Living Near the Edge: How Extreme Outcomes and Their Neighbors Drive Risky Choice

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Extreme stimuli are often more salient in perception and memory than moderate stimuli. In risky choice, when people learn the odds and outcomes from experience, the extreme outcomes (best and worst) also stand out. This additional salience leads to more risk-seeking for relative gains than for relative losses—the opposite of what people do when queried in terms of explicit probabilities. Previous research has suggested that this pattern arises because the most extreme experienced outcomes are more prominent in memory. An important open question, however, is what makes these extreme outcomes more prominent? Here we assess whether extreme outcomes stand out because they fall at the edges of the experienced outcome distributions or because they are distinct from other outcomes. Across four experiments, proximity to the edge determined what was treated as extreme: Outcomes at or near the edge of the outcome distribution were both better remembered and more heavily weighted in choice. This prominence did not depend on two metrics of distinctiveness: lower frequency or distance from other outcomes. This finding adds to evidence from other domains that the values at the edges of a distribution have a special role.

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In many domains, values that fall at the extreme edges of a distribution can have a privileged psychological status. In perceptual discrimination, for example, people are more accurate with values from the edges of a distribution than with values in the middle of a distribution—variously referred to as the "edge," "end," or "bow" effect (e.g., Braida & Durlach, 1972; Lacouture, 1997; Moon, Fincham, Betts, & Anderson, 2015). In memory, words paired with the highest and lowest value rewards in a set are better remembered than words paired with intermediate-value rewards (Madan & Spetch, 2012; see also Castel et al., 2016). Along the temporal dimension, items that occur at the edges (i.e., first or last) in a sequence are also better remembered (i.e., primacy and recency effects; Murdock, 1962). Similar edge effects have also been observed in experience-based risky choice, where outcome values at the extremes of the experienced distribution are both better remembered and more heavily weighted in choice (e.g., Madan, Ludvig, & Spetch, 2014). Here, in a series of four experiments, we assess the question of why extremes stand out in risky choice, contrasting two separate hypotheses: (a) that extremes stand out because they are close to the edges of the distribution or (b) that extremes stand out because they are distinct from other values.

Across a range of choice tasks, extremes have notable effects on behavior. For example, when people process a rapidly presented stream of values, the high- and low-value items more strongly

capture attention and have greater influence on valuation than more moderate outcomes (e.g., Kunar, Watson, Tsetsos, & Chater, 2017; Tsetsos, Chater, & Usher, 2012). In consumer choice tasks between items varying on more than one dimension (e.g., price and quality), people sometimes show extremeness aversion, preferring the item in the middle over items that are best on one dimension and worst on the other (Simonson & Tversky, 1992; Tversky & Simonson, 1993). In all of these cases, the items at one or both ends of a set impact behavior differently than items in the middle. Moreover, these effects are not due to the absolute value of the items because shifting the set changes which items have the most impact.

In experience-based risky choice, the outcomes at the extreme ends (highest and lowest) of the experienced distribution of outcomes also play an important role. When making choices that involve these extremes, people are more risk seeking for choices that involve the high extreme than equivalent choices with no extremes and vice versa (Ludvig, Madan, & Spetch, 2014b; Ludvig & Spetch, 2011). In this case, people are drawn to the extreme high value (the best relative gain) and repulsed from the extreme low value (the worst relative loss). For example, people will choose a 50/50 chance of winning 40 points over a certain 20 points, but choose the safe option for the same gamble in the loss domain (e.g., Ludvig et al., 2014b). This pattern of risk seeking for relative gains and losses in experience is opposite to the pattern when people prospectively state their preferences based on explicit descriptions. For these described choices, people typically show the classic *reflection effect* in which they are more risk seeking for losses than for gains (e.g., Kahneman & Tversky, 1979). This *reversed reflection effect* with experience-based choices has now been reported repeatedly in humans (e.g., Konstantinidis, Taylor, & Newell, 2017; Ludvig et al., 2014b; Madan et al., 2014) and in other animals (e.g., Heilbronner & Hayden, 2013, 2016; Ludvig, Madan, Pisklak, & Spetch, 2014a; but see Lakshminarayanan, Chen, & Santos, 2011; Marsh & Kacelnik, 2002). This divergence in choice occurs despite 50/50 odds for the risky options, extending the related finding that rare events appear to be weighted differently when encountered as descriptions than when learned about through experience (e.g., Barron & Erev, 2003; Hertwig, Barron, Weber, & Erev, 2004; Wulff et al., 2018, but see Glöckner, Hilbig, Henninger, & Fiedler, 2016; Kellen, Pachur, & Hertwig, 2016).

For experience-based choices, biases in memory for the experienced outcomes likely influence choice (Ludvig, Madan, & Spetch, 2015; Madan et al., 2014, 2017; Stewart, Chater, & Brown, 2006; Weber & Johnson, 2006). Previously, we proposed an *extreme-outcome rule*, whereby overweighting of the extreme outcomes in memory underlies the reverse-reflection effect (Ludvig et al., 2014b). According to this extreme-outcome rule, when risky options lead to the best or worst possible outcomes in a decision context (+40 or −40 in the example above), those extreme values are better remembered (Madan et al., 2014; Madan & Spetch, 2012), similar to the overweighting of peak events in the evaluation of past affective experiences (e.g., Fredrickson, 2000; Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993). Consequently, when making a choice, people are more likely to recall the extreme outcome when evaluating the risky option. This biased recall leads to more risk seeking when the best outcome in a given context is a possible outcome of the risky choice and less risk

seeking when the risky choice could lead to the worst outcome. Accordingly, the extreme-outcome rule adds to the many factors that influence risky choice, such as decision framing (Tversky & Kahneman, 1981), available alternatives (Stewart, 2009; Stewart, Reimers, & Harris, 2014), outcome recency (Hertwig et al., 2004; Wulff et al., 2018), method of elicitation (e.g., Hsee, 1996), and affective content (e.g., Suter, Pachur, & Hertwig, 2016).

This proposed role for memory in risky choice is consistent with growing evidence that memory plays a crucial role in the construction of preferences and the integration of information to guide decisions (e.g., Bornstein & Norman, 2017; Ludvig et al., 2015; Murty, FeldmanHall, Hunter, Phelps, & Davachi, 2016; Palombo, Keane, & Verfaellie, 2015; Shohamy & Daw, 2015; Weber & Johnson, 2006; Wimmer & Shohamy, 2012). The above biases in memory for extreme outcomes have previously been directly linked to the role of extreme outcomes in risky choice (e.g., Madan et al., 2014). After a risky-choice task where outcomes were learned from experience, people were more likely to report the extreme outcomes than the equally often-experienced intermediate (nonextreme) outcomes when asked which outcome first comes to mind for each risky option. In addition, people systematically misjudged the frequency of the more extreme outcomes (high and low), reporting them as having happened more often than nonextreme outcomes. This overweighting in memory correlated with risk preferences across individuals, consistent with an overweighting of extreme outcomes in memory driving the reversed reflection effect (Madan et al., 2014, 2017).

An important open question, however, is exactly what makes extreme outcomes stand out in choice and memory. One possibility, as supposed by the extreme-outcome rule, is that outcomes at the edges of a distribution (i.e., the best and worst possible) are more memorable than values in the middle of the distribution, merely by being close to the edge positions (Ludvig et al., 2014a; Ludvig & Spetch, 2011; Madan et al., 2014). According to this view, the edges gain psychological prominence because they define the boundaries of a person's experience in the experimental context. People begin the task with little concept as to what might possibly occur in terms of outcomes, and the edges quickly define for people the range of what is possible. The range of possibilities defined by these extremes is important for how people make many choices, including risky ones (e.g., Lim, 1995; Parducci, 1965; Stewart, 2009).

The memory literature, however, points to an alternate hypothesis as to why such extreme outcomes are more memorable: their distinctiveness (e.g., Brown, Neath, & Chater, 2007). There are many possible ways in which stimuli can be distinctive and stand out in memory. For example, they may come from a different semantic category than other items, appear in a different color or font, or even create a unique or bizarre image (Hunt & Worthen, 2006). In previous studies of extreme outcomes in risky choice, the extreme outcomes have typically had two properties that could mark them as potentially distinct and more memorable. First, they often occurred less frequently than other outcomes (e.g., Ludvig et al., 2014b; Ludvig & Spetch, 2011; Madan et al., 2014). Second, as opposed to other nonextreme outcomes, the extremes (by definition) only had neighbors on one side. As a result, they were more distant on average from other outcomes, especially given that the outcomes were fairly evenly distributed. This distinctiveness through distance from other neighboring values is known to influ-

ence both the perceptual salience and memorability of an item in an array (e.g., Neath, Brown, McCormack, Chater, & Freeman, 2006). In addition, a similar logic based on temporal distance is used by the SIMPLE memory model to explain recency and primacy effects (Brown et al., 2007; Murdock, 1962).

