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The effect of the 1-in-X numerical format on choices

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Abstract

The 1-in-X numerical format (e.g., 1 in 200) has been found to increase subjective probability evaluations and behavioral intentions in hypothetical scenarios compared with the N-in-NX format (e.g., 5 in 1000). However, it remains unclear whether this format can also bias choices between truly incentivized options. In four online studies ($N = 1039$), participants were presented with a small endowment (i.e., 1£) and an actual choice between two options: a sure loss of a part of such endowment and a lottery with the chance to lose the entire endowment, presented using either the 1-in-X or the N-in-NX format. In Studies 1–3, where the two options were equivalent in expected monetary value (EV) and the lottery was described with varying degrees of concreteness, participants preferred the lottery option to a lesser extent when the chance of losing the endowment was presented using the 1-in-X format compared with the N-in-NX format. The same effect was replicated in Study 4a when the lottery option had a higher EV than the sure loss, showing that the 1-in-X effect can also lead individuals to deviate from maximizing EV. However, the effect vanished in Study 4b when the difference in EV between the two options increased. Implications for risk communication and a possible interpretation of the results are discussed accordingly.

KEYWORDS
1-in-X effect, bias, choice, decision-making, numerical format, risk communication

1 | INTRODUCTION

In risk communication, various numerical formats can be used to convey quantitative information about hazards, and psychological research has shown that the numerical format used to convey such information can significantly influence risk perception (e.g., Brase, 2002; Oudhoff & Timmermans, 2015; Pighin et al., 2011, 2015; Slovic, 1972). Among the different numerical formats, the 1-in-X format (e.g., 1 in 10) has attracted particular attention since growing empirical evidence has raised concerns about its use to convey probabilistic risk information (Zikmund-Fisher, 2011, 2014): Despite its apparent simplicity, this format has been shown to be computationally difficult (Cuite et al., 2008) and to have a troubling impact on subjective probability evaluations. A number of experimental findings, indeed, speak in favor of what Pighin et al. (2011) initially named the 1-in-X effect, that is, the tendency to perceive the likelihood of an event as higher when its probability is communicated using a 1-in-X ratio (e.g., "1 in 20") rather than when the same probability is expressed using an N-in-NX ratio (e.g., "5 in 100"). Despite varying in effect size (see Jie, 2022; Sirota et al., 2014), such tendency has been repeatedly observed across different populations, languages, outcomes, and contexts (Oudhoff & Timmermans, 2015;

Pighin et al., 2011, 2015; Sirota et al., 2014; Sirota et al., 2018; Sirota & Juanchich, 2019; Suk et al., 2022).

Besides subjective probability evaluations, the 1-in-X format has proven to impact behavioral intentions as well. For example, more participants reported that they would have canceled a hypothetical trip if they were told that the chance of contracting an infectious disease was "1 in 13" than if they were told that the chance was "10 in 130" (Sirota & Juanchich, 2019; see also Sirota et al., 2018). Seemingly, the intention to vacation in a COVID-19 infected country was lower if potential tourists were told that "1 in 3811" people currently tested positive in that location rather than if they were told that "26 out of 100,000" people tested positive (Savadori et al., 2023). Similarly, but in a completely different context, Oudhoff and Timmermans (2015) showed that more participants preferred to buy a lottery ticket when the likelihood of winning was presented as, for example, "1 in 27" rather than as "37 in 1000" or "3.7%". Overall, all these results are in line with the idea that probabilities presented as 1-in-X rather than as N-in-NX (or as percentages) tend to be perceived as higher.

To the best of our knowledge, however, the investigation of the impact of the 1-in-X format has been virtually confined to subjective probability evaluations and behavioral intentions in hypothetical scenarios. A notable exception is the study of Suk et al. (2022). In their study, participants were informed that a charity organization was launching two campaigns to supply treatments to neglected individuals suffering from one of two illnesses, with the aim of reducing the mortality rate. In one campaign, the reduction in mortality rate was presented in the 1-in-X format (i.e., "from 1 in 181 to 1 in 667"), while in the other campaign, the same reduction was presented in the N-in-NX format (i.e., "from 55 in 10,000 to 15 in 10,000"). Results showed that when asked to choose between the two campaigns to make a real donation (i.e., by donating part of the compensation won in a previous phase of the study), the donation campaign presented in the 1-in-X format was selected by more participants and received, on average, larger donations than the one in the other format. While this result is very compelling and consistent with the 1-in-X effect, it should be noted that it is supposed to arise from a direct comparison between the two formats. As the authors themselves acknowledged, the effect appears to be driven by which element of the ratio is fixed (the numerator in the 1-in-X format and the denominator in the N-in-NX format) and how the probability levels affect the varying element in the ratio (the denominator in the 1-in-X format and the numerator in the N-in-NX format). This account does not directly apply to the 1-in-X effect, which has been previously investigated by asking participants to evaluate a single format and probability level at a time, without comparisons. Therefore, to date, there is no empirical evidence on how the 1-in-X format influences the actual choices of individuals.

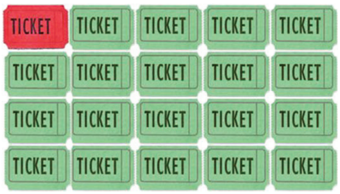
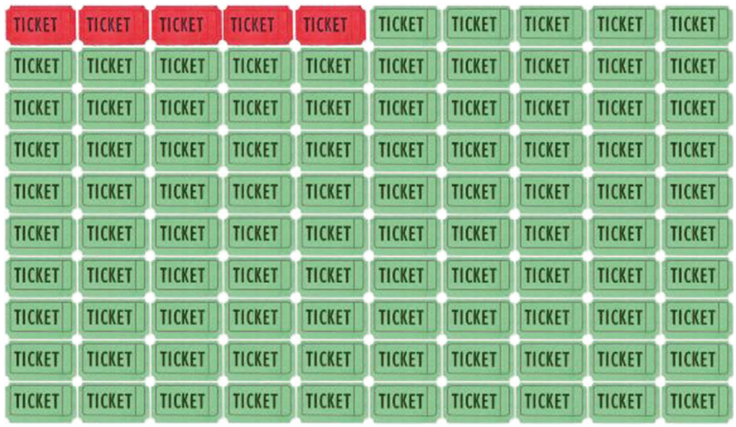
It is worth noting, however, that the 1-in-X effect appears to operate in contrast to another cognitive bias that significantly influences individuals' choices, known as the *ratio bias* phenomenon (Denes-Raj & Epstein, 1994; Kirkpatrick & Epstein, 1992; Pacini & Epstein, 1999). Both biases are linked to the numerical format used to convey probabilities, but the ratio bias phenomenon is commonly observed through the choice experimental paradigm introduced by Kirkpatrick and Epstein (1992). In this paradigm, participants are presented with two trays of jelly beans—one "large" tray containing a high absolute number of red beans (e.g., 30 out of 100) and one "small" tray containing a low absolute number of red beans (e.g., 3 out of 10). Participants are then asked to choose which tray they would prefer to draw from, with the goal of obtaining a red bean. Being the probability of drawing a red bean the same for both trays, one would expect preferences to be evenly distributed between the two, as participants should be indifferent. However, intriguingly, participants tend to favor the tray with a greater absolute number of red jelly beans (Kirkpatrick & Epstein, 1992), suggesting that individuals tend to perceive an event as more likely when its probability is presented as a ratio of larger (e.g., 30 in 100) versus smaller (e.g., 3 in 10) numbers. The most frequently discussed explanations for this bias are those proposed by dual-process theories such as the cognitive-experiential-self theory (Kirkpatrick & Epstein, 1992) and the fuzzy-trace theory (Reyna & Brainerd, 1995). These suggest that individuals may have a greater familiarity with (and better understanding of) small numbers compared with large numbers, leading them to intuitively consider ratios with larger numbers as greater (Kirkpatrick & Epstein, 1992) or that individuals show a general tendency to assign more weight to the numerator than the denominator of a ratio (denominator neglect), leading them to consider the ratio with the larger numerator as greater (Epstein, 1994; Reyna, 1991; Reyna & Brainerd, 1994). With regard to the 1-in-X effect, on the other hand, there is still no conclusive explanation. Whereas some evidence has been collected pointing to an ease of imagination triggered by the number "1" at the numerator (Oudhoff & Timmermans, 2015), there is no comprehensive understanding or definitive explanation, and research has yet to pinpoint the precise conditions under which either the ratio bias or the 1-in-X effect prevails.

