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Graphs versus numbers: How information format affects risk aversion in gambling

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Abstract

In lottery gambling, the common phenomenon of risk aversion shows up as preference of the option with the higher win probability, even if a riskier alternative offers a greater expected value. Because riskier choices would optimize profitability in such cases, the present study investigates the visual format, with which lotteries are conveyed, as potential instrument to modulate risk attitudes. Previous research has shown that enhanced attention to graphical compared to numerical *probabilities* can increase risk aversion, but evidence for the reverse effect — reduced risk aversion through a graphical display of *outcomes* — is sparse. We conducted three experiments, in which participants repeatedly selected one of two lotteries. Probabilities and outcomes were either presented numerically or in a graphical format that consisted of pie charts (Experiment 1) or icon arrays (Experiment 2 and 3). Further, expected values were either higher in the safer or in the riskier lottery, or they did not differ between the options. Despite a marked risk aversion in all experiments, our results show that presenting outcomes as graphs can reduce — albeit not eliminate — risk aversion (Experiment 3). Yet, not all formats prove suitable, and non-intuitive outcome graphs can even enhance risk aversion (Experiment 1). Joint analyses of choice proportions and response times (RTs) further uncovered that risk aversion leads to safe choices particularly in fast decisions. This pattern is expressed under graphical probabilities, whereas graphical outcomes can weaken the rapid dominance of risk aversion and the variability over RTs (Experiment 1 and 2). Together, our findings demonstrate the relevance of information format for risky decisions.

Keywords: lottery gambling; information format; risk aversion; conditional choice functions (CCFs).

1 Introduction

Psycho-economic research has shaped a sophisticated picture of human behavior in risky decision making (Fehr-Duda & Epper, 2012; Gigerenzer & Gaissmaier, 2011; Kahneman, 2003; Mishra, 2014). One of the most established phenomena in this domain is *risk aversion*, the preference of the safer option, even if the expected benefit of a riskier alternative is higher. The tendency to avoid risks is particularly expressed under positive prospects with medium to large probabilities (Holt & Laury, 2002; Tversky & Kahneman, 1992). Although risk preferences vary between individuals and are sensitive to factors, such as time pressure (Ben Zur & Breznitz, 1981), environmental conditions (Guiso, Sapienza & Zingales, 2013; Haushofer & Fehr, 2014), or the affective state of the decision maker (Nguyen & Noussair, 2014), risk aversion is a widespread attitude that is relatively stable within individuals over time (Glöckner & Pachur, 2012; Wölbert & Riedl, 2013). While effects have been mostly described in terms of choice proportions, risk aversion has also been shown in faster response times (RTs) for the safer option (Rubinstein, 2013). Indeed, recent approaches increasingly take advantage of both choice proportions and RTs, since both measures provide important information about risk preferences and choice difficulty (Busemeyer & Townsend, 1993; Busemeyer, 2015; Diederich, 2003; Usher & McClelland, 2004).

A grand proportion of evidence about risk aversion comes from gambling experiments, in which participants choose between lotteries, each with a given *probability* to get a certain *outcome*. In lotteries with positive prospects, risk aversion is characterized as preference of the lottery with the higher win probability. As consequence, participants repeatedly opt for the safer lottery despite a higher expected value (EV) in a riskier alternative. Here, an increase of risk taking would contribute to the optimization of decisions (in terms of outcome profitability), which is arguably a desirable goal in many situations. Such optimization would seem to require a more balanced consideration of probabilities and outcomes. The question therefore is, how can decision makers be persuaded to appreciate the importance of outcomes?

A straightforward idea to enhance the impact of a certain piece of information is to increase its perceptual salience, which is known to attract attention and to foster process-

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ing (Awh, Belopolsky & Theeuwes, 2012; Chun, Golomb & Turk-Browne, 2011). Compared to numerical information, for instance, a graphical representation can well be more salient, given that graphs offer a large variability in visual features that contribute to salience (e.g., shape, color, size, orientation; see Itti & Koch, 2001). Indeed, numerical and graphical information are common elements in experiments examining decisions under risk. Outcomes are usually displayed numerically, whereas probabilities are conveyed either in a numerical or in a graphical format. Yet, despite some previous work, influences of these different formats on risky decisions are not well established.

Prior research has predominantly investigated effects of different probability formats, and a number of studies showed relatively stable results. For instance, probabilities that were conveyed as numbers, histograms, pie charts, or natural frequencies, yielded qualitatively similar patterns of results concerning phenomena of coalescing and stochastic dominance (Birnbaum, Johnson & Longbottom, 2008; Birnbaum, 2004, 2006).

Other studies, especially in the health domain, demonstrated that decisions are sensitive to the format in which probabilities are shown. For instance, Chua, Yates, and Shah (2006) reported that graphical rather than numerical probabilities increase the readiness to avoid health risk. When quantities were shown graphically, people were more willing to pay for safer alternatives than when risk was communicated numerically. The authors proposed that graphs attract and hold attention more strongly than numerical information. Accordingly, enhanced processing increases the importance of graphical information and emphasizes its impact on the decision. It has also been argued that graphs can convey information more intuitively and hence facilitate understanding. Thus, under certain conditions, graphical components exhibit stronger influences on decisions than information in another format (Ancker, Senathirajah, Kukafka & Starren, 2006; Bodemer & Gaissmaier, 2012; Gaissmaier et al., 2012; Lipkus & Hollands, 1999; Visschers, Meertens, Passchier & de Vries, 2009).

Further support comes from eye tracking data. Smerecnik et al. (2010) examined processing differences between textual, tabular, and graphical risk information, and found that graphs receive more attention (as indicated by inspection times) and require less cognitive effort (as indicated by pupil size) than the other probability formats. In turn, it has been shown that gaze durations themselves affect preferences and decisions, and can therefore enhance the preference for graphical information (Armel, Beaumel & Rangel, 2008; Krajbich, Armel & Rangel, 2010; for a review see Orquin & Mueller Loose, 2013). Thus, there is some evidence that graphical *probabilities* have an impact on decisions and contribute to risk averse choices.

However, it is an open question whether this rationale can be reversed, that is whether graphically displayed *outcomes* can increase the impact of lottery gains and therefore modulate risk attitudes in a way that leads to reduced risk aversion. Systematic manipulations of presentation formats in gambling experiments are rare. One exception is a study by Fiedler and Unkelbach (2011), who crossed numerical and graphical formats of lottery constituents. In the graphical format, probabilities were displayed as spatially distributed winning (smileys) and losing (Xs) lottery tickets, and outcomes were illustrated as images of banknotes. Attractiveness ratings were then assessed for each lottery, which was presented in isolation. In line with risk averse preferences, the ratings indicated that attractiveness of lotteries increased with win probability. This pattern was particularly expressed under graphed probabilities and numerical outcomes. Critically, a graphical outcome attenuated the preference for the higher probability lottery, although it did not turn the pattern into absolute higher attractiveness of the higher outcome. The finding suggests that graphical outcomes can reduce risk aversion, but Fiedler and Unkelbach pointed to an asymmetry between format effects of probabilities and outcomes. They claimed that the comprehension advantage of a graphed compared to a numerical format is larger for probabilities than for outcomes, and experiencing outcomes as graphical quantities might even have detrimental effects if they increase cognitive demands.

Yet, these conjectures have hardly been empirically tested, so knowledge about the impact of graphical outcomes on risk aversion is sparse. Evidence that graphs can enhance the relative importance of information has been predominantly shown for probabilities, but it is not established how risk aversion changes when the same graphical representations reflect outcomes.

1.1 Present study

The present study aimed at further examining format effects and focused on the impact of graphical and numerical information on risk aversion. We conducted three experiments, in which participants repeatedly selected one of two simultaneously presented lotteries, A and B. Since strong risk aversion has been observed under non-negative prospects (Holt & Laury, 2002; Tversky & Kahneman, 1992), both lotteries offered positive and zero outcomes with certain probabilities. Probabilities and outcomes were presented in numerical or graphical formats. Graphical probabilities and outcomes were presented as pie charts (Experiment 1) or icon arrays (Experiment 2 and 3). To assess the influence of format on choices under different payoff combinations, lottery pairs A and B corresponded to one of four expected value (EV) conditions, in which either (a) the higher win probability (pro-prob), (b) the higher outcome (pro-out), (c) both constituents (congruent), or (d) neither of them (neutral) were indicative of the lottery with the higher EV.

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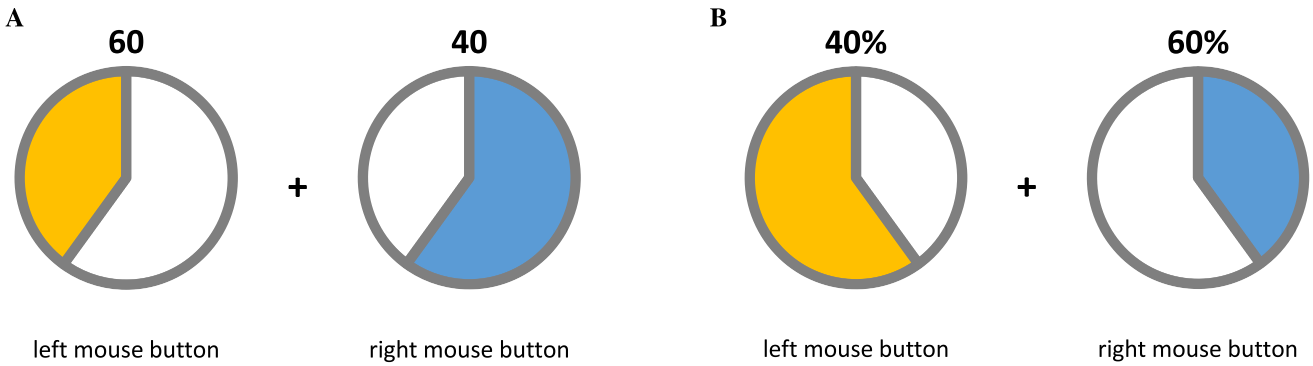
Figure 1: Stimulus example of Experiment 1. Participants chose between two lotteries presented to the left and right of a central fixation cross via clicks on the left or right mouse button. Colored pie chart areas reflect (A) win probabilities (graphed-probability format) or (B) non-zero outcomes (graphed-outcome format) of each lottery. Numbers above each chart reflect (A) non-zero outcomes (graphed-probability format) or (B) win probabilities (graphed-outcome format). Probabilities and outcomes of a lottery pair added to 100 percent and 100 points in each trial, respectively. Presentation format was manipulated between participants.