In previous studies of the interaction of risky choice and memory, the extremity and distinctiveness of the extreme outcomes were always confounded (e.g., Madan et al., 2014, 2017). The extreme outcomes were at the ends of the distribution (by definition), but were also distinct because they occurred less frequently and had fewer neighboring outcomes than nonextreme outcomes.[1] Following the example above (Madan et al., 2014), the nonextreme outcome (0) was common to both risky options, whereas the extreme outcomes (+40 and −40) were unique to the two risky options, appearing less frequently overall. In addition, the extreme outcomes (+40 and −40) only had one neighboring outcome 20 points away (the fixed outcome of + 20 or −20), whereas the nonextreme outcome (0) had neighboring outcomes on either side (both higher and lower), also 20 points away. Thus, it is possible that the extreme outcomes stood out in memory relative to the nonextreme outcomes not because of their placement at the edge of the experienced distribution, but rather because they were more distinct than other outcomes.

The two sets of experiments presented here used novel sets of outcomes to systematically test whether it is the distinctiveness of extreme outcomes due to low frequency (Experiment 1) or the distance from neighboring outcomes (Experiment 2) that can explain the previously observed overweighting of extreme outcomes. Experiments 1a and 1b used high- and low-outcome sets that did not overlap, thus controlling for difference in relative frequency (see Table 1). In Experiment 1a, all outcomes were positive, and in Experiment 1b, all outcomes were negative. Experiment 2a and 2b used larger decision sets to test whether outcomes at the ends of the distribution also need to be distant from other outcomes to be overweighted. In Experiment 2a, the decision set included both gains and losses, and in Experiment 2b, the decision set included only gains (see Table 2). The extreme-outcome rule predicts that in both experiments participants would be more risk-seeking for higher-value decisions than for lower-value decisions and that these behavioral preferences would map onto self-reported memory biases for the extreme risky outcomes. In contrast, the distinctiveness hypothesis predicts that any effects of extreme outcomes should be eliminated if the extremes are made nondistinct, either by reducing the overlap of nonextreme values (Experiment 1) or by adding neighboring values (Experiment 2). Together, these studies addressed the question of what makes extreme outcomes stand out in choice and memory.

General Method

The following methods were common to all four experiments in this article.

Participants

All research was approved by the University of Alberta Research Ethics Board. All participants provided written informed consent and were tested individually in separate rooms, but were recruited and instructed in groups of up to 15. All payments were in Canadian dollars.

Apparatus and Procedure

All testing was performed using Windows PCs running E-Prime. Participants played a computer-based task to earn points that were exchanged for money. On each trial, participants were presented with pictures of one or two visually distinct doors, which they clicked on to obtain an outcome. Clicking a door was immediately followed by removal of the door images and 1.2 s of feedback showing the number of points won or lost and a cartoon graphic of a pot of gold (gains) or robber (losses). Figure 1 shows the images used in Experiment 1a (see also Ludvig et al., 2014b).

The task used a partial-feedback procedure (see Hertwig & Erev, 2009) in which all choices were consequential, and only feedback for the chosen option was provided. The total accumulated points were continuously displayed at the bottom of the screen. Trials were separated by either a 1- or 2-s interval. The experiment consisted of several blocks of choice trials, which were separated by a brief break (an on-screen riddle), and the last block of choice trials was followed by two types of memory tests.

In all experiments, clicking on some doors (fixed doors) led to the same outcome every time, and clicking on other doors (risky doors) led to a 50/50 chance of a better or worse outcome. In all cases, the outcomes associated with each door were counterbalanced across participants, and the order of trials varied randomly within blocks. In addition, the left-right location of each door was counterbalanced within each trial type. *Single-option trials* presented only a single door, and the participant was required to click on the door to continue. These trials were designed to ensure that the participants experienced the contingencies associated with each door throughout the experiment regardless of their choices, thereby limiting the possibility that they would perpetually avoid initially unlucky options (i.e., hot-stove effects; Denrell & March, 2001). *Catch trials* presented a choice between one high- and one low-value door (i.e., objectively different expected values) and thereby provided a manipulation check that participants had learned the contingencies and were choosing to maximize points/money. As per our standard practice, all participants who picked the reward-maximizing option on fewer than 60% of the catch trials were excluded from all results (e.g., Ludvig & Spetch, 2011). Finally, the critical trials of interest were *decision trials.* These provided a choice between a door that yielded a fixed outcome (i.e., a safe door) and a door that provided a variable outcome (i.e., a risky door) of equal expected value (e.g., both high-value doors or both low-value doors). Because the expected value of these doors was equal, these trials provided a measure of risk preference independent of expected-value maximization.

After the choice task, participants' memory for the outcomes of each door was assessed. First, they were presented with each door individually and asked to enter the "number of points [they] first think of" upon seeing each door. This recall test served to assess the accessibility of memory for the outcome(s) associated with each door. The second test was a frequency judgment test, which assessed whether there were any distortions in the remembered frequency of the outcomes. In this test, each door was again

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[1] The lone exception is one previous experiment (Experiment 2 in Ludvig et al., 2014b) that did use nonoverlapping sets of values and found effects on risky choice, but that experiment used the same absolute numbers in positive and negative domains and did not test memory.
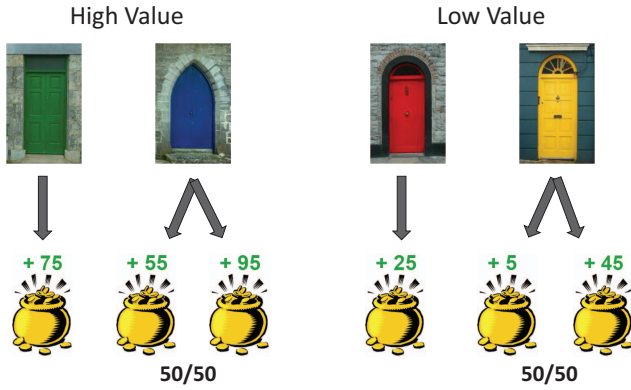
High Value   Low Value

+ 75   + 55   + 95   + 25   + 5   + 45

50/50   50/50

Figure 1. Diagram showing the doors and outcomes used in Experiment 1a. The contingencies between the doors and outcomes were counterbalanced across participants. See the online article for the color version of this figure.

presented individually along with a list of the possible outcomes. The participant was asked to type the "percentage of the time the door led to each of the listed outcomes" followed by (except in Experiment 1a) a confirmation screen which allowed participants to reenter their response for that trial. In Experiments 1a, 1b, and 2a, each door was presented with all of the possible outcomes in the experiment listed below the door for these frequency judgments. Based on comments from participants in Experiment 2a about the difficulty of typing in so many values (six doors and 10 possible outcomes for each), this test was simplified for Experiment 2b by presenting only the four risky doors and for each of these doors listing only the two outcomes associated with that door. The first-outcome-reported test always preceded the frequency-judgment test, and the presentation sequence of the doors in each memory test was randomly determined for each participant.

Raw data for all experiments are available at: *https://osf.io/ wfbnv/*. Statistics were calculated using MATLAB (Natick, MA) and JASP (jasp-stats.org), and all inferential statistics were cross-checked with statcheck.io.

Experiment 1

Method

Participants. In Experiment 1a, 58 participants were recruited from flyers posted around the University of Alberta campus (38 female; $M_{age} = 25.2$, $SD = 9.3$) and were compensated with a $12 honorarium plus a performance-based bonus of up to $8. In Experiment 1b, 56 participants (34 female; $M_{age} = 21.0$, $SD = 2.6$) were recruited from the University of Alberta psychology participant pool and received course credit plus a performance-based cash bonus of up to $8.

Procedure. Sessions contained six blocks of 48 trials each. In both experiments, there were a total of four doors, with one or two of the doors presented on each trial. In Experiment 1a, participants started with 0 points, and all doors led to gains: a low-value fixed gain (100%: 25 points), low-value risky gain (50%: 5 points; 50%: 45 points), high-value fixed gain (100%: 75 points), and high-

value risky gain (50%: 55 points; 50%: 95 points). In Experiment 1b, participants started with 2,300 points, and all doors led to losses: a low-value fixed loss (100%: −75 points), a low-value risky loss (50%: −55 points; 50%: −95 points), a high-value fixed loss (100%: −25 points), and a high-value risky loss (50%: −5 points; 50%: −45 points). In this case, participants were instructed to minimize the number of points lost (see Table 1 for a summary).

Each block included eight single-door trials, 24 decision trials, and 16 catch trials. Decision trials equally often involved choices between the two high-value doors or two low-value doors. Two participants in Experiment 1a and one participant in Experiment 1b were excluded based on catch-trial performance. Additionally, one participant was excluded from Experiment 1a for not following instructions (i.e., writing values down, despite explicit instructions not to). The two types of memory tests followed the last block of choice trials.

Data analysis. Risky choice was calculated as the proportion of choices of the risky option on decision trials (i.e., on the trials in which the choice was between a fixed and a risky option of equal expected value). Risky choice was calculated separately for choices between high-value options and choices between low-value options for each block of trials. All degrees of freedom for within-subjects ANOVA tests were corrected using Greenhouse-Geisser. Consistent with Madan et al. (2014), the average of the last three blocks of trials was used to assess stable choice preferences.