Importantly, since the 1-in-X format is widely used in many domains, such as health communication, risk communication, marketing, and public policy, examining how it may affect people's choices in these situations has a relevant practical reason. Thus, a crucial question remains: Can this format truly sway people's choices when genuine incentives are at stake? By exploring the 1-in-X effect in decisions with monetary incentives, we seek to uncover valuable insights that could impact decision-making across a range of different scenarios.

2 | PRESENT RESEARCH

In the present research, we moved beyond hypothetical scenarios and presented participants with a real choice between two options. Four, well-powered online studies employed the same procedure. At the beginning of the task, participants received a monetary endowment of 1£, and then, they were asked to actually choose between two options: to lose for sure a certain amount that was subtracted from the initial monetary endowment received (sure loss) and to play a lottery with some chances of losing the entire initial endowment. Depending on the experimental condition (see Table 1), we presented the chances of losing the entire endowment in the lottery option

TABLE 1 Descriptions of the lottery option employed in Studies 1–3.

Study	Description
1	*Abstract description*
	Play a lottery with a (1 in 20/5 in 100) chance of losing your endowment.
2	*Concrete description*
	Play a lottery where a ticket will be randomly drawn from a bowl containing (20/100) tickets. In this lottery, (1 in 20/5 in 100) tickets (causes/cause) you to lose your endowment.
3	*Concrete description plus visual representation*
	Play a lottery where a ticket will be randomly drawn from a bowl containing (20/100) tickets. In this lottery, (1 in 20/5 in 100) tickets (causes/cause) you to lose your endowment. This is the set of tickets contained in the bowl:
	(1 in 20 condition)  (5 in 100 condition) 

either in a 1-in-X format (e.g., "1 in 20") or in a N-in-NX format (e.g., "5 in 100"). At the end of the task, participants were remunerated according to their choices. Those choosing the sure loss received their hourly compensation along with the remaining amount of their initial endowment; those choosing the lottery were redirected to a background random assignment which had a 5% chance of displaying a "losing" message (i.e., "Unfortunately, the outcome of the lottery is that you lose your 1-pound endowment") and a 95% chance of displaying a "winning" message (i.e., "Fortunately, the outcome of the lottery is that you keep your 1-pound endowment"). Subsequently, the participants' hourly payments were adjusted based on the outcome of the lottery (i.e., the displayed message).

As previously mentioned, the 1-in-X effect has predominantly been observed when assessing the subjective magnitude of a probability. By hypothesizing, as we do here, that this effect can extend to decisions, we indirectly posit a shared underlying mechanism between the two processes. However, despite interconnected, evaluation and choice are distinct processes (e.g., Kahneman & Tversky, 1982), and substantial evidence exists showing that they do not always align. For example, instances of preference reversal (i.e., systematic changes in people's preference order between options when asked to choose between them or to evaluate them) are well-documented (e.g., Grether & Plott, 1979; Hsee et al., 1999; Lichtenstein & Slovic, 1971, 2006; Tversky & Thaler, 1990) and reveal a disproportionate influence of different option components, depending on whether the context requires an evaluation or a choice (Hsee et al., 1999; Lichtenstein & Slovic, 2006). Accordingly, our present study endeavors to examine the 1-in-X effect on both evaluations and choices in situations that could resemble real decision tasks, where genuine incentives are at stake, still remaining controlled within an experimental context.

In addition, for generalization purposes, two situational factors have been examined across studies: the concreteness of the option descriptions (Studies 1–3) and the relative expected values of the options (Studies 4a and 4b). Previous literature has suggested that concrete narrative information (such as descriptions representing the real world in terms of naturally occurring frequencies and pictorial representations) is clearer and easier to understand compared with other representational formats (e.g., verbal descriptions conveying probabilistic information using percentages or chances—see more on this in Brase, 2002) and that this clarity facilitates statistical reasoning when it is used to represent the likelihood of an event occurring (Brase, 2021; Brase et al., 1998; Gigerenzer & Hoffrage, 1995, 1999). Additionally, concrete narrative information promotes the generation of vivid mental images, resulting in stronger affective reactions and a higher perception of risk (Slovic et al., 2002, 2004). Studies have shown, for example, that concrete descriptions of hazards exacerbate negative emotions and increase risk perceptions more than abstract descriptions (Chandran & Menon, 2004; Henrich et al., 2015; Newell et al., 2008; Slovic et al., 2004). Although there is currently no definitive evidence, the 1-in-X effect itself may be ascribed to the greater concreteness, or a greater imaginability (Oudhoff & Timmermans, 2015), of the number "1" in the numerator, since small numbers are encoded and remembered in more detail than large

Welcome!

To take part in this study, you receive an endowment of 1£.

You have to choose between A or B:

Lose 5 pence of your endowment for sure.

Play a lottery with a 1 in 20 chance [5 in 100 chances] to lose your endowment.

[Study 1a]

How low or high does the [1 in 20 chance / 5 in 100 chances] of losing the 1£ seem to you?

Extremely low ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extremely high

What do you choose?

☐ A) Lose 5 pence of your endowment for sure.

☐ B) Play a lottery with a [1 in 20 chance / 5 in 100 chances] to lose your endowment.

[Study 1b]

What do you choose?

☐ A) Lose 5 pence of your endowment for sure.

☐ B) Play a lottery with a [1 in 20 chance / 5 in 100 chances] to lose your endowment.

How confident are you that the choice you've made is the right one for you?

Not confident at all ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extremely confident

FIGURE 1 Task employed in Studies 1a and 1b.

numbers (see the *concretive principle* proposed by Kirkpatrick & Epstein, 1992). In line with this idea, we varied the concreteness of the lottery option in three consecutive studies as detailed in Table 1. Specifically, we explored whether the 1-in-X format affects subjective probability evaluations and choices when different descriptions characterized by an increasing, supposed capacity to evoke vivid and concrete mental images of the lottery process were employed. Initially (Study 1), we used an abstract verbal description, typical of the gambling language, in which the lottery was presented simply through the chances (i.e., 1 in 20 vs. 5 in 100) of losing the endowment. In Study 2, we used a concrete verbal, frequentist description with vivid details in an attempt to facilitate the generation of coherent and vivid mental images. This description exploits the benefits of natural sampling (i.e., the process of counting and appropriately categorizing occurrences of events as they are encountered), by explicitly stating the total number of tickets in the lottery and the number of losing tickets out of the total. In Study 3, the same concrete verbal description was accompanied by an image depicting the set of (winning and losing) lottery tickets (i.e., an icon array).