Importantly, our procedure advances previous experimental protocols on format effects in two points. First, probabilities and outcomes across our conditions were represented by the same graphs. Consequently, we largely eliminate potential confounds due to low level visual differences, whereas Fiedler and Unkelbach (2011) used different graphical formats for probabilities and outcomes. Second, we assessed both choice proportions and RTs, since both measures together inform about preference strength and choice difficulty. For instance, it is well established that higher choice proportions usually come with shorter RTs (Busemeyer & Townsend, 1993; Busemeyer, 2015; Jamieson & Petrusic, 1977; Petrusic & Jamieson, 1978). Further, analyses of RT distributions (i.e., conditional choice functions, see below) enabled us to examine format effects on the dynamics of risk aversion, which goes beyond a static characterization of risk preferences.

In all experiments, we expected a marked tendency of risk aversion, which should show up as larger choice proportions and shorter RTs for the option with the higher win probability (i.e., lottery A).[1]

Besides these general predictions, we pursued two related questions: The first was whether graphical lottery outcomes can reduce risk aversion, just as graphical probabilities can foster risk aversion. As a possible pattern, we considered that graphical information may attract attention and hence increase the subjective importance of the graphical component. Graphical outcomes should then result in a relative increase of choices and a decrease of RTs for the riskier options (i.e., the lotteries with the higher outcomes). Alternatively, graphical displays may be particularly beneficial for the presentation of probabilities, so that graphed-outcome formats have no effect or, in case of detrimental influences (K. Fiedler & Unkelbach, 2011), even enhance risk aversion.

The second question was, how format affects the dynamics of risk aversion — that is, the relative change of choice proportions across the RT distribution. Specifically, rapid accessibility of graphical probabilities may promote risk averse choices particularly in fast responses. Such a pattern — if it exists — might be inverted or at least less pronounced with graphical outcomes.

2 Experiment 1

In Experiment 1, numbers and pie charts were used to display the lottery constituents. In the graphed-probability format, probabilities were presented as pie charts and outcomes were shown as numbers; this is a common format for lotteries that has been used in various gambling studies (Alós-Ferrer, Granić, Kern & Wagner, 2016; Grether & Plott, 1979; Hey & Orme, 2014; Rieskamp, 2008; Smith et al., 2009). Conversely, the graphed-outcome format displayed outcomes as pie charts and probabilities as numbers (Figure 1).

2.1 Methods

Participants. A total of 19 voluntary participants in the graphed-probability (11 female, mean age: 25.1 y; SD: 6.0 y) and another 18 participants in the graphed-outcome format (13 female, mean age: 22.3 y; SD: 3.5 y) were recruited

[1] By convention, we call the gamble with the higher win probability lottery A, irrespective of outcome magnitude. In contrast, lottery B refers to the gamble with the higher outcome magnitude in all EV-conditions, except for the congruent condition, where win probability as well as outcome was higher in lottery A. The terms lottery A and lottery B serve only as labels for the choice options in this paper. Participants were unaware of the lottery labels, and screen positions (left or right of the fixation cross) as well as colors (yellow or blue) varied randomly between lotteries A and B.

Table 1: Overview of EV-conditions and presentation formats in Experiments 1 and 2. In the congruent EV-condition, win probabilities as well as outcomes, and therefore expected values, were higher in lottery A than in lottery B. In neutral, pro-prob, and pro-out EV-conditions, win probabilities were higher in lottery A and outcomes were higher in lottery B. Expected values were equal for both lotteries in the neutral, higher for lottery A in the pro-prob, and higher for lottery B in the pro-out EV-condition. EV-conditions were identical in the graphed-probability and the graphed-outcome presentation format. A and B refer to lottery A and lottery B, respectively.

	Lottery components			**Number of trials per participant**	
EV-condition	**Win probability**	**Outcome**	**Expected value**	**Graphed-probability**	**Graphed-outcome**
congruent	A > B	A > B	A > B	320	320
neutral	A > B	A < B	A = B	240	240
pro-prob	A > B	A < B	A > B	320	320
pro-out	A > B	A < B	A < B	320	320

at the Universität Konstanz. Data from one further participant in the graphed-probability format was excluded because of insufficient task compliance.

Task and stimuli. In both presentation formats, participants performed a computerized gambling task with a total of 1200 choices between two lotteries A and B, which were presented to the left and right of a central fixation cross on the screen (Figure 1). Each lottery comprised a probability p of winning a positive amount of x points, and the counter-probability 1–p of winning *zero* points. Win probabilities as well as outcomes of each lottery pair summed up to 100 percent and 100 points, respectively. A detailed description of the lottery characteristics is given in the following (see also Table 1 and 2).

In lottery A the chance of winning was either 60%, 70%, or 80%, whereas the counter-probability of 40%, 30%, or 20%, respectively, was associated with a zero-gain. Lottery B reflected the inverse pattern, i.e., probabilities of non-zero gains of 40%, 30%, or 20%, and corresponding zero-gain probabilities of 60%, 70%, or 80%. Lottery pairs comprised non-zero outcomes of one of the following sets: either 85/15, 80/20, 75/25, 70/30, 65/35, 60/40, or 55/45 points.

Selected combinations of probabilities and outcomes set up four experimental EV-conditions (Table 1 and 2), which varied the predictive power of the two lottery constituents with respect to the expected value (EV): (1) In the *congruent* EV-condition, lottery A exhibited both a higher win probability and a higher outcome than lottery B; accordingly EV was higher in lottery A. (2) In the *neutral* EV-condition, both lotteries had the same EV, but lottery A had the higher win probability while lottery B had the higher outcome. (3) In the *pro-prob* EV-condition, the higher EV was linked to lottery A, which had a higher win probability but a lower outcome than lottery B. (4) In the *pro-out* EV-condition, the higher EV was held by lottery B, which had a higher outcome but a lower win probability than lottery A.

Across all EV-conditions, presentation format was varied between participants. In the *graphed-probability* format, probabilities were displayed as pie charts, whereas non-zero outcomes were shown as numbers above each chart. This format is relatively common in gambling studies. The reverse mapping was used for the *graphed-outcome* format, with outcomes as pie charts and win probabilities as numbers above each chart. In both formats, numerical lottery constituents were randomly jittered by ± 2 points in order to reduce recognition effects; an exception was the neutral EV-condition, where the absence of a jitter granted equal EVs between lotteries A and B.

In all lotteries, characters had a visual angle of approximately 0.46°horizontally and 0.69°vertically. The diameter of each pie chart extended to a visual angle of approximately 5.27°. The distance from the center of each pie chart to the fixation cross was 3.55°. Pie chart areas reflecting win probabilities (i.e., graphed-probability) or outcomes (i.e., graphed-outcome) were colored blue in one and yellow in the other lottery; colors as well as screen positions (i.e., left or right) were randomly assigned to lotteries A and B in each trial.

All stimuli were presented on a white background on an 18” color-monitor with a resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. A computer mouse served as response device. Stimulus presentation and response collection were controlled by the software Presentation (version 16.3, Neurobehavioral Systems).

Procedure. Participants were seated approximately 50 cm away from the monitor. Their task was to select one of two lotteries by pressing the corresponding mouse button with the index (left lottery) or the middle finger (right lottery) of their right hand.

Table 2: Combinations of win probabilities and outcomes set up a total of 15 lottery pairs in four EV-conditions.

		Win probabilities (in %)		**Outcomes (in points)**		**Expected values**	
	EV-condition	**Lottery A**	**Lottery B**	**Lottery A**	**Lottery B**	**Lottery A**	**Lottery B**
1	pro-out	80	20	15	85	12.0	**17.0**
2	pro-prob	80	20	45	55	**36.0**	11.0
3	neutral	80	20	20	80	16.0	16.0
4	pro-prob	80	20	25	75	**20.0**	15.0
5	congruent	80	20	75	25	**60.0**	5.0
6	pro-out	70	30	25	75	17.5	**22.5**
7	congruent	70	30	75	25	**52.5**	7.5
8	neutral	70	30	30	70	21.0	21.0
9	pro-prob	70	30	35	65	**24.5**	19.5
10	congruent	70	30	65	35	**45.5**	10.5
11	pro-out	60	40	35	65	21.0	**26.0**
12	congruent	60	40	65	35	**39.0**	14.0
13	neutral	60	40	40	60	24.0	24.0
14	pro-prob	60	40	45	55	**27.0**	22.0
15	pro-out	60	40	15	85	9.0	**34.0**

A trial started with a central fixation cross for a random interval between 250 and 750 ms. Then a lottery pair appeared and stayed on the screen until the participant responded. In the practice trials, a feedback screen for 1000 ms displayed the result of the chosen gamble (i.e., either the non-zero outcome or zero points) with the purpose to familiarize participants with the consequences of their decisions. No feedback was given in the main trials in order to prevent strategy changes over the course of the experiment. The result of each selected lottery was calculated by the computer and stored for later payment.