Results

Risky choice. Figure 2A presents the mean risky choice for high-value and low-value decisions across blocks in Experiment 1a. Participants were initially close to indifferent between the risky and fixed alternatives on both choices but showed a gradual decrease in risky choice (i.e., risk aversion) for low-value decisions. A 2 × 6 (Value [High, Low] × Block [1–6]) repeated-measures ANOVA showed a significant interaction, $F(3.3, 180.5) = 4.38$, $p = .004$, $\eta_p^2 = 0.075$. The main effects of block, $F(3.6, 195.5) = 3.61$, $p = .009$, $\eta_p^2 = 0.063$, and value, $F(1, 54) = 26.4$, $p < .001$, $\eta_p^2 = 0.33$, were also significant. Averaged across the last three blocks (i.e., after sufficient opportunity to learn the outcomes), participants chose the risky option 28.9 ± 3.8 (Mean ± SEM) percentage points more often for high-value choices ($53.3 \pm 4.3\%$) than for low-value choices ($24.4 \pm 3.4\%$); this difference was significant, $t(54) = 5.49$, $p < .001$, Cohen's $d = 1.01$, and in the direction predicted by the extreme-outcome rule.

Table 1

Outcome Values and Extremes of the Decision Context in Experiments 1a (All Gains) and 1b (All Losses)

	Low value		High value		Extreme values	
Experiment	Fixed	Risky	Fixed	Risky	Low	High
1a	+25	+5 or +45	+75	+55 or +95	+5	+95
1b	−75	−95 or −55	−25	−45 or −5	−95	−5

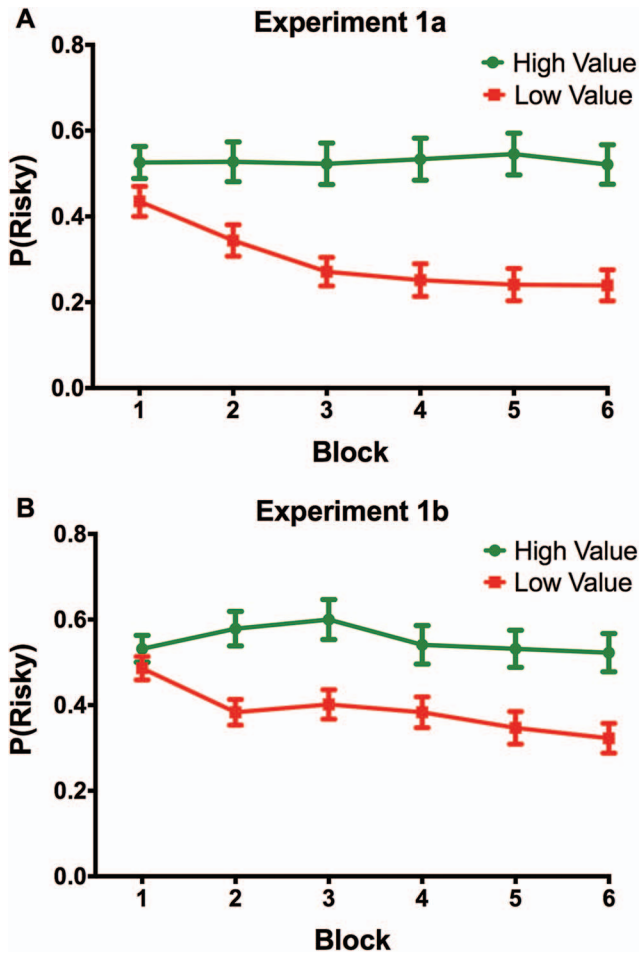*Note.* All risky options have a 50% chance of either outcome.

Figure 2. Proportion of choices of the risky option on decision trials between fixed and risky high-value options (green circles) and between fixed and risky low-value options (red squares) for each of the six trial blocks in: (A) Experiment 1a and (B) Experiment 1b. Error bars are SEM. See the online article for the color version of this figure.

Figure 2B shows the mean risky choice for each of the six blocks in Experiment 1b. Again, participants started near indifference on both choices, but showed a gradual decrease in risky choice on the low-value decisions. A 2 × 6 (Value [High, Low] × Block [1–6]) repeated-measures ANOVA showed a significant interaction, $F(4.0, 215.2) = 3.21$, $p = .014$, $\eta_p^2 = 0.056$. The main effect of block was marginally significant, $F(3.0, 161.2) = 2.67$, $p = .049$, $\eta_p^2 = 0.047$, and the main effect of value was clearly significant, $F(1, 54) = 22.5$, $p < .001$, $\eta_p^2 = 0.29$. Averaged across the last three blocks, participants chose the risky option 18.1 ± 4.2 percentage points more often for high-value choices ($53.2 \pm 4.2\%$) than for low-value choices ($35.1 \pm 3.2\%$); this difference was significant, $t(54) = 4.26$, $p < .001$, $d = 0.66$, and was again as predicted by the extreme-outcome rule.

Posttest memory. Figure 3A shows the frequency of participants' reports of the "first outcome to come to mind" for the high- and low-value risky doors in Experiment 1a. Participants were more likely to report the high extreme value (+95) than the nonextreme value (+55) for the high-value risky door, $\chi^2(1, N =$

46$) = 14.7$, $p < .001$, and the low extreme value (+5) than the nonextreme value (+45) for the low-value risky door, $\chi^2(1, N = 50) = 32.0$, $p < .001$.

Figure 3B illustrates the average judged frequency of each potential outcome on the risky high- and low-value doors. Even though the risky doors objectively led equiprobably to their outcomes, participants reported the extreme outcomes as occurring more frequently than the nonextreme outcomes. For the high-value risky door, participants rated the extreme outcome +95 as having occurred 12.0 ± 5.8 percentage points more often than the nonextreme outcome +55, $t(54) = 2.07$, $p = .04$, $d = 0.46$; and for the low-value risky door, they rated the extreme outcome +5 as having occurred 37.3 ± 6.1 percentage points more often than the nonextreme outcome +45, $t(54) = 6.17$, $p < .001$, $d = 1.43$.

Figure 4A shows the frequency of participants' reports of the "first outcome to come to mind" for the risky doors in Experiment 1b. Most participants entered all values without negative signs, but because all the numbers in the experiment were negative and participants were not specifically instructed to include the sign, we converted all entered numbers to negative values. Participants reported the extreme outcome (−5) more often than the nonextreme outcome (−45) for the high-value risky door, $\chi^2(1, N = 49) = 29.5$, $p < .001$, and the extreme outcome (−95) more often than the nonextreme outcome (−55) for the low-value risky door, $\chi^2(1, N = 44) = 10.8$, $p = .001$.

Figure 4B shows the judged frequencies of outcomes for the risky high- and low-value doors. Participants reported the extreme outcome as occurring 12.9 ± 4.9 percentage points more frequently than nonextreme outcomes for the high-value risky door,
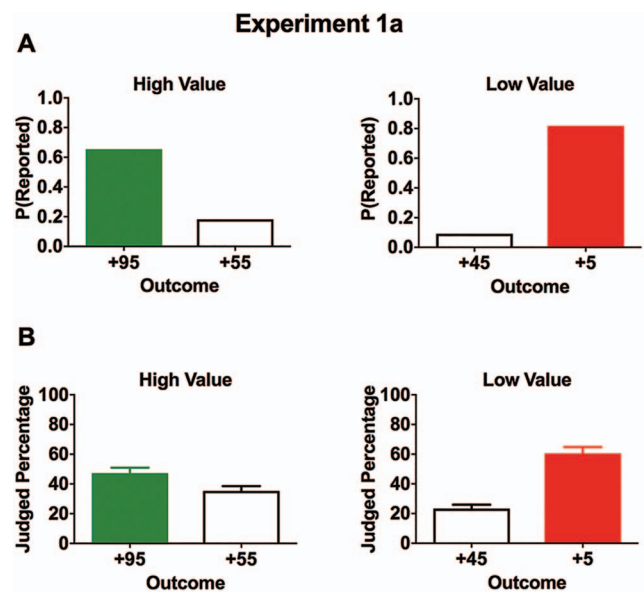

Figure 3. Results from self-report memory tests with the risky doors in Experiment 1a. (A) The proportion of participants who reported the extreme (filled green or red bars) and nonextreme values (white bars) as the "first outcome that came to mind" for each risky door. (B) The judged percentages for each risky door's outcome (± SEM). Note that some participants reported other values for both questions, thus the totals do not sum to 1 (in panel A) or 100 (in panel B). See the online article for the color version of this figure.
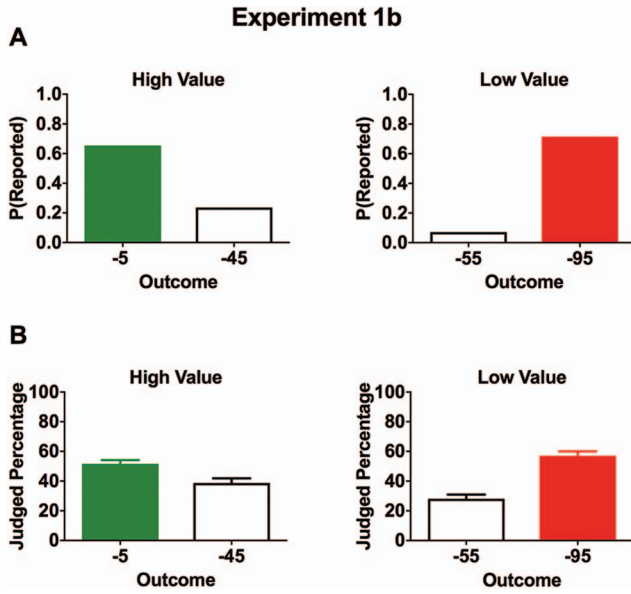
Figure 4. Results from self-report memory tests with the risky doors in Experiment 1b. (A) The proportion of participants who reported the extreme (filled red or green bars) and nonextreme values (white bars) as the "first outcome that came to mind" for each risky door. (B) The judged percentages for each risky door's outcome (± SEM). Note that some participants reported other values for both questions, thus the totals do not sum to 1 (in panel A) or 100 (in panel B). See the online article for the color version of this figure.