The second factor we varied across studies was the difference in expected monetary value (EV) between the two options. The EV of the sure loss was progressively decreased: It was equal to −5 pence in Studies 1–3, and it was lowered to −6 pence in Study 4a and to −7 pence in Study 4b. The aim was to explore the boundary conditions of the 1-in-X effect when varying the difference in EVs between options. By gradually increasing the relative EV of the lottery option, we aimed to observe whether the effect also replicated when the lottery option had a higher EV than the sure loss. This would show that the 1-in-X effect can also lead individuals to deviate from maximizing EV.

Thus, in this paper, we investigated how the 1-in-X format influences decision-making in real tasks with monetary incentives. We present a series of studies that varied the concreteness of the description (Studies 1–3) and the relative expected values of the options (Studies 4a and 4b), aiming to demonstrate the 1-in-X effect on actual behaviors.

3 | STUDY 1

The aim of Study 1 was to explore the impact of the 1-in-X format on participants' probability evaluations and actual choices when they faced real-incentivized options with the same EV. Participants received a monetary endowment of 1£ and were asked to choose between two options with equivalent expected values: a sure loss of 5 pence and a lottery with a 5% chance of losing the entire initial endowment (see Figure 1). The likelihood of losing the endowment in the lottery was communicated through an abstract verbal description (see Table 1), which, depending on the experimental condition, was presented either as a 1-in-X chance (e.g., 1 in 20) or as an N-in-NX chance (e.g., 5 in 100).

To prevent possible carryover effects between these two dependent measures of interest (i.e., subjective probability evaluation and choice), we conducted two separate studies. In Study 1a (as well as in Studies 2a and 3a), we measured participants' perceived probability, along with their subsequent choices (to enhance the realism of the task by framing it as a real decision-making situation). This allowed us to have a measure of the 1-in-X effect that could be compared with previous findings obtained with hypothetical scenarios. Consistent with prior research, we predicted that the probability of losing the endowment by choosing the lottery option would be perceived as higher when presented as a 1-in-X chance than when presented as an N-in-NX chance. In Study 1b (as well as in Studies 2b, 3b, and 4), we assessed participants' choices (without asking for the subjective probability evaluation in advance). Coherently with our previous expectation, we predict that the lottery option would be chosen by fewer individuals when presented as a 1-in-X chance than when presented as an N-in-NX chance. Furthermore, after participants made their choice in Study 1b (as well as in Studies 2b, 3b, and 4), they were also asked to rate the confidence in their choices. The inclusion of the confidence rating was aimed at capturing participants' internal beliefs regarding the strength of their preference for the chosen option in the two experimental conditions and allowed for a more detailed examination of the 1-in-X effect on choices. To achieve this, we adapted the question from De Martino et al. (2013) that intentionally incorporated a subjective element. Participants, indeed, were asked: "How confident are you that the choice you have made is the right one for you?" Regarding this matter, the existing knowledge surrounding the 1-in-X effect on subjective probability evaluations enables us to formulate some straightforward expectations. Even in the absence of an effect on choices, we expect that participants who prefer the lottery option over the sure loss will display reduced confidence in their selection when the probability is presented as 1-in-X compared with when it is expressed as N-in-NX. This is because the lottery option in the 1-in-X format should be perceived as inherently riskier than in the N-in-NX format. For instance, an individual who perceives the probability of losing the endowment presented in the 1-in-X format as higher, but still chooses it to avoid a sure loss, will demonstrate less confidence in their decision compared with if the same probability had been presented in the N-in-NX format.

An a priori power analysis using G*Power 3 (Faul et al., 2007) suggested that a sample size of 128 participants should provide 80% power for detecting at least a medium effect size (i.e., $d = 0.5$), assuming $\alpha = 0.05$ for comparing subjective probability evaluations in the two numerical format conditions. A similar sample size (i.e., 126) should also provide 92% power for detecting at least a medium effect size (i.e., $w = 0.3$), assuming $\alpha = 0.05$ for comparing choices in the two numerical format conditions. Accordingly, we recruited 130 participants for each study (as well as the subsequent ones).

TABLE 2 Participants' characteristics in all studies.

Study	Females (%)	Mean age (SD)
1a	64 (49%)	40 (11.2)[a]
1b	98 (75%)[b]	40 (12.8)[b]
2a	68 (52%)	39 (14.6)
2b	98 (75%)[c]	43 (14.0)[c]
3a	72 (55%)	39 (12.1)[d]
3b	81 (62%)	39 (13.1)
4a	115 (88%)	43 (12.3)
4b	69 (53%)[e]	42 (13.8)[e]

[a]In Study 1a, information about the age of one participant was not known.
[b]In Study 1b, information about the gender of one participant and about the age of three participants was not known.
[c]In Study 2b, information about the gender of one participant and about the age of one participant was not known.
[d]In Study 3a, the age of one participant was not known.
[e]In Study 4b, information about the gender of one participant and about the age of three participants was not known.

Online data collection was carried out through Prolific Academic (https://www.prolific.co/), involving British participants whose first language was English. Participants received 0.20 British pound for completing the task (which took about 2 min), plus the due compensation according to their choices. Analyses were conducted using R (R Core Team, 2022). Datasets of the studies and scripts of the analyses performed can be found online (https://osf.io/6v4ds/).

3.1 | Study 1a

In Study 1a, we manipulated between-subjects the numerical format used to convey the risk of losing the endowment in the lottery option: Participants were presented with either the 1-in-X format ("1 in 20 chance"; $n = 61$) or an N-in-NX format ("5 in 100 chance"; $n = 69$) (see Table 1). Participants had to rate subjective probability on an 11-point scale ranging from "extremely low" to "extremely high" and, then, to make a choice between the two presented options (Figure 1). Sample main characteristics are summarized in Table 2.

3.1.1 | Results

Results are reported in Figure 2. Consistent with previous findings using hypothetical scenarios, participants in the 1-in-X condition perceived a higher probability of losing the 1£ endowment ($M = 4.07$, $SD = 2.71$) than in the N-in-NX condition ($M = 3.06$, $SD = 2.54$), $t(128) = 2.18$, $p = .031$, $d = 0.38$, 95% CI [0.03, 0.73]). Participants' subsequent choices reflected their subjective probability judgments

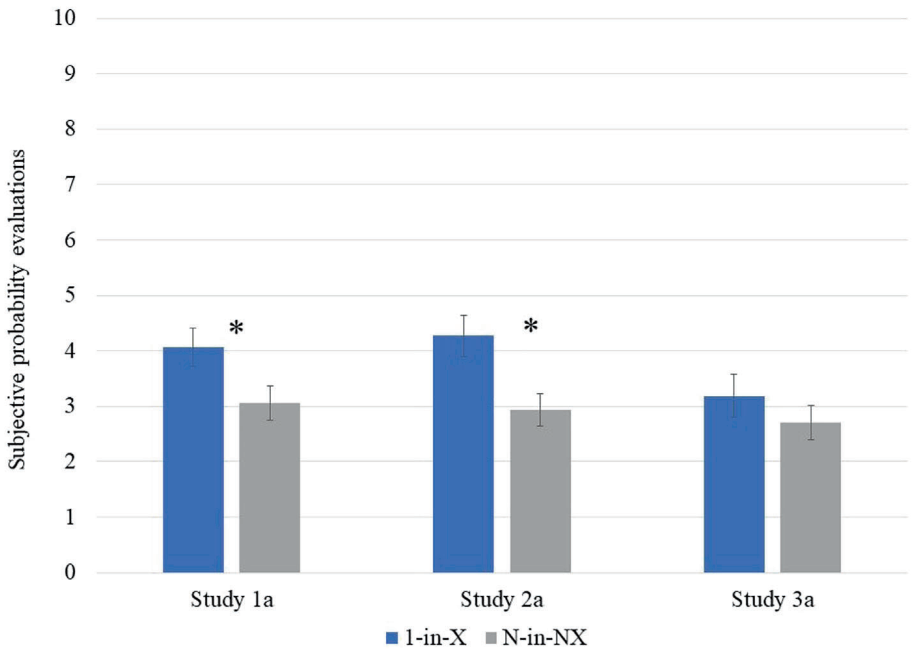


FIGURE 2 Mean subjective probability evaluations in the 1-in-X and N-in-NX conditions of Studies 1a, 2a, and 3a.