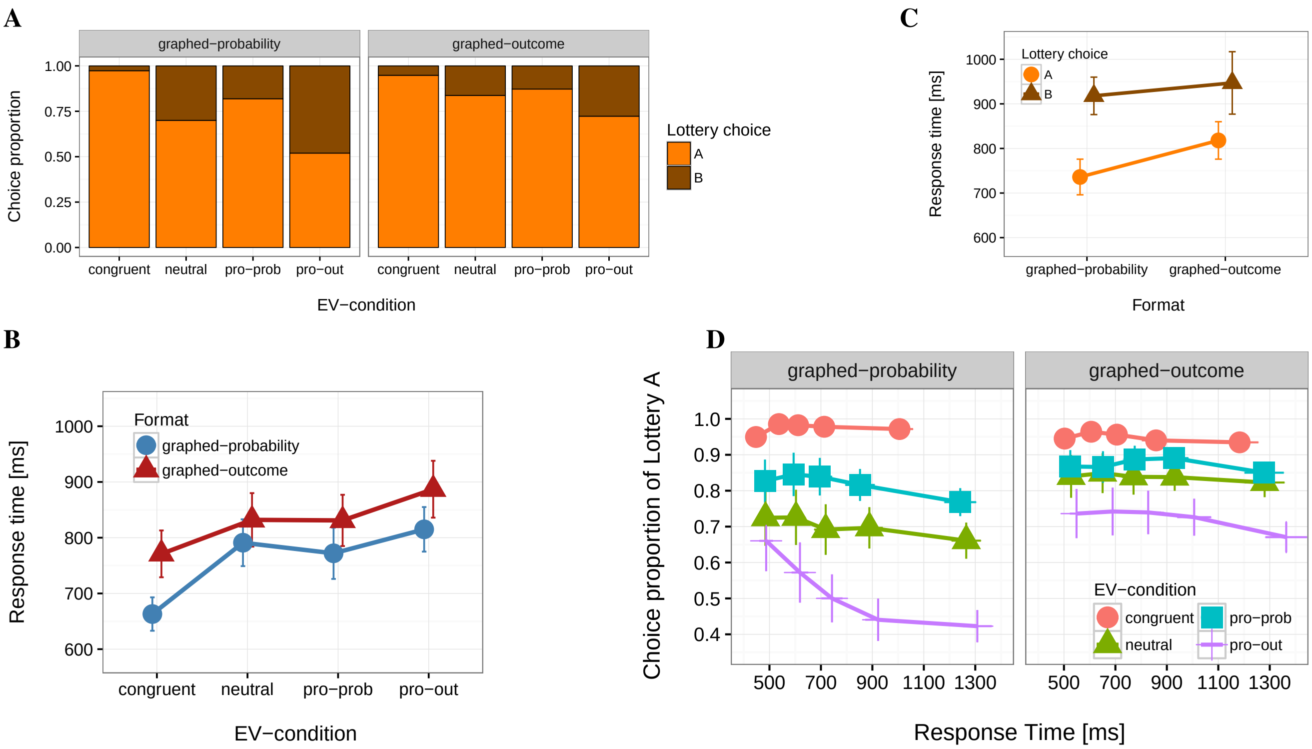
Participants received course credits or a base payment of 8 EUR. In addition, the points made through their lottery choices were converted into a monetary amount of up to 8 EUR, depending on the proportion of earned relative to the possible maximum points in the experiment.

Overall, the experiment comprised one practice block and 20 main blocks of 60 trials each and took around one hour. Thereafter, participants were presented with a questionnaire on risk behavior, which is not further reported here.

Analyses. Trials with RTs faster than 100 ms or slower than 2000 ms (4.4% in graphed-probability and 5.8% in graphed-outcome) as well as data from the practice block were excluded from analyses. We additionally dropped data from one participant in the graphed-probability format because 38% suboptimal choices in the congruent EV-condition (compared to an average of 2.74% in the graphed-probability and 7.47% in the graphed-outcome format) pointed to insufficient task compliance.

The remaining data (i.e., 21,798 lottery choices in graphed-probability and 20,346 choices in graphed-outcome) entered statistical analyses. We examined effects of EV-conditions and display formats on mean choice proportions and RTs. Further, we analyzed *conditional choice functions* (CCFs), a quantile-based representation of choice proportions and corresponding RTs across the response time distribution. Analogous to vincentized conditional accuracy functions (CAFs, e.g., Dambacher & Hübner, 2015), CCFs were calculated by sorting the data (according to RTs) into five 20% bins. For each bin, mean RT and mean choice proportions were computed separately for each participant and condition. The data points were then averaged across participants and plotted as choice proportions over RT bins. Thus, CCFs show changes of choice proportions across the duration of decisions and therefore provide information about the variability of risk aversion over RTs. Whereas CAFs are quite common tools to examine RT distributions, this is, to our knowledge, one of the first gambling studies that takes advantage from the joint consideration of RTs and choice proportions in the form of CCFs (Haffke & Hübner, 2015). We analyzed the CCFs in repeated-measures regressions using the lmList function of the lme4 package (version 1.1–8; Bates, Mächler, Bolker & Walker, 2015) and determined the difference of subject-based regression coefficients from zero via t-tests. The package ggplot2 (Wickham, 2009) was used

Figure 2: Empirical means in Experiment 1. (A) Choice proportions and (B) RTs across EV-conditions and presentation formats. (C) RTs for lottery A and B choices are averaged across EV-conditions. (D) Conditional choice functions across five quantiles of RT distributions. Error bars reflect standard errors of means.



to visualize the data. Both packages are embedded in the R environment for statistical computing (R Core Team, 2015).

2.2 Results

Choice proportions. Overall, participants chose the safer lottery A (i.e., the lottery with the higher win probability) more often than lottery B in both the graphed-probability (75%) and the graphed-outcome format (85%), confirming risk averse preferences in prospect of positive outcomes (Tversky & Kahneman, 1992). Figure 2A displays mean choice proportions across EV-conditions and presentation formats.

Mean choice proportions were analyzed in a two-way ANOVA with EV-condition (congruent, neutral, pro-prob, pro-out) as within-subject and presentation format (graphed-probability, graphed-outcome) as between-subject factors. A significant effect of EV-condition, $F(3{,}105) = 45.63$, $p < .001$, revealed that — despite the overall tendency to avoid risk — choice proportions followed EV differences (see Table 3). The proportion of lottery A choices gradually decreased from the congruent over the pro-prob and the neutral EV-condition to the pro-out EV-condition (pairwise comparisons: all $ps < .001$).

Further, a trend of presentation format, $F(1{,}35) = 3.10$, $p = .087$, was qualified by an interaction of EV-condition $\times$ presentation format, $F(3{,}105) = 5.46$, $p = .002$. Post-hoc tests revealed that the pro-out EV-condition exhibited more choices of the greater win probability (lottery A) in the graphed-outcome compared to the graphed-probability format ($p = .018$). The neutral EV-condition yielded a trend in the same direction ($p = .084$). Thus, participants were more risk averse when outcomes rather than probabilities were shown as pie charts. This result is at odds with the idea that attentional capture enhances the impact of graphed information, as this would have yielded fewer instead of more lottery A choices in the graphed-outcome format. Format effects in the congruent and the pro-prob EV-condition were not significant ($ps > .10$).

On average, participants received a bonus of EUR 3.30. The difference of earned points in the graphed-probability vs. the graphed-outcome format was not significant ($p = .15$).

RTs Mean RTs (Table 3) were analyzed in a two-way ANOVA with EV-condition as within-subject and presentation format as between-subject factors. Despite the visual impression in Figure 2B, the main effect of presentation format was not reliable, $F(1{,}35) = 1.37$, $p = .250$. However, an almost-significant interaction of EV-condition $\times$ presenta-

Table 3: Mean choice proportions of lottery A and RTs (lottery A and B choices combined) across EV-conditions and presentation formats in Experiment 1. Numbers in parentheses reflect standard errors of means.

	Choice proportions		**RTs (ms)**	
EV-condition	**Graphed-probability**	**Graphed-outcome**	**Graphed-probability**	**Graphed-outcome**
congruent	0.97 (0.01)	0.95 (0.01)	663 (30)	771 (42)
neutral	0.70 (0.06)	0.84 (0.05)	791 (42)	832 (48)
pro-prob	0.82 (0.05)	0.87 (0.03)	772 (46)	831 (46)
pro-out	0.52 (0.06)	0.72 (0.05)	815 (40)	887 (51)
mean	**0.75 (0.04)**	**0.85 (0.04)**	**760 (40)**	**830 (47)**

tion format, $F(3,105) = 2.60$, $p = .056$, pointed to faster RTs for the graphed-probability than for the graphed-outcome format in congruent trials ($p = .042$). No other EV-condition showed a reliable format effect (all $ps > .25$).

The main effect of EV-condition, $F(3,105) = 40.92$, $p < .001$, revealed an increase of RTs from congruent to pro-out trials, with RTs to neutral and pro-prob trials in between (Figure 2B). RTs were faster for trials in which probability and outcome jointly pointed to the higher EV option relative to trials in which magnitudes for win probability and outcome were crossed over the lotteries (congruent vs. neutral and congruent vs. pro-prob: $ps < .001$). Whereas the difference between the neutral and the pro-prob EV-condition was not significant ($p = .164$), decisions in the pro-out condition entailed the slowest RTs (pro-out vs. neutral and pro-out vs. pro-prob: $ps < .001$). The pattern suggests that outcome-oriented decisions took additional time in both the graphed-probability and the graphed-outcome format.

This was further supported in a separate analysis of RTs to lottery A and B choices (Figure 2C). A two-way ANOVA[2] on the within-subject factor choice (lottery A or B) and the between-subject factor presentation format (graphed-probability, graphed-outcome) yielded slower responses for lottery B than for lottery A choices, $F(1,35) = 32.33$, $p < .001$. Decisions favoring the high outcome of lottery B required more time than those opting for the high probability of lottery A. Presentation format had no reliable influence, neither as main effect nor in interaction with lottery choice, $Fs < 1$.