$t(54) = 2.63$, $p = .011$, $d = 0.61$, and 28.8 ± 4.6 percentage points more frequently than the nonextreme outcome for the low-value risky door, $t(54) = 6.30$, $p < .001$, $d = 1.33$.

In both experiments, for both high and low values, frequency judgments were significantly correlated with risky choice, consistent with Madan et al. (2014, 2017). To ensure that correlations between risky choice and memory judgments were not solely due to differences in how often each outcome was experienced, memory judgments and risk preference were correlated after controlling for the actual incidence rates of the outcomes for the risky doors across all trials in the experiment (i.e., a partial correlation; see Madan et al., 2014).

Figure 5 shows the correlations between the frequency judgments and risky choice for both experiments, split by high (Figures 5A and 5C) and low values (Figures 5B and 5D). In Experiment 1a, there was a marginally significant positive correlation between risky choice and judged frequency of the extreme outcome for high-value choices (+95), $r_p(52) = .28$, $p = .044$. For low-value choices, there was also a significant negative correlation between risky choice and judged frequency of the extreme outcome (+5), $r_p(52) = -.33$, $p = .017$. In Experiment 1b, there was again a significant positive correlation between risky choice and the judged frequency of the high extreme (−5), $r_p(52) = .44$, $p = .001$, and a significant negative correlation between risky choice and the judged frequency of the low extreme (−95; worst possible outcome), $r_p(52) = -.44$, $p = .001$. Too few participants in either experiment reported the nonextreme outcomes to perform appropriately powered correlations of first-outcome self-reports with risky choice.

Discussion

These experiments showed that the most extreme outcomes in a decision context are overweighted both in risky choice and in postchoice memory judgments. These experiments resolve an ambiguity in previous studies showing a link between memory biases and the reverse-reflection effect (e.g., Madan et al., 2014, 2017); in those studies, the nonextreme outcomes overlapped and were also associated with both the high- and low-value risky choices. As a result, in those studies, the nonextremes occurred more frequently than extreme outcomes. The outcome distribution used here did not contain overlapping outcomes, yet an extreme-outcome effect still emerged. These results support the hypothesis that outcomes at the edge of the distribution of experienced outcomes are overweighted in both choice and memory, and importantly, they explicitly rule out distinctiveness due to a lower frequency of occurrence as the reason for this effect of extreme outcomes.

Moreover, the comparable results across both experiments indicate that overweighting of extreme outcomes does not depend on absolute properties of the extremes, such as absolute numerical value or distance from zero. In Experiment 1a, the high extreme was +95 and the low extreme was +5, whereas in Experiment 1b, the high extreme was −5 and the low extreme was −95 (see Table 1). In both cases, participants chose the risky option more often for high-value decisions than for low-value decisions, consistent with previous demonstrations (Ludvig & Spetch, 2011) and in contrast to the standard reflection effect (Kahneman & Tversky, 1979).

Finally, self-report memory judgments made after testing suggested that most participants overrepresented the extreme outcomes in memory. Most participants reported the extreme outcomes as the first that came to mind for each risky door, and the extreme outcome was judged as having occurred more often than
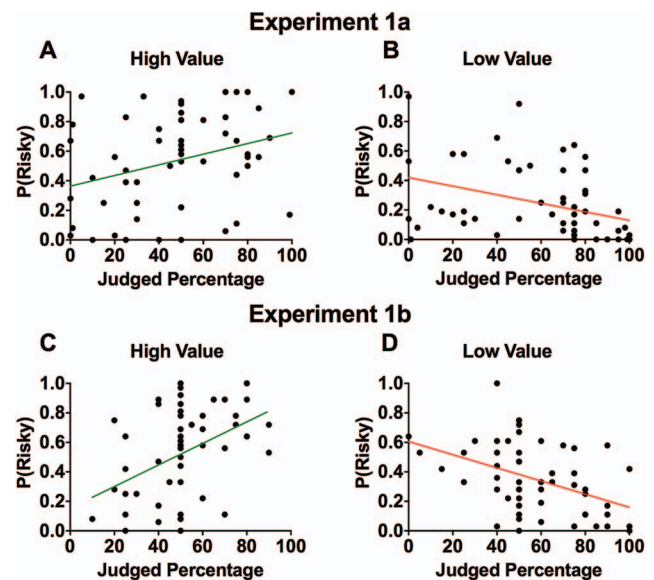
Figure 5. Scatterplots of the proportion of risky choices (averaged over last three blocks) as a function of the judged frequency of the extreme door for (A) high-value doors and (B) low-value doors (right) in Experiment 1a. (C–D) Same scatterplots for Experiment 1b. Each dot represents an individual participant. See the online article for the color version of this figure.

the nonextreme outcome; the latter judgments correlated with actual risky choices that participants made during the task. This corresponds with the suggestion made previously (Ludvig et al., 2014b; Madan et al., 2014) that participants oversample extreme outcomes from memory and thus overweight these outcomes in their risky decisions.

Experiment 2

Experiments 1a and 1b showed overweighting of outcomes at the ends of the distribution across different sets of absolute values in choice and memory. These experiments rule out interpretations in terms of differences in the frequency of extreme and nonextreme outcomes. Experiments 2a and 2b further evaluate what makes extreme outcomes stand out by varying the relative proximity of neighboring values. The extreme-outcome rule hypothesizes that extreme outcomes are salient because they are the largest or smallest in a context, independent of the values of the nonextreme outcomes. A second possibility drawn from the memory literature is that extremity depends on distinctiveness from nearby outcomes (e.g., Brown et al., 2007). By this hypothesis, extreme outcomes are more distinct (and memorable) than nonextreme outcomes because extreme outcomes only have neighbors on one side (either higher or lower), whereas nonextreme outcomes have neighbors on both sides (both higher and lower).

Experiments 2a and 2b assessed these hypotheses by using larger decision sets and varying the proximity of the nearest neighbors to the extreme outcomes across two groups (see Table 2). In particular, in group nearby, additional risky options were included which yielded *nearby* outcomes only a single point away from the extreme outcomes. In group remote, as a control, additional risky options were included which yielded outcomes that were only a single point away from the fixed outcome, but were *remote* from the extremes.

As per the preregistration, we tested five specific hypotheses with this design. First, for group remote, the *extreme-outcome-reliability hypothesis* predicted the usual extreme-outcome effect (more risk seeking for high-value choices; better memory for extremes), even with the new sets of outcomes. Second, for group nearby, there were two opposing predictions: The *value-distinctiveness hypothesis* supposed that extremity depends on distinctiveness in value from nearby neighbors, so the extreme-outcome effect would be reduced in both choice and memory, whereas the *edges hypothesis* supposed that extremity only depends on the range of values experienced, so the extreme-outcome effect would be equally strong in this group. Finally, we also tested a secondary set of opposing hypotheses regarding group nearby: The *interference hypothesis* supposes that neither the extremes outcomes nor the nearby neighbors will stand out in memory or choice, whereas the *edge-proximity hypothesis* supposes that both the extreme outcomes and the nearby neighbors will stand out in memory and choice.

The methods, hypotheses, and analyses for these experiments were all preregistered on the Open Science Framework (*https://osf.io/grj42/*).

Method

Participants. Participants were recruited from the University of Alberta psychology participant pool. They received credit to-

ward their introductory psychology course and a bonus of up to $5 (Canadian) depending on the points earned. In Experiment 2a, 205 participants were randomly assigned to either group nearby: $n = 100$ (63 female; mean age $= 19.0$) or group remote: $n = 105$ (61 female; mean age $= 19.3$). In Experiment 2b, 129 participants were randomly assigned to group nearby: $n = 65$ (44 female; mean age $= 20.5$) or group remote: $n = 64$ (50 female; mean age $= 20.8$).