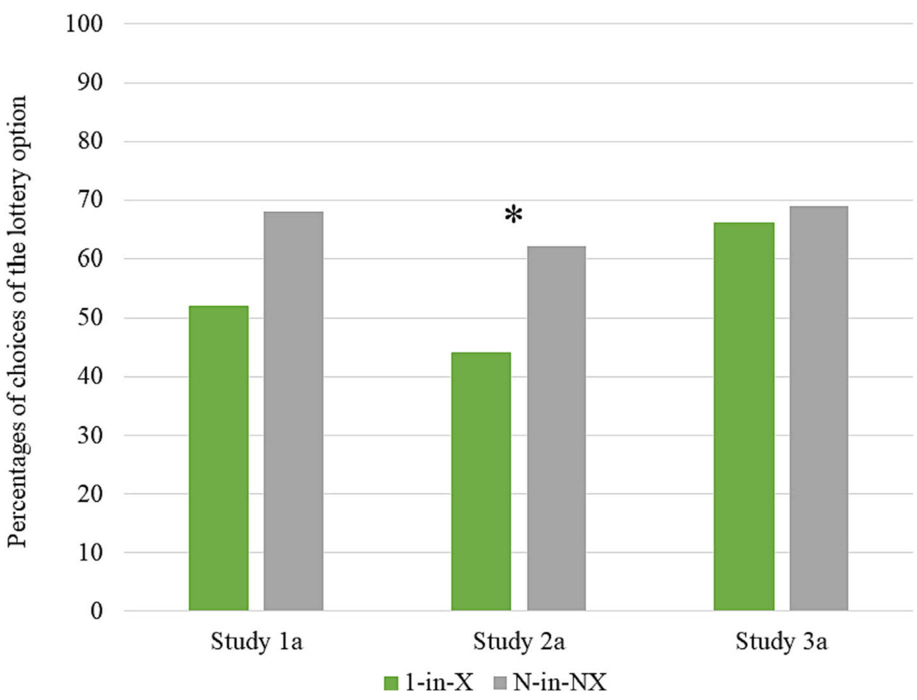


FIGURE 3 Percentages of choices of the lottery option in the 1-in-X and N-in-NX conditions of Studies 1a, 2a, and 3a.

(see Figure 3): The lottery option was chosen less often, although not significantly, in the 1-in-X condition (52%) than in the N-in-NX condition (68%), $\chi^2(1, N = 130) = 3.33$, $p = .068$.

3.2 | Study 1b

Study 1b employed the same task used in Study 1a, but in this case, participants had to choose between the two options (without providing before a subjective probability evaluation) and to express their degree of confidence in the choice they had just made (see Figure 1). Participants were randomly assigned to either the 1-in-X ($n = 61$) or the N-in-NX ($n = 69$) condition.

3.2.1 | Results

The results of Study 1b are shown in Figure 4. As in Study 1a, the lottery option was slightly less preferred in the 1-in-X (60%) than in the N-in-NX condition (75%), $\chi^2(1, N = 130) = 3.52$, $p = .061$). Whereas the two conditions approached but did not reached the statistical difference in terms of choices, confidence ratings proved to be in line

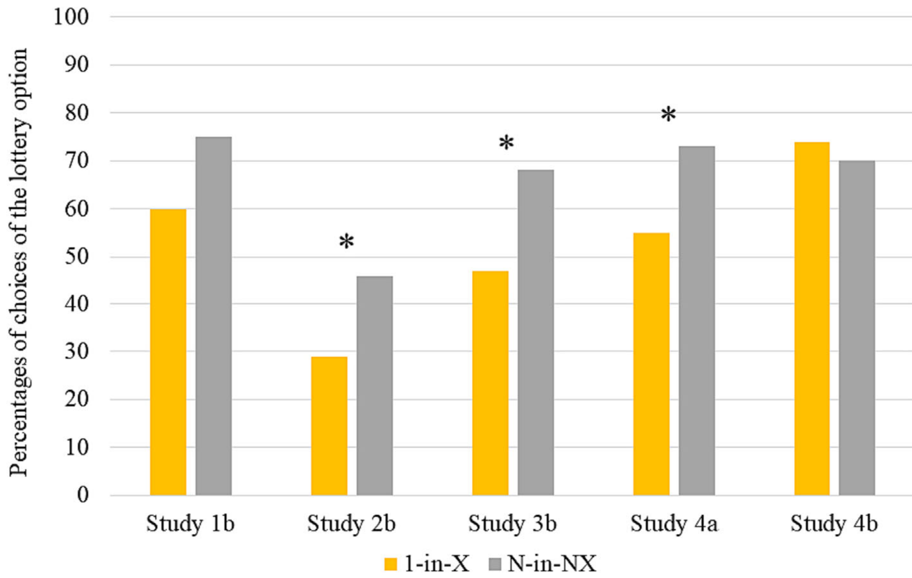


FIGURE 4 Percentages of choices of the lottery option in the 1-in-X and N-in-NX conditions in Studies 1b, 2b, 3b, 4a, and 4b.

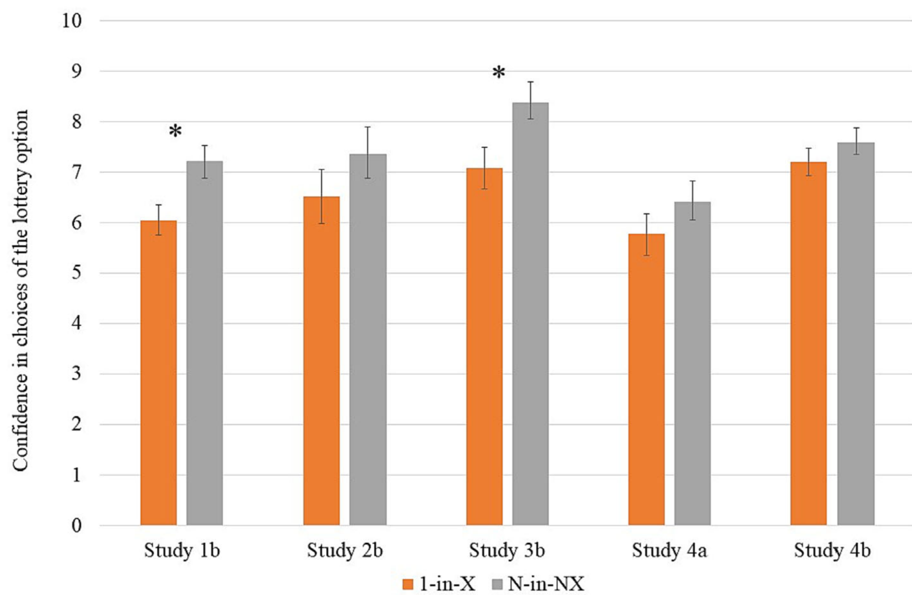


FIGURE 5 Mean confidence ratings for the choices of the lottery option in the 1-in-X and N-in-NX conditions in Studies 1b, 2b, 3b, 4a, and 4b.

with the 1-in-X effect (see Figure 5): participants who chose the lottery option in the 1-in-X condition expressed significantly less confidence in their choice than participants in the N-in-NX condition ($M = 6.05$, $SD = 1.95$ vs. $M = 7.22$, $SD = 2.37$, $t(86) = -2.49$, $p = .015$, $d = -0.53$, 95% CI [−0.97, −0.10]). This result suggests that, even if participants did not choose the lottery option significantly more in the 1-in-X condition, those who decided to take the risk of the lottery were less confident in their choices when the risk of losing the endowment was conveyed using the 1-in-X than the N-in-NX format.