Conditional choice functions (CCFs). We examined RT distributions in conditional choice functions (CCFs), which visualize decision dynamics as choice proportions over RTs (Figure 2D). In the graphed-probability format, repeated-measures regressions with choice proportions as criterion and EV-condition together with mean RT of each bin as predictors revealed no reliable differences between the intercept (congruent) and the main effects of the other EV-conditions (Table 4). This indicates that a general preference of the greater win probability is expressed in fast decisions, regardless of the EV. Further, the variation of choice proportions over RTs was not significantly different from zero in the congruent (intercept) and the neutral EV-condition. However, reliable interactions with RT revealed that the proportion of lottery A choices decreased with longer RTs in the pro-prob as well as in the pro-out EV-condition. This suggests that lottery outcomes had a greater impact in slower decisions. Such a trend is reasonable in the pro-out condition where the greater outcome of lottery B grants the higher EV. In the pro-prob condition, though, a decrease of lottery A choices also decreases profitability. Reduced risk aversion in slower responses therefore did not necessarily optimize choices.

Analogous analyses in the graphed-outcome format revealed no significant differences between the intercept and the other predictors. Accordingly, Figure 2D illustrates high choice proportions of lottery A across all EV-conditions and across RTs. Thus, in Experiment 1, a high and persisting level of risk aversion in the graphed-outcome format suggests only negligible influences of outcome-oriented information in the decision.

2.3 Discussion

In line with previous studies, participants in Experiment 1 showed risk averse preferences. Choice proportions were larger and RTs shorter for the option with the higher win probability. The data therefore confirm the finding that preferences show up in both choice proportions and RTs (Busemeyer & Townsend, 1993; Petrusic & Jamieson, 1978).

Further, decisions were modulated by EV-differences between lottery pairs. Risk aversion in choice proportions gradually decreased as the riskier lottery B became more

[2] We restricted the ANOVA to the two factors choice and presentation mode because the inclusion of the third factor EV-condition led to empty cells in the congruent EV-condition. This is because choice of lottery A or B is not experimentally controlled and is unequally distributed across conditions.

Table 4: Repeated-measures regressions of lottery A choice proportions over EV-conditions and RTs in the two formats of Experiment 1. Boldface marks significant predictors.

	Graphed-probability				**Graphed-outcome**			
	Estimate	**SE**	**t-value**	***p***	**Estimate**	**SE**	**t-value**	***p***
(Intercept)	**0.96253**	**0.01799**	**53.50**	**< 0.01**	**0.96945**	**0.01564**	**62.00**	**< 0.01**
RT	0.00002	0.00002	0.97	0.35	–0.00002	0.00003	–0.81	0.43
pro-prob	–0.07028	0.08019	–0.88	0.39	–0.08517	0.07013	–1.21	0.24
neutral	–0.20022	0.10944	–1.83	0.08	–0.11250	0.08154	–1.38	0.19
pro-out	–0.21156	0.12279	–1.72	0.10	–0.17883	0.09545	–1.87	0.08
RT × pro-prob	**–0.00016**	**0.00007**	**–2.29**	**0.03**	0.00004	0.00007	0.55	0.59
RT × neutral	–0.00015	0.00009	–1.71	0.10	0.00003	0.00008	0.41	0.69
RT × pro-out	**–0.00035**	**0.00010**	**–3.49**	**< 0.01**	–0.00002	0.00007	–0.36	0.72

profitable relative to the safer lottery A. Likewise, RTs were slower when the riskier lottery B was chosen. Apparently, deviations from the risk averse preference were associated with additional processing and thus longer decision times in both the graphed-probability and the graphed-outcome format.

Critically, the results also revealed effects of presentation format. Risk aversion was stronger in the graphed-outcome compared to the more common graphed-probability format. This pattern is surprising, because it contradicts the idea that graphs enhance attentional processing and therefore augment the impact of associated information (Smerecnik et al., 2010). Instead, the graphical format reduced the relevance of outcomes and led participants to rely on the numerical probability information. Notably, this effect was reliable in the pro-out EV-condition, where outcome — and not probability — is indicative for the more profitable option. This suggests that participants had difficulties in making use of the graphical outcome information, in line with Fiedler and Unkelbach's (2011) assumption that outcome graphs may have detrimental effects when they come with increased cognitive demands. In fact, the pie charts used in Experiment 1 are well established as representation of probabilities, but are uncommon as visualizations of monetary values. Consequently, participants chose a strategy that focuses on reliable and easily accessible information, numerical probabilities.

Analyses of CCFs additionally supported this view. In the graphed-outcome format, we found no variations of choice proportions over RTs. Risk aversion was comparably strong over the entire RT distribution, suggesting that increasing decision time was not related to additional evaluation that affected decisions. In contrast, the graphed-probability format was characterized by a marked risk aversion across all EV-conditions, particularly in fast responses. Risk aversion decreased for slower decisions in the pro-out and pro-prob EV-condition, suggesting that outcome information was considered more strongly.

3 Experiment 2

The results of Experiment 1 demonstrate that presentation format has a reliable effect on risk attitudes. However, against the prediction that graphs capture attention and enhance the impact of information, risk aversion increased rather than decreased with graphical outcomes. We suggested that pie charts are not intuitive means to convey lottery outcomes. Another variant of graphical representation, though, may yield a different pattern.

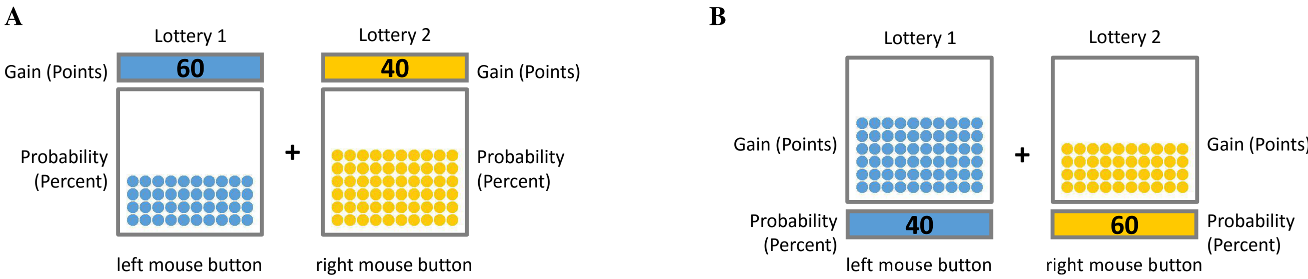
We tested this possibility in Experiment 2 by using icon arrays to represent lottery probabilities in the graphed-probability format and lottery outcomes in the graphed-outcome format (Figure 3). Otherwise, Experiment 2 closely resembled Experiment 1.

3.1 Methods

Participants Data were assessed at the Universität Konstanz from 21 voluntary participants in the graphed-probability (13 female, mean age: 24.4 y; SD: 4.7 y) and from another 20 participants in the graphed-outcome format (10 female, mean age: 24.6 y; SD: 4.8 y).

Stimuli, task and procedure. Lottery characteristics, task and procedure were adopted from Experiment 1 (see Table 1 and 2). Participants again made a total of 1200 choices between lottery pairs A and B. However, graphical information was presented as icon arrays of colored points (Figure 3). Because the maximum number of points within each lottery option amounted to 100, the number of colored points was equivalent to the absolute gain probability in the graphed-

Figure 3: Stimulus example of Experiment 2. Colored points reflect (A) win probabilities (graphed-probability format) or (B) non-zero outcomes (graphed-outcome format) of each lottery. Numbers above each graph reflect (A) non-zero outcomes (graphed-probability format) or (B) win probabilities (graphed-outcome format). Probabilities and outcomes of a lottery pair added to 100 percent and 100 points in each trial, respectively. Presentation format was manipulated between participants.



probability format and to the absolute outcome magnitude in the graphed-outcome format. Non-graphical lottery constituents were presented as numbers. Outcomes were always shown above probabilities, independent from format. Additional labels next to the lotteries guarded against confusion of the constituents.

In all lotteries, characters had a visual angle of approximately 0.46°horizontally and 0.69°vertically. Each icon array had a visual angle of 12.03°. The distance from the array center to the fixation cross was 9.17°.

Feedback of the chosen lottery outcome familiarized participants with the results of their decisions in one practice block. No feedback was given in the 20 main blocks of 60 trials each. Participants received course credits or a base payment of 8 EUR, together with a proportional monetary compensation of their earned points.

Analyses Excluding trials with RTs faster than 100 ms or slower than 2000 ms resulted in a total of 24,374 lottery choices in the graphed-probability format (i.e., drop of 3.3 %) and 23,152 choices in the graphed-outcome format (i.e., drop of 3.5%). Analogous to Experiment 1, we examined effects of presentation format and EV-conditions on mean choice proportions, RTs and conditional choice functions (CCFs).

3.2 Results

Choice proportions. In line with risk averse preferences, participants selected lottery A more often than lottery B in both the graphed-probability (80%) and the graphed-outcome format (79%). Choice proportions across EV-conditions and presentation formats are shown in Figure 4A and Table 5.

A two-way ANOVA on choice proportions with EV-condition (congruent, neutral, pro-prob, pro-out) as within-subject and presentation format (graphed-probability, graphed-outcome) as between-subject factors revealed a significant effect of EV-condition, $F(3,117) = 44.41$, $p < .001$. Choice proportions of lottery A decreased with the relative increase of EVs in lottery B (Table 5): the proportion of lottery A choices was higher in the congruent than in the pro-prob EV-condition, in the pro-prob compared to the neutral EV-condition, as well as in the neutral compared to the pro-out EV-condition (*ps* < .001).

Neither presentation format nor the interaction of format × EV-condition yielded reliable differences in choice proportions (*Fs* < 1). Thus, the finding of Experiment 1, that outcome graphs (pie charts) enhance risk aversion, did not generalize to icon arrays.

On average, participants earned 3.33 EUR in Experiment 2. The difference between the format conditions was not significant ($p = .52$).