Procedure. The procedure was similar to that used in Experiment 1 except that there was a total of six doors that provided the choice options and 10 possible outcomes as outlined in Table 2. In both experiments, two of the doors always led to *fixed* outcomes, two of the doors led to *risky extreme* outcomes with a 50/50 chance, and the remaining two doors to led to *risky neighbor* outcomes with a 50/50 chance.

In Experiment 2a, the decision set included gains and losses. The *fixed* gain door led to $+45$, and the *fixed* loss door led to -45. The *risky extreme* doors included one gain door ($+15$ or $+75$) and one loss door (-15 or -75). The outcomes for the *risky neighbor* doors differed for the two groups: In group nearby, the *risky neighbor* gain door led to $+16$ or $+74$ and the *risky neighbor* loss door led to -16 or -74 (i.e., the outcomes were near to those for the extreme doors); in group remote, these doors lead to different gain outcomes ($+44$ or $+46$) and loss outcomes (-44 or -46). Note that all gain doors had an expected value of $+45$ and all loss doors had an expected value of -45.

In Experiment 2b, the decision set included high- and low-value gains. The *fixed* high-value door let to $+75$, and the *fixed* low-value door led to $+25$. The *risky extreme* doors included one high-value door ($+55$ or $+95$) and one low-value door ($+5$ or $+45$). The outcomes for the *risky neighbor* doors differed for the two groups: In group nearby, the *risky neighbor* high-value door led to $+56$ or $+94$ (i.e., one away from the extreme), and the *risky neighbor* low-value door led to $+6$ or $+44$; in group remote, these doors led to different high-value outcomes ($+74$ or $+76$) and low-value outcomes ($+24$ or $+26$). In this experiment, all high-value doors had an expected value of $+75$, and all low-value doors had an expected value of $+25$.

Table 2
List of Options and Possible Outcomes for the Two Groups in Experiment 2

Outcome	Group nearby	Group remote
Experiment 2a		
Fixed gain	+45	+45
Risky extreme gain	+15 or +75	+15 or +75
Risky neighbor gain	+16 or +74	+44 or +46
Fixed loss	−45	−45
Risky extreme loss	−15 or −75	−15 or −75
Risky neighbor loss	−16 or −74	−44 or −46
Experiment 2b		
Fixed high value	+75	+75
Risky extreme high value	+55 or +95	+55 or +95
Risky neighbor high value	+56 or +94	+74 or +76
Fixed low value	+25	+25
Risky extreme low value	+5 or +45	+5 or +45
Risky neighbor low value	+6 or +44	+24 or +26

Note. All risky options have a 50/50 chance of either outcome.

In both Experiments 2a and 2b, the choice task consisted of five blocks of 66 trials, each consisting of 12 single-door trials, 18 catch trials, and 36 decision trials. All decision trials involved choices between options that provided the same expected value: in each block, 12 choices were between an extreme door and a fixed door, 12 were between a neighbor door and a fixed door, and 12 were between an extreme door and a neighbor door. In both experiments, one participant in group nearby and two participants in group remote were excluded based on catch-trial performance ($<60\%$ reward-maximizing choices).

Analyses

Risky choice. The primary dependent measures were the percent risky choice for gain and loss options (Experiment 2a) or the high-value and low-value options (Experiment 2b) averaged over the last three blocks. Risky choice was defined as selecting the risky option when pitted against the fixed outcome of equal expected value. The percent risky choice was calculated for both the risky extreme doors and for the risky neighbor doors. As per the preregistration and as detailed above, three main hypotheses were tested for the risky-choice results:

Extreme-Outcome-Reliability Hypothesis. Group remote will show the extreme-outcome effect (more risk seeking for higher valued outcomes) for risky choices involving the extreme outcomes.

We conducted paired one-tailed t tests of the a priori prediction that for extreme risky choices, group remote would show higher risk seeking for gains than for losses (Experiment 2a) and for high-value than low-value choices (Experiment 2b).

Value-Distinctiveness Hypothesis. If the effects of extremity depend on distinctiveness in value from nearby neighbors, then the extreme-outcome effect will be stronger in group remote than group nearby.

Edges Hypothesis. If the effects of extremity are solely defined by the range of values experienced (not distance from neighbors), then the extreme-outcome effect will not be reliably influenced by group.

The latter two hypotheses are opposing predictions, and we tested them with a 2×2 mixed-factor ANOVA on the extreme risky choices, with a within-subjects factor of value (gain or loss in Experiment 2a; high or low in Experiment 2b) and a between-subjects factor of group (nearby and remote).

Finally, we also tested a secondary set of opposing hypotheses[2] regarding the values in group nearby.

Interference Hypothesis. Neither the extremes nor the close neighbors will be treated as extreme outcomes.

Edge-Proximity Hypothesis. Both the extremes and the close neighbors will be treated as extreme outcomes.

We tested the additional predictions from these final two hypotheses about the neighbor doors with an additional 2×2 (Value $\times$ Group) mixed-factor ANOVA on the neighbor risky choices.

Memory tests. The two measures of memory (first outcome reported and frequency judgments) were analyzed separately for the gain and loss risky doors (Experiment 2a) and for the high-value and low-value risky doors (Experiment 2b). For the first outcome reported, only data from those who reported one of the two outcomes associated with the door were included in the

statistical analysis, and the responses were analyzed with a chi-square test. An extreme-outcome effect should yield more reports of the extreme outcome than the nonextreme outcome. For the frequency judgments, data from a participant were excluded for a given door if the summed responses for that door fell outside of 75% to 150%. The frequency judgments were analyzed with t tests. An extreme-outcome effect should yield higher percentage scores for the extreme outcome than for the nonextreme outcome. The three main hypotheses listed above were tested by comparing these memory reports across value and group for the risky extreme doors. The two secondary hypotheses were additionally evaluated by examining the memory reports for the risky neighbor doors. An extreme-outcome effect was observed when the extremes (highest or lowest) were reported more often or judged as more frequent in the memory tests.

Results

Risky choice. Figures 6A and 6B present the mean risky choice in Experiment 2a for each type of risky decision, for group remote and group nearby, respectively. Figures 6C and 6D present these same data for Experiment 2b.

The extreme-outcome effect (more risk seeking for relative gains than for relative losses) was weak in Experiment 2a (gains and losses), but was very strong in Experiment 2b (high- and low-value gains). In group remote of Experiment 2a, the extreme-outcome effect was weak and only marginally significant even with the directional hypothesis, with participants choosing the risky option only 7.1 ± 4.2 (Mean $\pm$ SEM) percentage points more often for gains than for losses, $t(102) = 1.66$, $p = .050$ (one-tailed), Cohen's $d = 0.16$. In group remote of Experiment 2b, there was a very robust extreme-outcome effect for extreme risky choice, with participants choosing the risky option 29.8 ± 4.8 percentage points more often for high-value choices than for low-value choices, $t(61) = 6.23$, $p < .001$, $d = 0.79$. Thus, the *Extreme-Outcome-Reliability Hypothesis* was strongly supported by Experiment 2b, but only weakly supported by Experiment 2a.

As can be seen in Figure 6A and 6B, there were no consistent differences between groups in Experiment 2a. The overall ANOVA on the extreme risky choices in Experiment 2a showed no significant effects (value: $F(1, 200) = 0.68$, $p = .41$, $\eta_p^2 = .003$; group, $F(1, 200) = 0.87$, $p = .35$, $\eta_p^2 = .004$; Value $\times$ Group, $F(1, 200) = 2.27$, $p = .13$, $\eta_p^2 = .011$). Similarly, there were no significant effects for the ANOVA on the neighbor risky choices (value: $F(1, 200) = 0.26$, $p = .61$, $\eta_p^2 = .001$; group, $F(1, 200) = 0.23$, $p = .63$, $\eta_p^2 = .001$; Value $\times$ Group, $F(1, 200) = 0.31$, $p = .581$, $\eta_p^2 = .002$).