3.3 | Discussion

The results of Study 1 suggested that the 1-in-X format had some impact on participants' actual choices: the lottery description using the 1-in-X format affected both participants' subjective probability evaluations and their confidence in choosing the risky option. Participants tended to choose the lottery option less frequently in the 1-in-X condition compared with the N-in-NX condition, although this difference was not statistically significant.

4 | STUDY 2

In Study 2, we extended the investigation of the impact of the 1-in-X format on actual choices by employing a more concrete description of the lottery option compared with Study 1. Specifically, we explicitly provided the total number of tickets in the lottery and the number of losing tickets out of the total that determine the probability of losing the endowment (see Table 1). Past research has suggested that concrete descriptions of hazards can have a significant impact, not only on risk comprehension (for a review see McDowell & Jacobs, 2017) but also on how people perceive and respond to risks: People are more likely to have stronger anticipatory emotional responses and to perceive a hazard as riskier when they are able to form clear mental images of a risk associated with that hazard (Slovic et al., 2002, 2004). A number of different manipulations proved to be effective in increasing risk perception by eliciting clear mental images, such as using short versus long time frames (e.g., Chandran & Menon, 2004; Jones et al., 2017), frequencies versus percentages (e.g., Chapman et al., 2015; Newell et al., 2008; Slovic et al., 2000), and detailed versus general information (e.g., Peters et al., 2007; Stone et al., 1994). As mentioned above, the 1-in-X effect itself may arise due to the concreteness and vividness of this specific numerical format: small numbers are more concrete and easily comprehended than large numbers (Denes-Raj & Epstein, 1994; Kirkpatrick & Epstein, 1992), and empirical evidence exists that when the 1-in-X format is used to convey the probability of an event, individuals imagine such event more easily (see Oudhoff & Timmermans, 2015). Accordingly, the influence of the 1-in-X effect on choice should generalize to situations in which the lottery option is made concrete by describing it in terms of the tickets involved in the drawing process, as this should create a clear mental image of the risk of losing the endowment.

4.1 | Study 2a

Study 2a employed the exact same task used in Study 1a, but the lottery option was described in more concrete, frequentist terms by saying that a lottery ticket will be randomly drawn from a bowl containing 20 (vs. 100) tickets and that 1 in 20 (vs. 5 in 100) tickets causes (vs. cause) the participant to lose the endowment (see Table 1 for exact wording). Participants (see Table 2 for main characteristics) were randomly assigned to either the 1-in-X ($n = 59$) or the N-in-NX ($n = 71$) condition.

4.1.1 | Results

Results are reported in Figures 2 and 3. As expected, participants' subjective probability evaluations of losing the 1£ endowment were significantly higher in the 1-in-X condition ($M = 4.27$, $SD = 2.82$) than in the N-in-NX condition ($M = 2.93$, $SD = 2.49$), $t(128) = 2.88$, $p = .005$, $d = 0.51$, 95% CI [0.15, 0.86]). As in Study 1a, overall, participants' subsequent choices were in line with their subjective probability evaluations: the lottery option was less preferred in the 1-in-X (44%) than in the N-in-NX condition (62%), but this time, the difference was statistically significant, $\chi^2(1, N = 130) = 4.16$, $p = .041$, $OR = 2.07$, 95% CI [1.02, 4.18]).

4.2 | Study 2b

Study 2b employed the same lottery description used in Study 2a, but as in Study 1b, participants had simply to choose between the two options and to express their degree of confidence in their choice. Again, N participants (see Table 2) were randomly assigned either to the 1-in-X condition ($n = 65$) or to the N-in-NX condition ($n = 65$).

4.2.1 | Results

In Study 2b, the lottery option was significantly less preferred in the 1-in-X (29%) than in the N-in-NX condition (46%), $\chi^2(1, N = 130) = 3.96$, $p = .047$; $OR = 2.08$, 95% CI [1.01, 4.28]. Confidence ratings of participants who chose the lottery option were in line with what was predicted, but no statistical difference was observed between the 1-in-X ($M = 6.53$, $SD = 2.32$) and N-in-NX conditions ($M = 7.37$, $SD = 2.66$), $p = .264$.[1]

4.3 | Discussion

The findings from Study 2 offer further support to the notion that the 1-in-X format can exert a significant influence on actual decisions, since the influence of the 1-in-X format was evident in both subjective probability evaluations and choices. Specifically, when the lottery option was described in a way that enhanced the vividness of the mental image of the drawing process and the associated probability, participants perceived a higher likelihood of losing their endowment (Study 2a) and opted for the lottery option less frequently (Study 2b) when the risk was conveyed using the 1-in-X format compared with the N-in-NX format.

5 | STUDY 3

In Study 3, we sought to expand our investigation of the impact of the 1-in-X format on actual choices by enhancing the description of the lottery option used in Study 2 with a visual representation of the probability information. While previous research has investigated different visualization designs for representing (both aleatory and epistemic) uncertainty, a consensus has not yet been reached regarding the most effective visual aid to support decision-making tout court (Garcia-Retamero & Cokely, 2014, 2017; Zipkin et al., 2014) since different risk communication formats cater to various types of inference and decision-making processes (e.g., some formats may better support intuitive or quick decisions, while others are better for deliberative or analytical ones). However, icon arrays emerge as strong contenders in this context, serving as efficient tools for risk communication, since they excel at clarifying the part-to-whole relationship and providing robust support for presenting numerical information in a ratio format. Notably, they demonstrate effectiveness in facilitating accurate Bayesian inferences (e.g., Brase, 2009, 2021; Tubau et al., 2019),

[1]In Study 2b, the lottery option was chosen far less frequently than the sure loss. Thus, it is plausible that the absence of a significant difference in confidence ratings between the two conditions may be due to limited statistical power in the comparison.

enhancing the understanding of treatment risk reductions (Garcia-Retamero & Galesic, 2010), and mitigating issues such as denominator neglect (e.g., Garcia-Retamero et al., 2010; Reyna, 1991; Reyna & Brainerd, 2008) and framing effects (Garcia-Retamero & Cokely, 2011; Garcia-Retamero & Galesic, 2010). Notably, icon arrays have found wide application in the medical community for risk communication (Ancker et al., 2006; Edwards et al., 2002; Elmore & Gigerenzer, 2005; Paling, 2003; Trevena et al., 2013). Accordingly, in the present study, we employed an icon array visualization to represent the information concerning the number of tickets comprised in the lottery (see Table 1). Specifically, we utilized a grid of ticket figures (see Table 1), arranged in a sequential layout with different colors (red for losing tickets and green for winning tickets) to facilitate easy reference.