RTs. Mean RTs (Table 5 and Figure 4B) were analyzed in a two-way ANOVA with EV-condition as within-subject and presentation format as between-subject factor. Presentation format had no reliable influence on RTs, neither as main effect ($F < 1$) nor in interaction with EV-condition, $F(3,117) = 1.20$, $p = .311$. However, a strong effect of EV-condition, $F(3,117) = 46.81$, $p < .001$, attested an increase in RTs as the EV of lottery A relative to lottery B decreased (Figure 4B). Accordingly, RTs were fastest in congruent trials (congruent vs. pro-prob and congruent vs. neutral: *ps* < .001) and slowest in pro-out trials (pro-out vs. pro-prob and pro-out vs. neutral: *ps* < .001). The difference between the neutral and the pro-prob EV-condition was not significant ($p = .101$). This pattern confirms our previous finding that an increase of outcome-oriented choices comes with additional time costs.

The result was substantiated in a separate two-way ANOVA on RTs with the within-subject factor choice (lottery A or B) and the between-subject factor presentation format (graphed-probability, graphed-outcome; see Figure 4C). The main effect of choice, $F(1,39) = 48.70$, $p < .001$, revealed slower RTs for lottery B than for lottery A choices. Notably, this pattern was qualified by a significant choice × format interaction, $F(1,39) = 9.51$, $p = .003$, which showed

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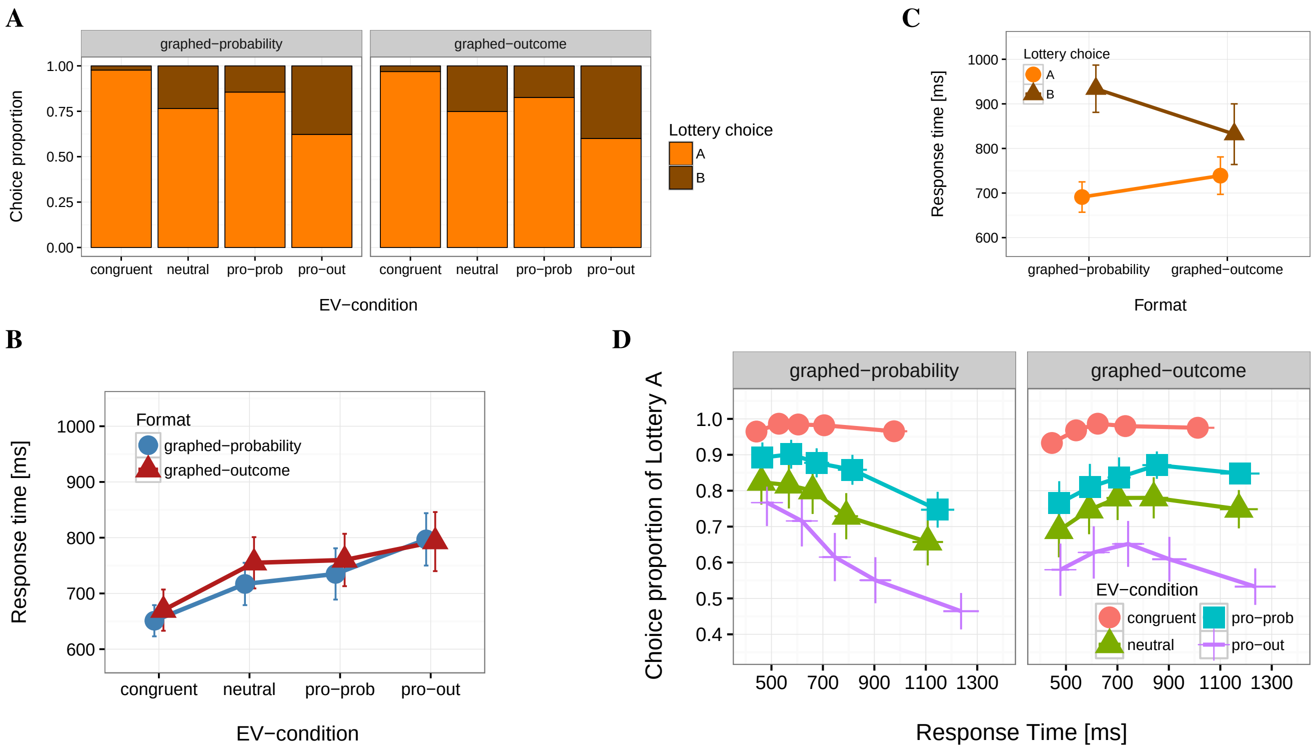
Figure 4: Empirical means in Experiment 2. (A) Choice proportions and (B) RTs across EV-conditions and presentation formats. (C) Separate choice RTs for lottery A and B are averaged across EV-conditions. (D) Conditional choice functions across five quantiles of RT distributions. Error bars reflect standard errors of means.



that the RT advantage of lottery A choices was smaller when outcomes rather than probabilities were presented graphically. The main effect of format was not significant ($F < 1$).

Conditional choice functions (CCFs). CCFs were scrutinized in repeated-measures regressions with mean RTs of the bins and EV-conditions as predictors. In the graphed-probability format, coefficients for the EV-conditions did not reliably differ from the intercept (congruent; see Table 6). Thus, all EV-conditions revealed a strong preference of the lottery with the greater win probability in fast decisions (Figure 4D). Further, the main effect of RT was not reliable, indicating that choice proportions for congruent items did not substantially vary across RTs. However, significantly negative slopes in the interaction terms revealed a decrease of lottery A choices with longer RTs in all other EV-conditions. This is compatible with the results of Experiment 1, where risk aversion in the graphed-probability format was particularly strong in fast responses and dropped for slower decisions. The pattern holds for pro-out and neutral trials, as well as for pro-prob trials, where the decrease of lottery A choices comes at the cost of profitability.

CCFs in the graphed-outcome format yielded a different pattern. Here, differences between the Intercept and the coefficients of the other EV-conditions revealed a reduced propensity towards higher win probability: compared to the congruent intercept, regression coefficients were significantly smaller in the pro-out, the neutral, as well as the pro-prob EV-condition. Thus, in line with our hypotheses, the graphical lottery outcome reduced risk aversion in fast decisions. Notably, variations of choice proportions over time are visually small (Figure 4D, right panel), and interactions with RTs are not reliable.

3.3 Discussion

With icon arrays as graphical lottery components, we again found strong risk averse preferences that showed up as larger choice proportions and faster responses for the option with the higher win probability. Participants were also sensitive to the EV of lottery pairs. Choice proportions of the safer lottery A dropped as the relative EV of the riskier lottery B increased. Analogously, RTs increased as lottery A became less profitable across EV-conditions. This confirms the finding of Experiment 1 that a deviation from risk averse preferences comes with longer decision times.

Concerning format effects, choice proportions yielded no effect. Thus, we did not replicate the finding of Experiment 1, where graphical outcomes enhanced risk aversion. This

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Table 5: Mean choice proportions of lottery A and RTs (lottery A and B choices combined) across EV-conditions and presentation formats in Experiment 2. Numbers in parentheses reflect standard errors of means.

	Choice proportions		**RTs (ms)**	
EV-condition	**Graphed-probability**	**Graphed-outcome**	**Graphed-probability**	**Graphed-outcome**
congruent	0.97 (0.01)	0.97 (0.01)	651 (28)	670 (37)
neutral	0.77 (0.06)	0.75 (0.06)	717 (38)	755 (46)
pro-prob	0.86 (0.04)	0.83 (0.05)	735 (46)	760 (47)
pro-out	0.62 (0.06)	0.60 (0.06)	797 (47)	793 (53)
mean	**0.80 (0.03)**	**0.79 (0.03)**	**723 (38)**	**743 (45)**

Table 6: Repeated-measures regressions of lottery A choice proportions over EV-conditions and RTs in the two formats of Experiment 2. Boldface marks significant predictors.

	Graphed-probability				**Graphed-outcome**			
	Estimate	**SE**	**t-value**	***p***	**Estimate**	**SE**	**t-value**	***p***
(Intercept)	**0.98263**	**0.00989**	**99.36**	**<0.01**	**0.93408**	**0.03175**	**29.42**	**<0.01**
RT	–0.00001	0.00002	–0.33	0.74	0.00007	0.00004	1.63	0.12
pro-prob	0.03521	0.04733	0.74	0.47	**–0.18269**	**0.08710**	**–2.10**	**0.05**
neutral	–0.02907	0.07636	–0.38	0.71	**–0.22080**	**0.07952**	**–2.78**	**0.01**
pro-out	–0.03116	0.09041	–0.34	0.73	**–0.25856**	**0.09936**	**–2.60**	**0.02**
RT × pro-prob	**–0.00024**	**0.00005**	**–4.40**	**<0.01**	0.00008	0.00008	0.99	0.34
RT × neutral	**–0.00026**	**0.00006**	**–4.04**	**<0.01**	–0.00001	0.00004	–0.28	0.78
RT × pro-out	**–0.00043**	**0.00007**	**–6.09**	**<0.01**	–0.00012	0.00008	–1.45	0.16

supports our assumption that the effect resulted from comprehension difficulties of the uncommon representation of outcome as pie charts. We therefore conclude that graphical outcomes do not generally increase risk aversion. Notably, though, displaying outcomes as icon arrays also did not show a reduction of risk aversion in choice proportions, which would be expected if graphs increased the impact of outcomes.