Figure 6C and 6D show that there was a very strong extreme-outcome effect for both groups in Experiment 2b, supporting the *Edges Hypothesis* and contrary to the *Value-Distinctiveness Hypothesis.* An ANOVA on the extreme risky choices showed a

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[2] The *Interference* and *Edge-Proximity Hypotheses* were initially presented as sub-Hypotheses in the preregistration. We realized that the logic of our hierarchical hypothesis structure was problematic, however, because the *Edge Proximity Hypothesis* could be true regardless of whether the *Value-Distinctiveness Hypothesis* was true. We therefore present them here as independent secondary hypotheses. The naming scheme for the hypotheses has also been added for clarity.
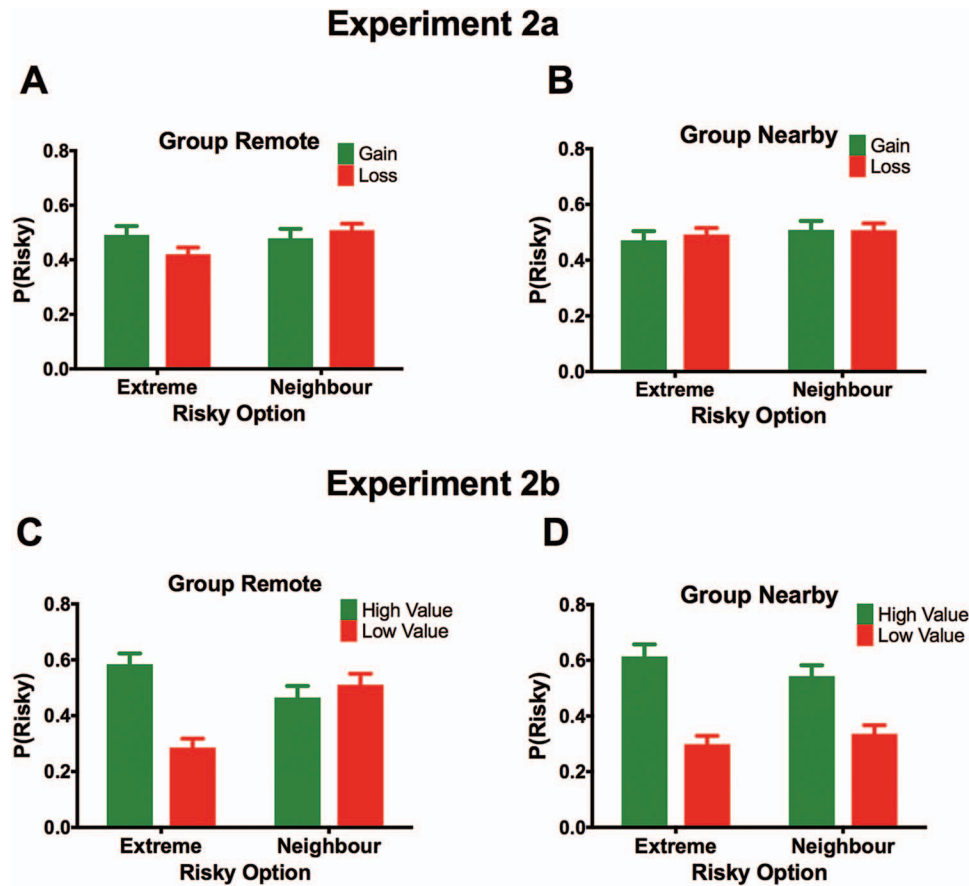
Experiment 2a

Experiment 2b

Figure 6. Proportion of choices of the risky option on decision trials between fixed and risky high-value options (green bars) and between fixed and risky low-value options (red bars) for the choices involving risky extreme doors or risky neighbor doors in: (A) Experiment 2a, Group Remote; (B) Group Nearby; (C) Experiment 2b, Group Remote; and (D) Group Nearby. Error bars are SEM. See the online article for the color version of this figure.

significant main effect of value, $F(1, 124) = 80.84$, $p < .001$, $\eta_p^2 = .40$, but not of group, $F(1, 124) = 0.30$, $p = .59$, $\eta_p^2 = .002$, and no significant interaction between value and group, $F(1, 124) = 0.06$, $p = .81$, $\eta_p^2 = .00$.

In Experiment 2b, the two groups, however, differed in their responses to the risky neighbor doors. Figure 6C and 6D show how, in group nearby, choices for the risky neighbor doors were similar to those for the extreme doors, whereas, in group remote, choices were close to indifferent between both neighbor doors and the fixed outcomes. This pattern is corroborated by a significant main effect in the ANOVA of value, $F(1, 124) = 5.06$, $p = .026$, $\eta_p^2 = .039$, but not of group, $F(1, 124) = 1.48$, $p = .23$, $\eta_p^2 = .012$. In addition, there was a significant interaction between value and group, $F(1, 124) = 12.38$, $p < .001$, $\eta_p^2 = .091$. This interaction reflected a significant extreme-outcome effect for the neighbor risky choices in group nearby (i.e., where the neighbor door outcomes were near the edges of the distribution), $t(63) = 4.25$, $p < .001$, $d = .53$, but not in group remote (where the neighbor doors outcomes were similar to the fixed outcomes), $t(61) = 0.86$, $p = .39$, $d = .11$. These results strongly support the *Edge-*

Proximity Hypothesis and are contrary to the *Interference Hypothesis*.

Memory tests.

Risky extreme doors. Figures 7A and 7B show the percentages of participants who reported the "first outcome to come to mind" for the risky extreme doors in Experiment 2a. For group remote, significantly more participants reported the extreme outcome than the nonextreme outcome for both the gain door: $\chi^2(1, N = 76) = 5.26$, $p = .022$, and the loss door: $\chi^2(1, N = 78) = 18.51$, $p = <.0001$. Participants in group nearby were also significantly more likely to report the extreme outcome than the nonextreme outcome for the gain door, $\chi^2(1, N = 58) = 5.59$, $p = .018$, but only had a trend toward reporting the extreme outcome more than the nonextreme outcome for the loss door $\chi^2(1, N = 50) = 2.88$, $p = .090$. Figures 7C and 7D show the judged frequency of each outcome for the extreme risky doors in Experiment 2a. Neither group showed a significant difference in the judged frequencies of the two outcomes that followed the risky extreme gain doors (group remote: mean difference $-7.3 \pm 3.9\%$, $t(97) = 1.89$, $p = .062$, $d = 0.19$; group nearby: mean difference
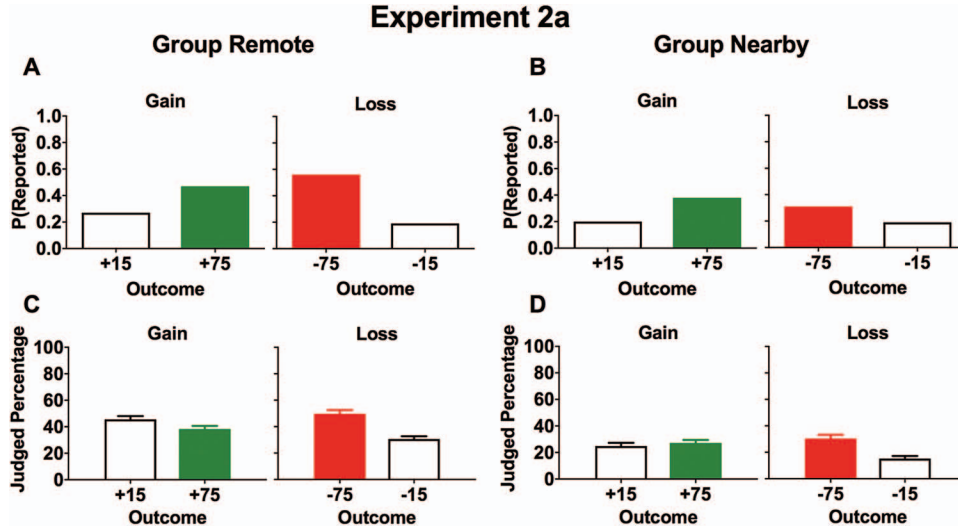
Figure 7. Results from self-report memory tests with the risky extreme doors in Experiment 2a. (A, B) The proportion of participants in each group who reported the extreme (filled red or green bars) and nonextreme values (white bars) as the "first outcome that came to mind" for each risky door (C, D). The judged percentages for each risky door's outcome (± SEM). Note that the totals do not sum to 1 (top row) or 100 (bottom row) because participants also reported and assigned percentage to other outcomes. See the online article for the color version of this figure.

$1.6 \pm 3.4\%$, $t(88) = 0.64$, $p = .53$, $d = 0.067$). For the risky extreme loss door, however, both groups reliably reported the extreme outcome as having occurred more often than the nonextreme outcome (group remote, mean difference $19.1 \pm 4.0\%$, $t(92) = 4.84$, $p < .001$, $d = 0.50$; group nearby, mean difference $15.2 \pm 3.6\%$, $t(83) = 4.20$, $p < .001$, $d = 0.46$).