It is worth mentioning that previous studies that investigated the 1-in-X effect using icon arrays in hypothetical scenarios have produced inconsistent findings: Pighin et al. (2011) reported that the 1-in-X effect did not replicate when participants were presented with both an icon array and numerical information, while Oudhoff and Timmermans (2015) found no attenuation of the effect under the same conditions.

5.1 | Study 3a

Study 3a employed the same task of Studies 1a and 2a, but the concrete description of the lottery option presented in Study 2a was accompanied by an icon array displaying the proportion of winning and losing tickets included in the lottery (see Table 1). Participants (see Table 2 for main characteristics) were randomly assigned either to the 1-in-X ($n = 53$) or to the N-in-NX ($n = 77$) condition.

5.1.1 | Results

Unlike Studies 1a and 2a, participants' subjective probability evaluations of losing the 1£ endowment (Figure 2) did not differ significantly in the 1-in-X condition ($M = 3.19$, $SD = 2.88$) than in the N-in-NX condition ($M = 2.70$, $SD = 2.73$), $p = .331$. In line with this, also, participants' choices (Figure 3) did not seem to be affected by the numerical format: The lottery option was preferred to an equal extent in the 1-in-X (66%) than in the N-in-NX condition (69%), $p = .738$.

5.2 | Study 3b

Study 3b employed the same task of Study 3a (see Table 1), but as in Studies 1b and 2b, participants had simply to choose between the two options and to express their degree of confidence in their choice. Participants (see Table 2) were randomly assigned to either the 1-in-X ($n = 68$) or the N-in-NX ($n = 62$) condition.

5.2.1 | Results

In Study 3b, the difference between participants' choices in the two experimental conditions (Figure 4) was statistically significant: Participants chose the lottery option to a lesser extent in the 1-in-X (47%) than in the N-in-NX condition (68%), $\chi^2(1, N = 130) = 5.66$, $p = .017$; $OR = 2.36$, 95% CI [1.16, 4.83]. Also, confidence ratings were in line with a 1-in-X effect (Figure 5), showing that participants who chose the lottery option in the 1-in-X condition expressed lower confidence in their choice than those participants who chose the lottery option in the N-in-NX condition ($M = 7.09$, $SD = 2.32$ vs. $M = 8.38$, $SD = 2.13$, $t(72) = -2.48$, $p = .016$, $d = -0.58$, 95% CI [-1.06, -0.10]).

5.3 | Discussion

The findings of Study 3 indicate that concrete visual aids, such as the icon arrays, may play a crucial role on how the 1-in-X format affects decision-making, possibly moderating its effect differently for subjective probability evaluations and choices. In line with the study of Pighin et al. (2011), indeed, using an icon array to display the lottery information eliminated the differences in subjective probability evaluations between the 1-in-X and N-in-NX conditions. Therefore, the 1-in-X effect on subjective probability does not seem to generalize in the presence of an icon array that illustrates the ratio of winning and losing tickets, which might act as a debiasing technique (see more on this below). However, the findings of Study 3b revealed that presenting an icon array to display the lottery information did not weaken the 1-in-X effect on choices. Indeed, fewer individuals chose the lottery option in the 1-in-X condition than in the N-in-NX condition, suggesting that the risky loss was less attractive when expressed in 1-in-X than in N-in-NX format, supposedly because it was deemed more likely in the former that in the latter format.

As already mentioned, subjective probability judgments and choices reflect different, albeit closely related, processes. As the weight of different components of an option may vary depending on whether the task involves evaluation or choice (e.g., Lichtenstein & Slovic, 1971), it is reasonable to surmise that the way in which the option is presented has the potential to exert distinct influences on these two processes. The findings from Study 3 potentially provide support to this claim, given that, in the presence of the icon array, the numerical format used to convey the probability affected participants' choices but not their probability judgments. The icon array used in Study 3 shows both the probability of losing (i.e., 1 losing ticket out of 20 tickets or 5 losing tickets out of 100 tickets) and the probability of winning (i.e., 19 winning tickets out of 20 tickets or 95 winning tickets out of 100 tickets). This may foster the elaboration of all the mathematical quantities involved in the lottery (i.e., both terms of the odd: 1 vs. 19 and 5 vs. 95), leading to a more analytical evaluation of the chances of losing. When explicitly asked to evaluate how high or low the "1 in 20 (5 in 100) chances" of picking the losing ticket/s were, individuals could not ignore the mathematical properties of the odds, which included not only the number of losing tickets but also the number of winning tickets. This shift in focus, possibly induced by the icon array, would hamper the emergence of the 1-in-X effect in individuals' subjective probability evaluations. As a consequence, both participants in the 1-in-X and the N-in-NX conditions must have realized that the chances of picking the losing ticket were quite low when provided with frequentist pictorial information (indeed, across numerical format conditions, participants in Study 3a provided the lowest subjective probability evaluations observed in our set of studies). Conversely, in Study 3b, when participants were asked to choose between the lottery option and the sure loss, in line with the 1-in-X effect, they showed a decreased preference for a lottery that depicted a single losing red ticket and 19 winning green tickets compared with a lottery that showed five losing red tickets and 95 winning green tickets. This result is in line with the psychic numbing account and the identifiability effect (Slovic, 2007; Slovic et al., 2013; Västfjäll et al., 2014), according to which, as the magnitude of numbers increases, individuals may experience a reduced emotional response or become desensitized to the significance of the event or its impact, and single elements (e.g., a single victim vs. more than one victim) may hold more emotional and empathetic weight than multiple elements.

As a result, while the 1-in-X effect may have little or no impact on subjective probability judgments in the presence of the icon array, it can still significantly influence choices. To summarize, the icon array did not eliminate the 1-in-X bias in choice (Study 3b), but it did prevent the bias from emerging in subjective probability judgments (Study 3a).

6 | STUDY 4

Overall, the results of Studies 1, 2, and 3 consistently indicate that the use of the 1-in-X format to convey risk information has a significant impact on incentivized choices between options of equal EV, especially when the risk is described in a vivid and concrete way. However, it is yet unclear whether the 1-in-X effect replicates when the two options offer unequal EV. We designed Study 4 with the objective of exploring the boundary conditions of the 1-in-X effect on choices by examining whether this effect could also lead individuals to deviate from maximizing EV. The study employed the exact same procedure used in Study 3b where participants had to make a choice between the two options and rate their confidence in their choice, but the EV of the sure loss was progressively decreased, while keeping the EV of the lottery option constant.

6.1 | Study 4a

In Study 4a, participants had to choose between losing for sure 6 pence of their initial endowment and playing a lottery with a (1 in 20/5 in 100) chance of losing the 1£ endowment entirely. The difference between the expected value of the two options was just 1 penny, in favor of the lottery option. Participants (see Table 2) were randomly assigned to either the 1-in-X ($n = 64$) or the N-in-NX ($n = 66$) condition.

6.1.1 | Results

In Study 4a, participants' choices of the lottery option differed significantly between the two conditions: The lottery option was chosen less frequently in the 1-in-X condition (55%) than in the N-in-NX condition (73%), $\chi^2(1, N = 130) = 4.58$, $p = .032$; $OR = 2.21$, 95% CI [1.06, 4.59]. Whereas in the expected direction, confidence ratings of participants who chose the lottery option did not differ significantly between the two conditions ($M = 5.77$, $SD = 2.49$ vs. $M = 6.42$, $SD = 2.44$ in the 1-in-X and in N-in-NX condition respectively, $p = .241$).