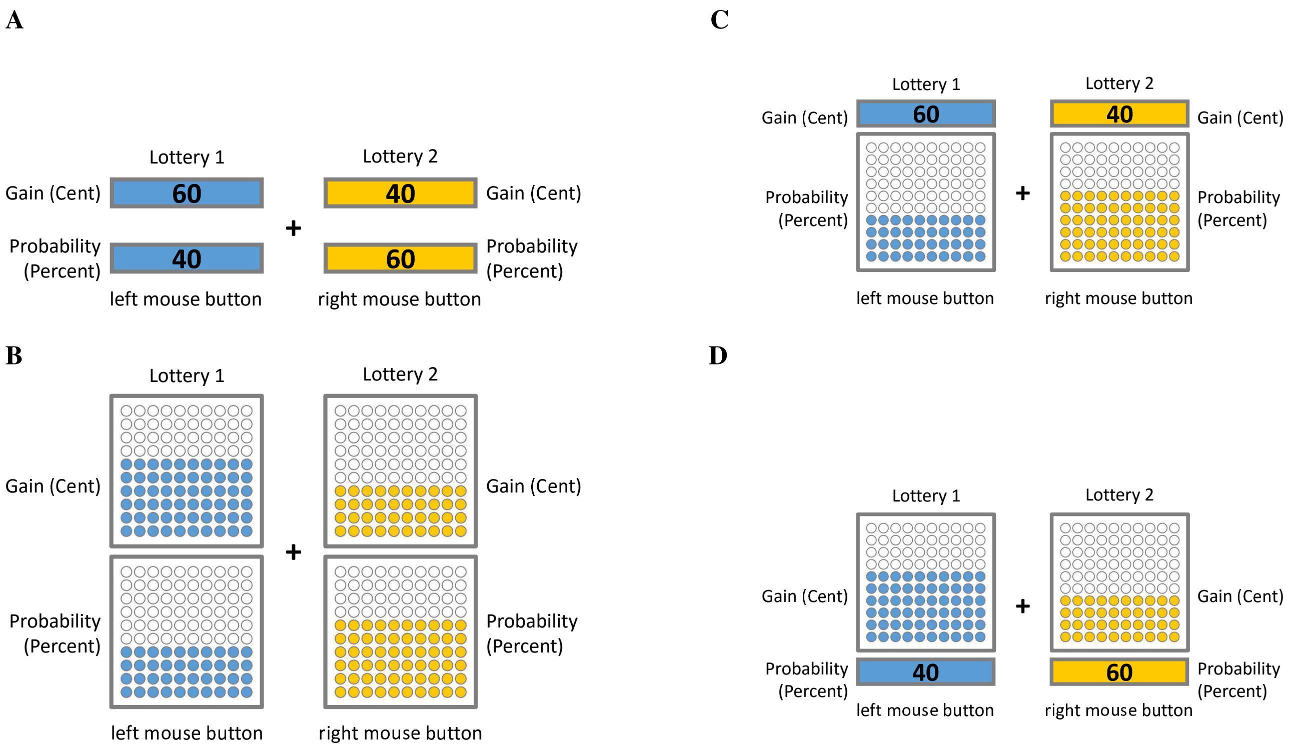
Yet, the pattern of RT results indicates some format-driven modulations of risk attitudes. The RT advantage for choices of the safer option was smaller when outcomes were presented graphically. It appears that graphical outcomes facilitated choices of the riskier high-outcome lottery, suggesting reduced risk aversion in parts of the decision process.

The finding was corroborated in CCF analyses. As in Experiment 1, the graphed-probability format revealed strong risk aversion across all EV-conditions in fast responses. At slower decisions, risk aversion decreased in the pro-out, neutral, as well as the pro-prob EV-condition. In contrast, the pattern was different for CCFs in the graphed-outcome format. Here, significant main effects of the pro-out, neutral, as well as the pro-prob EV-conditions revealed reduced risk aversion relative to the intercept at the fastest decisions, and the absence of interactions with RT shows that this effect was relatively stable over the entire response time distribution. Thus, RTs and CCFs in Experiment 2 together point to some reduction of risk aversion in response to graphical outcomes.

4 Experiment 3

The previous two experiments varied presentation formats between participants. Advantageously, this prevents decision makers from transferring response strategies from one format to another, which might blur specific effects. As a flipside, it remains unclear whether and how preferences change when the same participants are faced with different formats. Two open questions therefore are: Would graphical outcomes reduce risk aversion when participants have experience with other graphical and numerical constellations? And does the dominance of risk aversion in rapid decisions generalize across formats that are exposed to the same participants?

Figure 5: Stimulus example of Experiment 3. Lottery pairs in the presentation formats (A) all-numeric, (B) all-graphed, (C) graphed-probability, and (D) graphed-outcome. Presentation format was manipulated within participants.



We addressed these questions in Experiment 3, where we manipulated presentation formats within participants. Further, we increased the number of formats by fully crossing lottery components (probability, outcome) and presentation format (numerical, graphical). Thus, in addition to the graphed-probability and the graphed-outcome format of the previous experiments, we introduced an all-numeric and an all-graphed format, in which both probabilities and outcomes were presented as numbers and graphs, respectively. Graphical components were again represented by icon arrays (see Experiment 2), but due to the higher number of formats, we implemented only two EV-conditions (pro-prob and pro-out).

Despite these changes, we expected (1) overall risk averse preferences in choice proportions and RTs, (2) reduced risk aversion in the graphed-outcome format, and (3) at least in the graphed-probability format, stronger risk aversion in fast compared to slower decisions.

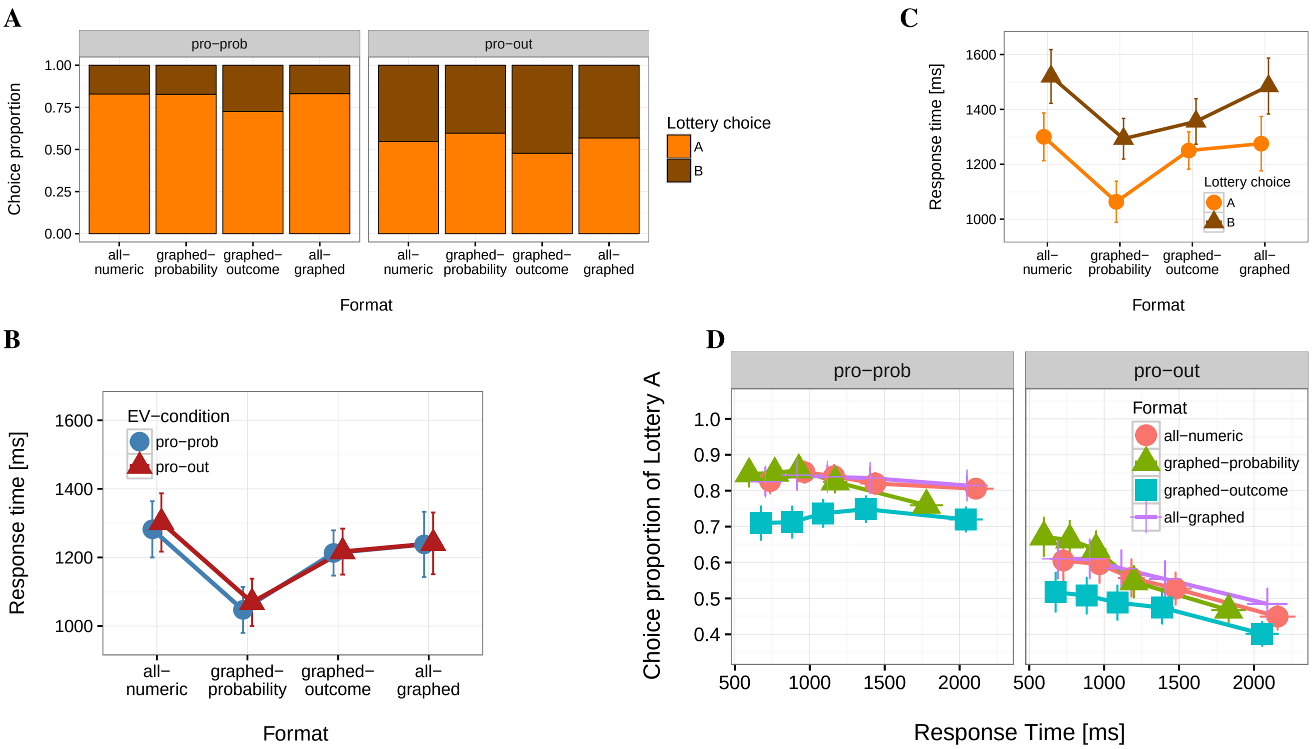
4.1 Methods

Participants. A total of 52 voluntary participants were recruited at the Universität Konstanz. Data from four participants were excluded, because they did not comply with task instructions or did not wear their vision aids during the experiment. Hence, data from 48 participants (33 female, mean age: 23.4 y; SD: 5.9 y) entered statistical analyses.

Task and stimuli. The task closely resembled Experiment 2. Participants made a total of 1056 choices between pairs of lotteries A and B. Different from the previous presentation formats, graphed (i.e., icon arrays) and numerical probabilities and outcomes were fully crossed within participants. In particular, each participant made 264 lottery choices in each of four presentation formats (Figure 5): all-numeric (i.e., numerical probability and outcome), graphed-probability (together with numerical outcome), graphed-outcome (together with numerical probability), and all-graphed (i.e., graphical probability and outcome). The graphed-probability and the graphed-outcome format were therefore very similar to those of Experiment 2, but now varied within the same participants. Presentation formats were blocked and their sequence was counterbalanced across the 48 participants.

As in the previous experiments, probabilities as well as outcomes of lottery A and B in each pair summed up to 100 percent and points (Euro cents), respectively. However, probabilities and outcomes now featured a greater variability than in Experiments 1 and 2. In lottery A, gain probabilities took values between 59% and 91%, and outcome magnitudes between 49 points and 1 point. Accordingly, probabilities in lottery B varied between 41% and 9%, and

Figure 6: Empirical means in Experiment 3. (A) Choice proportions and (B) RTs across EV-conditions and presentation formats. (C) Separate choice RTs for lottery A and B are averaged across EV-conditions. (D) Conditional choice functions across five quantiles of RT distributions. Error bars reflect standard errors of means.



outcomes between 51 and 99 points. Lottery A and B pairs set up two EV-conditions: in the pro-prob condition, EVs were higher in lottery A, whereas in the pro-out condition, they were higher in lottery B. Additionally, the difference between EVs in lottery A and B was manipulated in two levels (low, high). However, this factor revealed no interactions with presentation format and is therefore not further pursued here.

Lottery characters had a visual angle of 0.46°horizontally and 0.69°vertically. Icon arrays extended to a visual angle of 12.03°. The distance from the array center to the fixation cross was 9.17°.