Figures 8A and 8B show the percentages of participants who reported the "first outcome to come to mind" for the extreme risky

doors in Experiment 2b. Participants in both groups were significantly more likely than chance to report the extreme outcomes for both the high- and low-value doors (group remote: high value $\chi^2(1, N = 45) = 24.2$, $p < .0001$, low value, $\chi^2(1, N = 50) = 25.9$, $p < .0001$; group nearby: high value, $\chi^2(1, N = 45) = 18.7$, $p < .0001$, low value, $\chi^2(1, N = 26) = 7.54$, $p = .006$), and the relative proportions in both groups were not reliably different from each other (high value: $\chi^2(1, N = 90) = 0.38$, $p = .56$; low value: $\chi^2(1,$
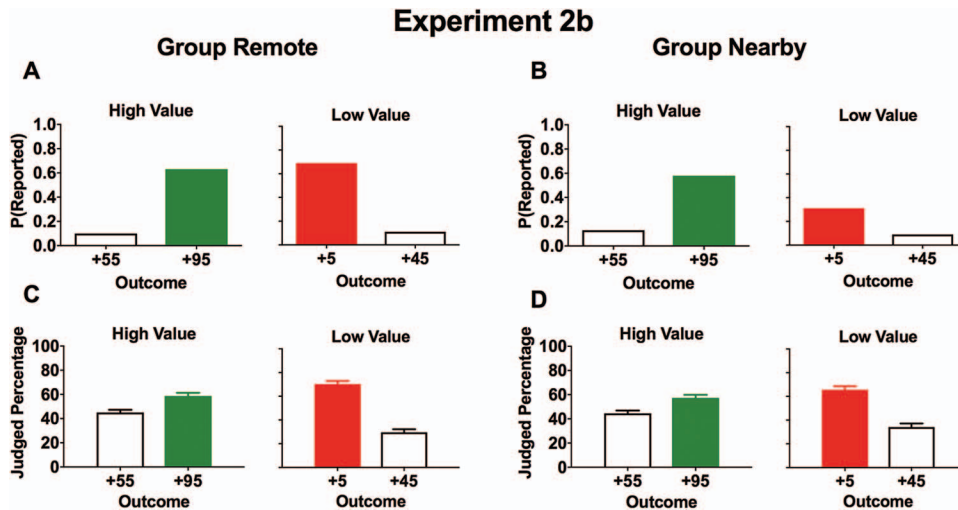

Figure 8. Results from self-report memory tests with the risky extreme doors in Experiment 2b. (A, B) The proportion of participants in each group who reported the extreme (filled red or green bars) and nonextreme values (white bars) as the "first outcome that came to mind" for each risky door. Note that the totals do not sum to 1 (top row) because participants also reported other outcomes (C, D). The judged percentages for each risky door's outcome (± SEM). See the online article for the color version of this figure.

$N = 76) = 0.99$, $p = .32$). Figures 8C and 8D show the judged frequency of each outcome for the extreme risky doors for Experiment 2b. Participants reported that the extreme outcome occurred more often in all cases (group remote: high-value, mean difference $= 13.8 \pm 4.7\%$, $t(57) = 2.93$, $p = .005$, $d = 0.38$; low-value, mean difference $= 40.6 \pm 5.3\%$, $t(54) = 7.64$, $p < .001$, $d = 1.03$; group nearby: high-value, mean difference $= 12.9 \pm 4.8\%$, $t(62) = 2.70$, $p = .009$, $d = 0.34$; low-value, mean difference $= 31.4 \pm 6.1\%$, $t(55) = 5.17$, $p < .001$, $d = 0.69$).

Thus, although the two outcomes occurred with equal probability, people's subjective reports in both experiments indicated that the extreme low outcome occurred substantially more often than the nonextreme low outcome. In Experiment 2b, people additionally reported that the extreme high outcome occurred more often than the nonextreme high outcome. This pattern strongly supports the *Extreme-Outcome-Reliability Hypothesis*. In addition, the overweighting of extremes in memory in most instances in group nearby is consistent with the *Edge hypothesis* and inconsistent with the *Distinctiveness hypothesis*.

Risky neighbor doors. Figure 9A and 9B display the first outcome reported for the risky neighbor doors in Experiment 2b (see Fig. S2 for Experiment 2a). In group remote, no outcome was reliably reported more often for either risky neighbor door, though there was a trend toward reporting the lower outcome for the low-value door (low value: $\chi^2(1, N = 30) = 3.33$, $p = .068$; high value: $\chi^2(1, N = 29) = 0.03$, $p = .85$). In group nearby, the outcome $(+6)$ one away from the low extreme was reported more often, $\chi^2(1, N = 38) = 6.73$, $p = .009$, and there was also a trend toward reporting the outcome $(+94)$ one away from the high extreme, $\chi^2(1, N = 23) = 3.52$, $p = .061$. Note that the sample sizes here are all very small because, for each door, many participants reported values that never occurred with that door (see online supplemental materials and Fig. S5 for a detailed breakdown of these errors).

Figures 9C and 9D show the frequency judgments for the risky neighbor doors for groups remote and nearby, respectively. In group remote, for the high-value door, participants judged the lower outcome $(+74)$ as 10.6 ± 3.8 (Mean $\pm$ SEM) percentage points more frequent than the higher outcome $(+76)$, $t(57) = 2.76$, $p = .008$, $d = 0.36$; for the low-value door, participants also judged the lower outcome $(+24)$ as 7.5 ± 4.3 percentage points more frequent than the higher outcome $(+26)$, though this latter difference was not statistically reliable, $t(55) = 1.77$, $p = .08$, $d = 0.23$. This overweighting of the lower outcome in memory is consistent with previous results where none of the outcomes were extreme (Ludvig et al., 2015). In group nearby, for the low-value outcome, participants judged the outcome that was one away from the low extreme $(+6)$ as 33.0 ± 6.2 percentage points more frequent than the other possible outcome $(+44)$ for that door, $t(57) = 5.32$, $p < .001$, $d = 0.70$, but there was no significant difference $(1.1 \pm 3.9\%)$ in the judged frequencies for the high-value outcomes $(+56/+94)$, $t(62) = 0.27$, $p > .5$, $d = 0.03$. The general trend toward the overweighting of the near-extreme outcome is consistent with the *Edge-Proximity hypothesis*, whereby outcomes near the edge of the distribution are all overweighted, and inconsistent with the *Interference hypothesis*.

Discussion

The results of Experiment 2b clearly indicate that outcomes at the edges of the experienced distribution are overweighted in both memory and choice, even if they are very close to another neighboring outcome. Thus, outcomes appear to be treated as extreme by virtue of their end position and not solely because of their distinctiveness based on distance to other outcomes (e.g., Brown et al., 2007).

Another interesting finding in Experiment 2b was that the neighboring outcomes in group nearby were also overweighted in both
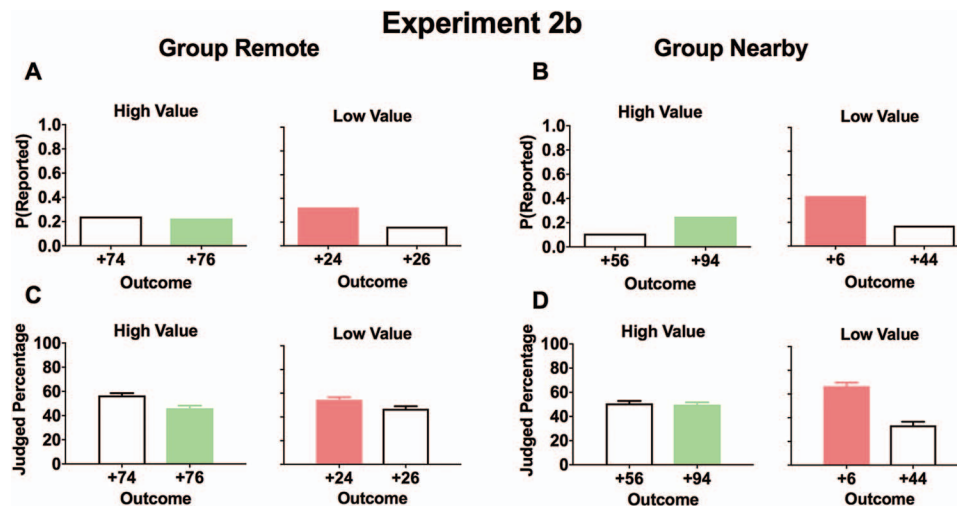

Figure 9. Results from self-report memory tests with the risky neighbor doors in Experiment 2b. (A, B) The proportion of participants in each group who reported the more extreme (light red or green bars) and nonextreme values (white bars) as the "first outcome that came to mind" for each risky door. Note that the totals do not sum to 1 (top row) because participants also reported other outcomes (C, D). The judged percentages for each risky door's outcome ($\pm$SEM). See the online article for the color version of this figure.

risky choice and memory (see Figure 6D and Figure 9). This finding suggests that an outcome does not need to be at the exact edge of the distribution to be overweighted, but rather may only need to be near the edge. A detailed examination of the results from the memory tests indicated that some participants may have failed to discriminate between the extreme outcome and the adjacent neighboring outcome; nevertheless, as reported in the online supplementary materials, there was no significant correlation between the degree of confusion and risky choice. Although further research is needed to clarify exactly how close to the edge of a distribution an outcome needs to be for overweighting, these results clearly indicate that close proximity to a neighboring value does not prevent the outcomes at the ends from being overweighted. These results indicate that distinctiveness based on separation from other values in the distribution (e.g., Brown et al., 2007; Neath et al., 2006) is not a necessary factor for the overweighting of extreme outcomes in experience-based risky choice.

One incidental finding in these experiments was a striking difference between the two experiments in the size of the extreme-outcome effect: specifically, the effect was weak in Experiment 2a (gains and losses) but extremely robust in Experiment 2b (high- and low-value gains). Although past research has shown reliable extreme-outcome effects with sets consisting of gains and losses (Ludvig & Spetch, 2011; Ludvig et al., 2014b; Madan et al., 2014, 2017), the effect seems to be larger when the decision set includes all gains or all losses. In the former instance, attending to category information (i.e., gain or loss) may overshadow learning of the specific outcomes. Overshadowing by category information might have been particularly pronounced in this experiment because of the larger set of outcome values to learn (i.e., five gains and five losses) compared with our past studies, which typically had only three outcomes per category (e.g., Ludvig & Spetch, 2011). Future work will follow up on this incidental finding.