6.2 | Study 4b

In Study 4b, participants had to choose between losing for sure 7 pence of their initial endowment and playing a lottery with a (1 in 20/5 in 100) chance of losing the 1£ endowment entirely. The difference between the expected value of the two options, in this case, was slightly higher than the one of Study 4a, that is 2 pence in favor of the lottery option. Participants (see Table 2) were randomly assigned to either the 1-in-X condition ($n = 65$) or the N-in-NX condition ($n = 65$). Unfortunately, a technical issue resulted in the exclusion of one participant's responses from the N-in-NX condition due to inaccurate recording. As a result, the final sample size for the N-in-NX condition was reduced to 64 participants.

6.2.1 | Results

In Study 4b, participants' choices of the lottery option did not differ between the 1-in-X and the N-in-NX condition: The proportion of choices for the lottery option was approximately the same in the two conditions (74% vs. 70% in the 1-in-X and the N-in-NX condition respectively, $\chi^2(1, N = 129) = 0.200$, $p = .655$). Additionally, the results showed no significant difference between the 1-in-X and the N-in-NX conditions in terms of participants' confidence ratings ($M = 7.21$, $SD = 1.90$ vs. $M = 7.60$, $SD = 1.67$, $p = .295$).

6.3 | Discussion

Studies 4a and 4b aimed to explore the 1-in-X effect on choices between options with unequal expected value. When the difference in the EVs was minimal (just 1 penny, as shown in Study 4a), the 1-in-X format still exerted a significant influence on participants' choices. Specifically, they were still more inclined to avoid a lottery when presented in the 1-in-X format than when presented in the N-in-NX format. As a result, they chose a sure loss of lower expected

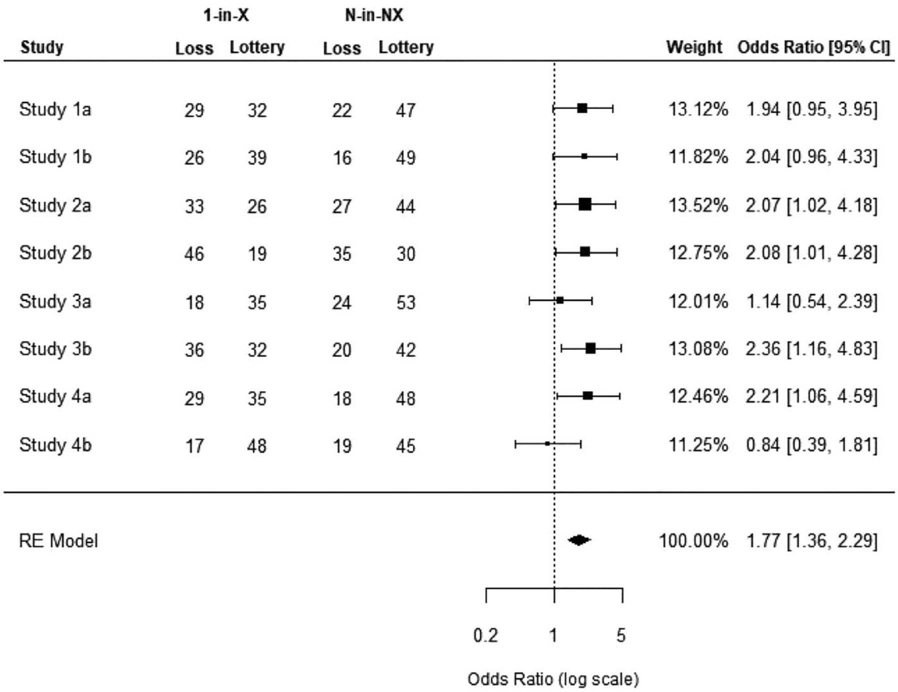


FIGURE 6 Forest plot of the small-case meta-analysis run on the eight studies of the present work, reporting their respective data, weights and effect sizes (expressed as odds ratios).

value, thus deviating from the principle of maximizing EV. However, as the difference in EV increased, individuals tended to maximize the EV by choosing the option with the higher expected value, even when described in the 1-in-X format (as shown in Study 4b).

7 | COMBINED ANALYSIS

While the findings reported in this research appear to support the existence of the 1-in-X effect on incentivized choices, some of the studies presented here did not reject the null hypothesis. To investigate the robustness of the effect on choices, we combined data from our studies ($N = 1039$) and conducted two additional analyses. First, we calculated a meta-analytical Bayes factor to assess support for both the null and the alternative hypothesis. Second, we estimated the overall effect size of the 1-in-X effect using a mini meta-analysis (Goh et al., 2016).

The meta-analytical Bayes factor was computed using the R package metaBMA (Heck et al., 2019). The analysis yielded a two-tailed meta-analytical Bayes factor of $BF_{10} = 58.26$, indicating that, overall, the results of the studies strongly supported the existence of a 1-in-X effect on choices (Jeffreys, 1961). We then conducted a small-scale meta-analysis through the metaphor package (Viechtbauer, 2010) to estimate the actual size of the effect (Figure 6). To this end, a random effect model was fitted on the log odds ratios (*logOR*) of the eight studies (that were homogeneous, $Q(7) = 6.52$, $p = .480$), resulting in a significant overall effect, $logOR = 0.569$, $p < .001$, 95% CI [0.311, 0.827].

In addition to previous analyses, two logistic regressions were fit on aggregated data to explore how, across studies, choices were affected by differences in two factors we have varied in our experimental designs: the concreteness of the lottery description and the differences, in terms of expected value, between the sure loss and the lottery option. The first analysis explored the impact of the former. To this end, we combined data from Studies 1b, 2b, and 3b, in which the sure loss and the lottery had the same EV but where the lottery descriptions were progressively more concrete. The dependent measure was the choice between the sure loss and the lottery, predicted by the numerical format (1-in-X vs. N-in-NX), the description concreteness (abstract vs. concrete vs. concrete plus visual representation), and their interaction. The regression model (Nagelkerke $R^2 = 0.12$) returned a significant main effect of the format, $\chi^2(1) = 13.044$, $p < .001$, with choices in favor of the lottery being more frequent when participants were exposed to the N-in-NX format (63%) than to the 1-in-X format (46%). Additionally, the main effect of description concreteness was significant, $\chi^2(2) = 25.351$, $p < .001$. Post-hoc tests (Bonferroni corrected) indicated that participants chose the lottery less when presented with the concrete description (38%) rather than with the abstract (68%, $p < .001$) or the concrete plus visual representation (57%, $p = .004$) description, while the comparison between these latter two description conditions did not differ ($p = .266$). The interaction between numerical format and description concreteness was not significant, $p = .954$.

The second analysis focused on the possible influence of differences, in terms of expected value, between the sure loss and the lottery. In this case, we combined data from Studies 3b, 4a, and 4b, in which the type of lottery description was identical (i.e., the concrete plus visual representation description) but where the lottery was increasingly more advantageous compared with the sure loss. The dependent measure for the regression was, again, the choice between the two options, and the predictors were the numerical format (1-in-X vs. N-in-NX), the difference in the expected value between the two options (0 vs. 1 penny vs. 2 pence), and their interaction. The regression model (Nagelkerke $R^2 = 0.06$) showed a significant main effect of the format, $\chi^2(1) = 5.142$, $p = .023$, again in the direction of more frequent lottery choices when participants were provided with the N-in-NX (70%) rather than with the 1-in-X format (58%). The main effect of the expected value difference only approached significance, $\chi^2(2) = 5.767$, $p = .056$. Post-hoc tests (Bonferroni corrected) suggested that this result was driven predominantly by the comparison between the 0 penny and 2 pence difference levels, $p = .052$, with the former making participants less prone to select the lottery (57%) compared with the latter (72%). The other comparisons presented $ps \geq .532$. The interaction between the two factors was not significant, $p = .103$.