Procedure. The experiment was divided into four blocks, in which the lotteries were sequentially presented in the four formats. At the beginning of each block, 13 practice trials familiarized participants with the new format, and feedback informed about the outcome of the selected lottery. In the following 264 main trials of each block, no feedback was given. Participants took a short break between blocks and after half of the trials in each block.

Participants received course credits or a base payment of five Euros, and in addition, the summed outcome of 24 randomly selected trials. Accordingly, lottery outcomes in Experiment 3 symbolized Euro cents.

Analyses. Compared to the previous experiments, RTs were slower in Experiment 3. Outlier criteria were therefore adjusted, so that RTs faster than 100 ms or slower than 4000 ms were excluded. This resulted in a total of 48,524 lottery choices with a drop of 5.6% in the all-numeric, 2.2% in the graphed-probability, 3.5% in the graphed-outcome format, and 5.8% in the all-graphed format. We examined effects of presentation formats and EV-conditions on choice proportions, RTs and conditional choice functions (CCFs).

4.2 Results

Choice proportions. Overall greater choice proportions of the lottery with the higher win probability (68 % lottery A choices) confirmed risk averse preferences. Choice proportions across EV-conditions and presentation formats are listed in Table 7 (see also Figure 6A).

A two-way ANOVA on choice proportions with EV-condition (pro-prob, pro-out) and presentation format (all-numeric, all-graphed, graphed-probability, graphed-outcome) as within-subject factors yielded a significant effect of EV-condition, $F(1,47) = 39.64$, $p < .001$. Higher choice proportions of lottery A in the pro-prob than in the pro-out EV-condition (Table 7) showed that participants were sensitive to the EV manipulation.

Table 7: Mean choice proportions of lottery A and RTs (lottery A and B choices combined) across EV-conditions and presentation formats in Experiment 3. Numbers in parentheses reflect standard errors of means.

	Choice proportions		**RTs (ms)**	
Format	**Pro-prob**	**Pro-out**	**Pro-prob**	**Pro-out**
all-numeric	0.83 (0.03)	0.55 (0.05)	1282 (82)	1302 (85)
graphed-probability	0.83 (0.03)	0.60 (0.05)	1047 (67)	1069 (69)
graphed-outcome	0.73 (0.04)	0.48 (0.05)	1213 (66)	1217 (67)
all-graphed	0.83 (0.03)	0.57 (0.05)	1238 (95)	1241 (90)
mean	**0.80 (0.02)**	**0.55 (0.02)**	**1179 (62)**	**1189 (61)**

There was no interaction of EV-condition and presentation format, $F(3,141) = 1.53$, $p = .209$. However, the main effect of presentation format was significant, $F(3,141) = 5.56$, $p = .001$. Pairwise comparisons of the four formats revealed that choice proportions of lottery A were lower in the graphed-outcome relative to the remaining formats (all $ps < .01$). Differences of choice proportions between all other formats (all-numeric, graphed-probability, all-graphed) were not reliable (all $ps > .40$). Thus, graphical lottery outcomes together with numerical probabilities was the only format that reduced risk aversion in choice proportions. This reduction was independent from EV-condition, although fewer choices of lottery A were only profitable in pro-out, but not in pro-prob trials.

Notably, the graphed-outcome format also yielded the highest gain (Euro cents) across all trials (i.e., not the actual payoff, where only a subset of trials was selected). On average, the overall gain per participant in the graphed-outcome format amounted to 48.44 EUR, which was significantly higher than the gain in the graphed-probability (46.67 EUR, $p = .037$) and the all-graphed (45.74 EUR, $p = .002$) format. The difference to the all-numeric (47.16 EUR, $p = .248$) format as well as differences between the other formats were not reliable ($ps > .19$).

RTs. Mean RTs (Table 7 and Figure 6C) were analyzed in a two-way ANOVA with EV-condition and presentation format as within-subject factors. EV-condition had no reliable influence, neither as main effect nor in interaction with presentation format ($Fs < 1$). However, a significant main effect of presentation format, $F(3,117) = 3.92$, $p = .010$, revealed that RTs were faster in the graphed-probability than in all other formats (pairwise comparisons: all $ps < 0.01$). RT differences between the all-numeric, the graphed-outcome, and the all-graphed format were not significant (pairwise comparisons: all $ps > 0.34$). Thus, the within-subject design of Experiment 3 augments the results from Experiments 1 and 2 where RT advantages of the graphed-probability format showed only up in numerical trends. This suggests that graphic probabilities together with numerical outcomes reflect a highly intuitive format for risky decision making.

RTs for choices of lottery A and B were further examined in a separate two-way ANOVA with the within-subject factors choice (lottery A or B) and presentation format (all-numeric, graphed-probability, graphed-outcome, all-graphed) (Figure 6B). The main effect of choice, $F(1,47) = 11.99$, $p = .001$, revealed slower RTs for lottery B than for lottery A choices. Further, a significant effect of presentation format confirmed the result of fastest RTs in the graphed-probability format, $F(3,141) = 4.082$, $p = .008$. The interaction of choice $\times$ presentation format was not significant, $F(3,141) = 1.88$, $p = .137$, but exploratory post-hoc tests within each presentation format confirmed the visual impression of Figure 6B that the marked RT advantage of lottery A in the all-numeric ($p = .001$), the graphed-probability ($p < .001$), and the all-graphed format ($p = .012$), is somewhat attenuated in the graphed-outcome format ($p = .072$).

Conditional choice functions (CCFs). CCFs were analyzed in repeated-measures regressions with mean RTs in the bins, EV-conditions, and presentation format as within-subject predictors (Figure 6D). Relative to the intercept (i.e., pro-prob EV-condition in the all-numeric format), Table 8 reveals three significant effects. First, the pro-out EV-condition exhibits less lottery A choices. Second, a format-related decrease of risk averse choices is present only in the graphed-outcome format, whereas effects of the graphed-probability and the all-graphed format are not significant. Third, the RT $\times$ pro-out interaction reveals that lottery A choices in the pro-out condition decrease with longer decision times across all formats, whereas the RT-dependent variation in the pro-prob EV-condition was not reliable and yielded only a trend for the interaction of RT $\times$ graphed-probability format.

Table 8: Repeated-measures regressions of lottery A choice proportions over EV-conditions and RTs in the four formats of Experiment 3. Boldface marks significant predictors.

	Estimate	SE	t-value	*p*
(Intercept)	**0.86700**	**0.04870**	**17.80**	**<0.01**
RT	–0.00005	0.00004	–1.45	0.15
Pro-out	**-0.16100**	**0.05960**	**–2.71**	**0.01**
graphed-probability	0.04770	0.05360	0.89	0.38
Graphed-outcome	**–0.13900**	**0.04020**	**–3.47**	**<0.01**
all-graphed	–0.00405	0.03780	–0.11	0.92
RT × pro-out	**–0.00010**	**0.00003**	**–3.56**	**<0.01**
RT × graphed-probability	–0.00008	0.00005	–1.71	0.09
RT × graphed-outcome	0.00005	0.00004	1.45	0.15
RT × all-graphed	0.00002	0.00004	0.55	0.59
pro-out × graphed-probability	0.03680	0.04030	0.91	0.37
pro-out × graphed-outcome	0.02480	0.04860	0.51	0.61
pro-out × all-graphed	–0.01810	0.03280	–0.55	0.58
RT × pro-out × graphed-probability	–0.00004	0.00003	–1.13	0.27
RT × pro-out × graphed-outcome	0.00001	0.00004	0.38	0.71
RT × pro-out × all-graphed	0.00001	0.00003	0.46	0.65

4.3 Discussion

As in the previous experiments, we observed risk averse preferences in choice proportions and RTs. Overall, the safer lottery A was chosen more often and more rapidly than the riskier lottery B. Yet, choice proportions were also related to profitability: the riskier lottery B was selected more frequently in the pro-out than in the pro-prob EV-condition, indicating that participants took lottery outcome into account in all presentation formats. The safer lottery A also yielded faster RTs than lottery B, but compared to Experiments 1 and 2, RTs were overall considerably slower. We speculate that this was a consequence of the within-subject design in Experiment 3, where changes of presentation formats may have reduced response routines and encouraged participants to spend more time on decisions.

Importantly, we also found clear format effects. Relative to all other presentation formats, choice proportions of the riskier lottery B were higher in the graphed-outcome format. This is in line with the hypothesis that graphs can enhance the impact of outcomes and hence increase risk taking. Indeed, presenting outcomes as icon arrays together with probabilities as numbers was the only format that reduced risk aversion in choice proportions. This effect was observed across EV-conditions, despite the fact that an increase of lottery B choices was profitable only in pro-out, but not in pro-prob trials. We therefore suggest that the reduction of risk aversion is due to the higher visual salience, and hence an attentional advantage of graphical outcomes relative to numerical probabilities (Smerecnik et al., 2010). In addition to salience, though, icon arrays hold the necessary accessibility to reflect outcomes (in contrast to pie-charts in Experiment 1). Although the increase of risk taking in the pro-prob EV-condition reduced profitability, the graphed-outcome format yielded the highest overall gain compared to the other formats. This supports our claim that the reduction of risk aversion through an adequate presentation format can optimize the profit of risky decisions.

The effects on choice proportions are neatly summarized in the CCF regressions. Significant main effects attested to reduced risk aversion across EV-conditions in the graphed-outcome format, as well as across all formats in the pro-out EV-condition. In addition, the interaction of RT with the pro-out EV-condition demonstrates a decrease of risk aversion with increasing decision time. Risk aversion is again dominant in fast decisions and declines with RT. Interestingly, however, this effect now generalized across all presentation formats, whereas similar dynamics of risk aversion in Experiments 1 and 2 showed up only in the graphed-probability format. We assume that the repeated exposure to different formats in the within-subject design of Experiment 3 has caused strategy transfers and training effects between the formats. Yet, over all three experiments our CCF analyses consistently show that risk attitudes can change with RTs, attesting the value of examining decision dynamics.

