emotional valence of internal arguments: A query theory account of the unusual disease problem. *Judgement and Decision Making*, *15*(5), 685–703.

Wallin, A., Paradis, C., & Katsikopoulos, K. V. (2016). Evaluative polarity words in risky choice framing. *Journal of Pragmatics*, *106*, 20–38. https://doi.org/10.1016/j.pragma.2016.09.005

Wang, X. T. (1996). Framing effects: Dynamics and task domains. *Organizational Behavior and Human Decision Processes*, *68*(2), 145–157. https://doi.org/10.1006/obhd.1996.0095

Wang, X. T. (2002). Risk as reproductive variance. *Evolution and Human Behavior*, *23*, 35–57. https://doi.org/10.1016/S1090-5138(01)00091-5

Wang, X. T. (2008). Risk communication and risky choice in context: Ambiguity and ambivalence hypothesis. *Annals of the New York Academy of Sciences*, *1128*(1), 78–89. https://doi.org/10.1196/annals.1399.009

Wang, X. T., & Johnson, J. G. (2012). A tri-reference point theory of decision making under risk. *Journal of Experimental Psychology: General*, *141*(4), 743–756. https://doi.org/10.1037/a0027415

Wang, X. T., Rao, L. L., & Zheng, H. (2017). Neural substrates of framing effects in social contexts: A meta-analytical approach. *Social Neuroscience*, *12*(3), 268–279. https://doi.org/10.1080/17470919.2016.1165285

West, R. F., Toplak, M. E., & Stanovich, K. E. (2008). Heuristics and biases as measures of critical thinking: Associations with cognitive ability and thinking dispositions. *Journal of Educational Psychology*, *100*(4), 930–941. https://doi.org/10.1037/a0012842

Wilkening, F., & Anderson, N. H. (1982). Comparison of two rule-assessment methodologies for studying cognitive development and knowledge structure. *Psychological Bulletin*, *92*(1), 215–237. https://doi.org/10.1037/0033-2909.92.1.215

Yechiam, E., & Hochman, G. (2012). Losses as modulators of attention: Review and analysis of the unique effects of losses over gains. *Psychological Bulletin*, *139*(2), 497–518. https://doi.org/10.1037/a0029383

Zadelaar, J. N., Weeda, W. D., Waldorp, L. J., Van Duijvenvoorde, A. C. K., Blankenstein, N. E., & Huizenga, H. M. (2019). Are individual differences quantitative or qualitative? An integrated behavioral and fMRI MIMIC approach. *NeuroImage*, *202*, Article 116058. https://doi.org/10.1016/j.neuroimage.2019.116058

Zakay, D. (1985). Post-decisional confidence and conflict experienced in a choice process. *Acta Psychologica*, *58*(1), 75–80. https://doi.org/10.1016/0001-6918(85)90035-6

Zakay, D. (2020). Post-decisional confidence— can it be trusted? In R. Ranyard, W. R. Crozier, & O. Svenson (Eds.), *Decision making: Cognitive models and explanations* (pp. 19–34). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9780203444399-26/post-decisional-confidence%E2%80%94can-trusted-dan-zakay

Zhen, S., & Yu, R. (2016). All framing effects are not created equal: Low convergent validity between two classic measurements of framing. *Scientific Reports*, *6*, Article 30071. https://doi.org/10.1038/srep30071

Zheng, H., Wang, X. T., & Zhu, L. (2010). Framing effects: Behavioral dynamics and neural basis. *Neuropsychologia*, *48*(11), 3198–3204. https://doi.org/10.1016/j.neuropsychologia.2010.06.031

Zickar, M., & Highhouse, S. (1998). Looking closer at the effects of framing on risky choice: An item response theory analysis. *Organizational Behavior and Human Decision Processes*, *75*(1), 75–91. https://doi.org/10.1006/obhd.1998.2783

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