Overall, these findings suggest that variations in the lottery descriptions and in the expected value of the two options had some impact on the proportion of choices for the sure loss and lottery option but that they did not interact with the numerical format utilized to convey the probability of the outcome in the lottery option. The impact of a 1-in-X effect on choices between genuinely incentivized options, indeed, was not significantly altered by the variations implemented in our study designs.

However, the interpretation of these latter two aggregate analyses requires a cautious approach due to two methodological considerations. Firstly, the changes in the lottery description and in expected value across studies were designed predominantly to enable a wider generalization, rather than being based on concrete hypotheses. We utilized this extensive approach to encompass a larger range of scenarios and bolster the external validity of our results. However, this approach did not include the manipulation of such features within a single study, thereby circumscribing the conclusions we can derive about their impact on choices. Secondly, we should note that the four studies were executed at distinct time intervals, which introduces potential temporal variations that inhibit a direct methodological comparison between them. These time-related differences could affect various aspects, including the context and characteristics of the participants, which subsequently detracts from the methodological soundness of a direct comparison.

8 | GENERAL DISCUSSION

The aim of the present research was to investigate the impact of the 1-in-X format on actual decisions between incentivized options. The results of the studies presented here suggest that the 1-in-X format can have a significant influence on decision-making: Overall, the use of the 1-in-X format in describing the chances of losing in a lottery option lead to a decreased likelihood of choosing that option compared with when the N-in-NX format was used. Such an effect is clearly in line with the tendency to perceive a higher probability when this is presented using the 1-in-X format, as compared with the N-in-NX format.

The 1-in-X effect on choice does not appear to be substantially altered by the two factors that have been varied across studies, namely, the description of the lottery option and the difference in expected value between the two options. Regarding the first factor, it is intriguing to note that the 1-in-X effect appears to extend to scenarios involving risk depicted through real-world natural frequencies and pictorial representation, both of which enhance the transparency and accessibility of the underlying probabilities (Brase, 2009, 2021; Brase et al., 1998; Gigerenzer & Hoffrage, 1995; Newell et al., 2008) and counteract some cognitive distortions (see Garcia-Retamero & Cokely, 2011; Garcia-Retamero & Galesic, 2010; Gigerenzer & Hoffrage, 1995). Although indirect, this can be regarded as evidence supporting the idea that the 1-in-X effect on choices is less tied to purely analytical aspects and more linked to factors related to affective reactions and negative emotions elicited by this numerical format (see Slovic et al., 2002, 2004). Moreover, the results of Study 3 showed that when the description of the lottery option was accompanied by a pictorial representation, the 1-in-X effect had a differential impact on choices and on subjective probability evaluations: The effect seemed to disappear on probability evaluations (in line with Pighin et al., 2011), but it persisted on choices. While the explanation for this inconsistency is not the focus of this research, it is possible that the processes activated by the visual aid used in Study 3 have different effects on the two dependent measures. Specifically, the icon array explicitly presented the winning odds (i.e., 19:1 in both conditions) in addition to the losing odds, which may have encouraged participants to engage in a more analytical evaluation of the probabilities and prevented bias in their subjective probability assessments. However, when participants were asked to make a choice, the vivid image of a single losing red ticket in the 1-in-X condition may have triggered stronger emotional reactions and affective processing than the image of five losing red tickets in the N-in-NX condition, leading to a heightened 1-in-X effect on choices.

Overall, while it is prudent to approach the interpretation of the results from the proposed combined analyses with caution, data suggest that our participants were responsive to the factors varied in our study design. Across numerical format conditions, for example, participants preferred the sure loss to a greater extent when presented with the concrete description (Study 2a) rather than with the abstract description (Study 1a) or the concrete description accompanied by the icon array (Study 3a) or the concrete description accompanied by the icon array (Study 3a). In addition, participants' choices demonstrated a preference for maximizing expected value, as evidenced by a slight increase in favoring the lottery option as the EV of the sure option was gradually reduced. In this regard, it is interesting to note that, when the difference between the two options in terms of EV was minimal (Study 4a), the 1-in-X effect was still effective, pushing a larger number of participants toward the sure option, despite lower in expected value. This denotes the fact that the 1-in-X effect can cause individuals to deviate from the principle of maximizing expected value. Nonetheless, the influence of the 1-in-X format seems to have some clear limits, as it vanished as the advantage in expected value of the lottery option increased (Study 4b).

While the present research sheds light on the influence of the 1-in-X format on choices, there are some limitations to consider.

Firstly, the studies were limited to situations where both options involved a low EV, and the outcomes examined in the present research may not capture the full range of economically or psychologically relevant outcomes that individuals encounter in real-life decision-making contexts. Secondly, it is important to acknowledge that the lottery option had a fixed probability of losing of 5%, which falls within the range of likelihood where the 1-in-X effect seems to be particularly inflated (Oudhoff & Timmermans, 2015). Accordingly, further studies are needed to determine whether the present findings can be generalized to scenarios with different probability values, as the influence of the 1-in-X format may vary across different likelihood ranges. Third, the studies only examined the effect of using a concrete description and an icon array representation on the influence of the 1-in-X format, leaving room for exploration of other manipulations that may moderate the effect. Finally, as noted in the introduction, the 1-in-X effect seems to operate in opposition to the well-established phenomenon of the ratio bias. This is especially evident considering the results from Studies 3b and 4a, which demonstrated the persistence of the 1-in-X effect on choices even when participants were presented with a pictorial representation akin to the standard paradigm employed to study the ratio bias. We thus hope that continued research endeavors will illuminate the nature of these two phenomena, notably by exploring the precise conditions favoring the prevalence of one over the other, in order to foster a more comprehensive understanding of the underlying cognitive processes and of their implications for decision-making.

Albeit relatively small in terms of effect size, the 1-in-X effect has shown a substantial impact. The difference in choice proportions induced by the format spanned from 15% to 21% across our studies,[2] underlining the influence that seemingly subtle alterations in equivalent numerical formats can exert on individual decision-making. In the domain of risk communication, it is not uncommon to encounter effects that are comparable or even smaller in magnitude than the one observed in this research (e.g., Freeman et al., 2021). Nevertheless, it is crucial to acknowledge that findings characterized by small effect sizes can still wield significant influence when informing policies, such as mass communications campaigns targeting broader populations.

The present findings highlight the importance of carefully considering the presentation format in decision-making contexts, along with the need of finding ways to debias individual choices. While the present results may not be generalizable to all probability values and contexts, they do suggest that the 1-in-X format could be a useful tool for nudging decisions toward safer alternatives in a variety of situations, including those related to financial, medical, and environmental concerns. For example, presenting the risks associated with a particular investment or medical treatment in a 1-in-X format could help individuals make safer choices. Similarly, using this format to convey the risks associated with certain environmental practices could encourage individuals to adopt more sustainable behaviors. Further investigation is needed to fully understand the potential of the 1-in-X effect in different contexts, but the present results suggest that it is a promising approach for influencing decision-making in a variety of settings. By carefully considering the presentation format and utilizing tools like the 1-in-X format, decision-makers can help individuals make ultimately safer choices.

DATA AVAILABILITY STATEMENT

Data are available online (https://osf.io/6v4ds/).

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