Finally, presentation format also affected RTs, which were fastest in the graphed-probability format. This effect substantiates analogous numerical trends in Experiments 1 and 2. Together, the patterns indicate that deciding between risky options is easiest when probabilities are shown as graphs, and outcomes as numbers. A plausible reason is that this format is a common visualization of risky choices, such that its familiarity facilitates decisions.

5 General discussion

Risk aversion — the preference of the safer choice option despite a more lucrative riskier alternative — is a well-established phenomenon in decision making (K. Fiedler & Unkelbach, 2011; Holt & Laury, 2002; Kahneman & Tversky, 1984), which can lead to over-conservative choices that are suboptimal for the maximization of decision outcomes. Because of potential benefits from more risk taking, the identification of factors influencing individual risk preferences without manipulating the content of the choice options is of great interest. One plausible idea to reduce risk aversion is to modulate the format of risky information in a way that increases the impact of outcomes relative to that of probabilities.

The present study addressed this issue and investigated effects of presentation format on risk aversion in three gambling experiments. Participants repeatedly chose between two lotteries with non-negative prospects, and we varied whether either probabilities or outcomes (Experiment 1–3), or both (Experiment 3) were presented in a numerical or a graphical format. The rationale was that increased attention to salient graphical outcomes may encourage decisions towards riskier options with higher outcomes.

Despite a marked risk aversion with higher choice proportions and shorter RTs for the safer lottery in all experiments, the results of Experiment 3 confirmed that graphical outcomes can decrease risk aversion. Yet, not all graphs are suitable in this respect, and the choice of non-intuitive graphs can even lead to the opposite effect (Experiment 1). Further, concerning decision dynamics, we found strongest risk averse preferences in fast responses, especially when risk information was presented graphically (Experiment 1 and 2); at slower responses, risk aversion declined. We discuss these results in more detail in the following.

5.1 Graphs vs. numbers

Prior research indicated that the presentation format can influence choices between risky options. Specifically, presenting probabilities as graphs instead of numbers enhanced risk aversion, an effect that has been attributed to the higher salience of graphs, which attracts attention. The resulting processing advantage increases the influence of graphical information on the decision (Chua et al., 2006; K. Fiedler & Unkelbach, 2011; Smerecnik et al., 2010).

It is therefore tempting to assume that the direction of this effect can be reversed. Presenting outcomes instead of probabilities as graphs should then enhance attention towards outcomes and therefore increase choices of riskier options. However, Fiedler and Unkelbach (2011) reasoned that the advantage of graphed outcomes is weak and can even turn into a disadvantage as graphical outcomes may increase cognitive demands.

Indeed, this is what we observed in Experiment 1. While pie chart probabilities yielded strong risk aversion, presenting outcomes as pie charts enhanced rather than reduced risk aversion. In line with Fiedler and Unkelbach's prediction, we reasoned that pie charts are uncommon and non-intuitive outcome representations and are therefore hard to evaluate. As a consequence, decision makers relied on the accessible — and in this case numerical — probability information, which resulted in preferences for the safer options. However, the increase of risk aversion through pie-chart outcomes does not necessarily generalize to other graphical formats.

We therefore used icon arrays as graphs in two additional experiments. The results in Experiment 2 were mixed. Choice proportions did not reveal a format effect, but a reduced RT advantage for safer lotteries suggested some facilitation of risky choices when outcomes were presented as graphs. Clear evidence for reduced risk aversion was found in Experiment 3 where risky choices were more frequent in the graphed-outcome compared to three other formats. Notably, choice proportions did not differ when both outcomes and probabilities were shown graphically or numerically, so that the reduction of risk aversion was driven by the specific combination of graphical outcomes with less salient numerical probabilities.

Our results thus confirm that certain graphical outcomes can attenuate, albeit not eliminate, risk aversion. This finding is not trivial considering previous reports of choice insensitivity to different formats (Birnbaum et al., 2008; Birnbaum, 2004, 2006) as well as the increase of risk aversion due to graphical outcomes in Experiment 1. The present study therefore unveils possibilities and limits of format-related modulations of risk attitudes. We used pie charts and icon arrays as two common graphical formats for risky decisions. Obviously, though, there are countless other formats, some of which may well be better suited to reduce risk aversion. Consequently, a systematic investigation of the visual features of graphical formats would be a desirable next step to further guide this research. For instance, psychophysical methods could help to assess how distinct salience parameters of graphs translate into subjective representations of outcomes and probabilities.[3] The usage of

[3] We thank a reviewer for suggesting this point.

eye tracking could additionally inform about attentional processes. The resulting evidence about the role of stimulus format may eventually advance models of decision making.

5.2 Correlates of risk aversion

In addition to the demonstration of format effects, our study enriches the landscape of correlates of risk preferences. Risk aversion, usually assessed via choice proportions, is reflected in more choices of the safer option (Holt & Laury, 2002; Kahneman & Tversky, 1984). Also in our experiments we observed a marked risk aversion in choice proportions across all conditions. Overall, participants selected the safer lottery in around 75% of the trials, and even in trials featuring a higher EV for the riskier lottery (i.e., pro-out EV-condition), participants opted for the safer alternative in 58% of all choices. Risk averse preferences were also reflected in RTs. Faster responses for the safer lottery indicated that decisions following the higher win probability were easier than those relying on the higher outcomes of the riskier lottery (Rubinstein, 2013). This observation is in line with previous findings of shorter RTs for preferred choice options (Busemeyer & Townsend, 1993; Busemeyer, 2015; Jamieson & Petrusic, 1977; Petrusic & Jamieson, 1978).

Going beyond the separate examination of RTs and choice proportions, we considered the two measures jointly in conditional choice functions (CCFs; Haffke & Hübner, 2015). Clearly, CCFs permit no inferences about causal relationships between RTs and choice proportions, but they inform about the dynamics of risk preferences and, in the present study, revealed that risk aversion varies with RTs. When probabilities were presented graphically in Experiments 1 and 2, choice preferences for the safer option were particularly expressed in fast responses, irrespective of lottery EVs, whereas risk aversion was lower for slower decisions. This decline was not restricted to the pro-out condition, where the riskier lottery offered the higher EV. The same trend was observed in the pro-prob condition, where profitability was actually reduced when risk aversion dropped. Thus, slower decisions in Experiments 1 and 2 did not necessarily increase profitability.

This may seem surprising, because longer RTs are often associated with controlled information processing and hence expected to result in better decisions. However, this conclusion is problematic since slower responses can also result from low preferences or low discriminability between options (Krajbich, Bartling, Hare & Fehr, 2015). Nevertheless, the dynamics in the CCFs are informative, and decision theories may capture the expressed risk aversion at fast RTs as a response bias that leads to a selection advantage of the safer option. For instance, models of evidence accumulation assume that, for binary choices, stimulus information is accumulated over time until one of two response criteria (i.e., one for each option) is reached and the associated response is initiated (e.g., Ratcliff & McKoon, 2008; Ratcliff, 1978). Response biases occur if one of the criteria is closer to the initial level of evidence at the beginning of the accumulation process (e.g., through a shift of the starting point of evidence accumulation or through asymmetric response criteria). In risky decisions, such a bias towards the criterion for the safer option would lead to a greater proportion of safe lottery choices especially at fast RTs — i.e., the pattern we observed in the graphed-probability format of Experiments 1 and 2 (Mulder, Wagenmakers, Ratcliff, Boekel & Forstmann, 2012). Response biases may therefore contribute to the impression of sometimes automatic-intuitive characteristics of risky decisions (S. Fiedler & Glöckner, 2012).

Interestingly, in the graphed-outcome format of Experiments 1 and 2, the CCFs revealed no variation of choice proportions over RTs. With pie charts (Experiment 1), risk aversion remained high even for slow responses. With icon arrays in (Experiment. 2), risk aversion was reduced already at fast decisions. The graphed-outcome format therefore yielded rather stable preferences across RTs, consistent with a reduced response bias in the context of evidence accumulation.

In comparison, CCFs in Experiment 3 revealed a decrease of risk aversion with longer RTs in all presentation formats within the pro-out EV-condition. Thus, also the graphed-outcome format showed expressed — and perhaps biased — risk aversion under rapid responses. Yet, this fast trend was absent in the pro-prob EV-condition. Overall, decisions in Experiment 3 therefore became more profitable with increasing RTs. A potential reason for this difference to Experiments 1 and 2 is that repeated exposure to different presentation formats in the within-subject design of Experiment 3 enabled participants to gain experience with the formats and to transfer response strategies that supported the optimization of decisions. Indeed, the reduction of risk aversion in the graphed-outcome format increased the overall gains of participants.

In summary, this study shows that choice proportions and RTs as well as their combination (CCFs) reflect useful correlates of risk preferences, which provide unique information. So far, psycho-economic studies often base their conclusions on choice proportions and provide no or only superficial RT analyses (e.g., Demaree, Burns, Dedonno, Agarwala & Everhart, 2012; Dong, Lin, Zhou & Du, 2014; Glöckner, Fiedler, Hochman, Ayal & Hilbig, 2012; Hertwig et al., 2004; Holt & Laury, 2002; Pachur, Hertwig, Gigerenzer & Brandstätter, 2013; Payne & Braunstein, 1978). One plausible reason is, of course, that RT recording is not always practical, as for instance in paper-pencil experiments. However, RT measures may sometimes also be omitted because they seem not to be of interest. Our results argue against this view as they show that RTs and CCFs can augment the understanding decision dynamics.

6 Conclusions

The present results demonstrate that graphical representations of lottery outcomes can reduce risk aversion. We propose that this effect is due to the greater salience of graphs, which attracts attention to larger outcomes and therefore increases the readiness to opt for riskier choices. Non-intuitive formats, though, can yield the opposite effect. Thus, our findings support the view that information format in risky decisions is a non-trivial factor, which deserves further investigation.

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