General Discussion

Together these experiments show that outcomes at or near the edges of a distribution are overweighted in memory and choice. The first two experiments extend previous evidence that overweighting of extremes occurs with sets consisting of all gains or all losses, and they rule out the possibility that differences in frequency are responsible for the overweighting of these outcomes. The second two experiments addressed the question of whether extreme outcomes are overweighted because of their placement at the ends of the distribution or because of their distance from other neighboring values (e.g., Brown et al., 2007). Although Experiment 2a produced equivocal results, Experiment 2b showed very strong extreme-outcome effects for values at the edges of the distributions, even when those outcomes had directly adjacent neighboring values. These results indicate that the extreme-outcome effect does not depend on the distinctiveness of the values and are consistent with other findings, which also suggest that edge values are particularly salient (e.g., Moon et al., 2015; Tsetsos et al., 2012). Interestingly, group nearby in Experiment 2a showed overweighting in memory and in risky choice both for the extreme risky outcomes and for the directly adjacent neighboring outcomes. Thus, outcomes that are near the edges of a distribution can also function as extreme values, suggesting perhaps that the psychological representation of the edges is fuzzy (e.g., Reyna, 2012).

On the surface, these results contradict other findings from the memory literature, which suggest that memory strength depends on stimulus distinctiveness, due to the psychological proximity of other possible target items (Brown et al., 2007; Neath et al., 2006). In particular, the SIMPLE model of memory proposes that the distinctiveness of an item, and as a result memorability, is a function of proximity to its nearest neighbors. In this experiment, this supposition only held to a limited degree. Inserting immediately nearby items in Experiment 2b (e.g., +94 to +95) did not eliminate the overweighting of the extreme outcomes in memory or choice. With the nearby neighbors, however, there was an apparent reduction in the overall frequency of reporting a correct outcome for the extreme doors in the first-outcome memory metrics (see Figures 7–8), though the extremes were still reported more often than nonextremes.

One major difference here from standard memory protocols is that the main task was a choice task, whereby distinctions between nearby outcomes were unnecessary or potentially even detrimental to effective performance. This choice procedure may thus have even encouraged the chunking of the very-nearby items into a single psychological unit (e.g., Miller, 1956), especially given the sheer number of outcomes (10) in Experiment 2. For example, in Experiment 2B, perhaps +95 and +94 were treated as an extreme chunk and +55 and +56 were treated as an intermediate chunk. According to this view, these extreme chunks are what stood out, rather than the individual outcomes, because they have fewer neighboring chunks than the intermediate chunks. As a result, both extremes and their nearby neighbors became overweighted in choice and memory (Figure 6 and Figure 9). This alternate interpretation would seem to rescue the distance-based distinctiveness hypothesis by redefining what counts as the relevant distance. One challenge for such an interpretation would be to specify exactly when neighboring items would form chunks as opposed to act as individual items. Moreover, our analysis of the errors on the first-outcome memory tests in Experiment 2B indicated that, even people who made no confusion errors (i.e., swapping an extreme for a neighbor or vice versa) still showed a strong overweighting of the extremes. Presumably, these people kept the individual items separate in memory, yet they still overweighted the extremes and their neighbors.

These results have implications for theories of choice, especially those that rely on sampling outcomes from memory (e.g., Ratcliff & Smith, 2004; Shohamy & Daw, 2015; Stewart et al., 2006; Weber & Johnson, 2006). Here, memories for past outcomes are systematically biased such that the most extreme outcomes (and their nearby neighbors) are both better remembered and overweighted in choice (see Figures 6, 8, and 9). When modeling decisions based on past experience, sampling models would likely need to include a similar type of bias. Not all outcomes are equally likely to be retrieved and accumulated as evidence toward making a decision. There would seem to be a function relating proximity to the edge of the distribution to recall probability and choice weighting, though, at the moment the exact form of the function is underconstrained.

The present study adds to the literature from other domains, such as perception, learning, and memory, indicating that outcomes at the end of a range can have a privileged status (e.g., Castel et al., 2016; Jou, 1997, 2011; Kahneman et al., 1993; Lacouture, 1997; Moon et al., 2015). Why might this be the case?

One possibility is that the edges of a distribution (whether based on time, space, or value) provide the boundary conditions for an experience. In these experiments, the extremes define for the participant how much money they could possibly stand to win or lose on any given trial. More generally, attending to the ranges or boundaries that define an experience may have general ecological relevance across many situations. For example, foraging animals would be well served to know the range of possible outcomes that a food patch might return, tracking both the best and worst returns. Such a memory for the range of outcomes could allow the adaptive coding of values, something observed in humans (e.g., Khaw, Glimcher, & Louie, 2017) and even encoded in the reward prediction errors reported by the dopamine system (Tobler, Fiorillo, & Schultz, 2005).

Our results provide strong support for the extreme-outcome rule, which suggests that when people make experience-based risky choices, they are more likely to remember outcomes at the edges of the experienced distribution (Ludvig et al., 2014b). The results also suggest a refinement to this rule, whereby proximity to the edge suffices for the overweighting in choice and memory. This memory bias leads people to be relatively more risk seeking for high-value choices (where the risky choice could lead to a good extreme) than for low-value choices (where the risky choice could lead to a bad extreme). This pattern of choice could have implications for real-world situations in which people make experience-based risky choices, such as in casino gambling. In such situations, people typically experience a mixture of big wins and small losses, and thus the saliency of the extremes in memory and choice might increase the likelihood of future gambling. Numerous interesting questions remain, however, about what constitutes the decision context, how stable such memory biases are, what other memory factors influence risky choice, and how this extreme-outcome bias interacts with the tendency to underweight rare events in experience-based choice (e.g., Hertwig et al., 2004).

Context Paragraph

The experiments reported here are part of a program of research to resolve how humans and other animals make risky choices when they learn about the odds and outcomes from experience. The notion that the overweighting of extreme outcomes may drive risky choice was originally proposed by Ludvig and Spetch (2011) and expanded in later articles (Ludvig et al., 2014b; Madan et al., 2014). Inspired by the peak-end effect (Kahneman et al., 1993) and consistent with findings by Madan and Spetch (2012), we hypothesized that values at the extremities of a distribution were more salient and better remembered. This article presents research that supports this hypothesis, and it specifically tests opposing predictions from two hypotheses that could explain the previous extreme-outcome effects: (a) that the ends of the distribution are more salient, and (b) that items that are distinct from other values are more salient.

References

Barron, G., & Erev, I. (2003). Small feedback-based decisions and their limited correspondence to description-based decisions. *Journal of Behavioral Decision Making, 16,* 215–233. http://dx.doi.org/10.1002/bdm .443

Bornstein, A. M., & Norman, K. A. (2017). Reinstated episodic context guides sampling-based decisions for reward. *Nature Neuroscience, 20,* 997–1003. http://dx.doi.org/10.1038/nn.4573

Braida, L. D., & Durlach, N. I. (1972). Intensity perception. II. Resolution in one-interval paradigms. *The Journal of the Acoustical Society of America, 51,* 483–502. http://dx.doi.org/10.1121/1.1912868

Brown, G. D., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review, 114,* 539–576. http://dx.doi.org/10 .1037/0033-295X.114.3.539

Castel, A. D., Friedman, M. C., McGillivray, S., Flores, C. C., Murayama, K., Kerr, T., & Drolet, A. (2016). I owe you: Age-related similarities and differences in associative memory for gains and losses. *Aging, Neuropsychology and Cognition, 23,* 549–565. http://dx.doi.org/10.1080/ 13825585.2015.1130214

Denrell, J., & March, J. G. (2001). Adaptation as information restriction: The hot stove effect. *Organization Science, 12,* 523–538. http://dx.doi .org/10.1287/orsc.12.5.523.10092

Fredrickson, B. L. (2000). Extracting meaning from past affective experiences: The importance of peaks, ends, and specific emotions. *Cognition and Emotion, 14,* 577–606. http://dx.doi.org/10.1080/026999300402808

Glöckner, A., Hilbig, B. E., Henninger, F., & Fiedler, S. (2016). The reversed description-experience gap: Disentangling sources of presentation format effects in risky choice. *Journal of Experimental Psychology: General, 145,* 486–508. http://dx.doi.org/10.1037/a0040103

Heilbronner, S. R., & Hayden, B. Y. (2013). Contextual factors explain risk-seeking preferences in rhesus monkeys. *Frontiers in Neuroscience, 7,* 7. http://dx.doi.org/10.3389/fnins.2013.00007

Heilbronner, S. R., & Hayden, B. Y. (2016). The description-experience gap in risky choice in nonhuman primates. *Psychonomic Bulletin & Review, 23,* 593–600. http://dx.doi.org/10.3758/s13423-015-0924-2

Hertwig, R., Barron, G., Weber, E. U., & Erev, I. (2004). Decisions from experience and the effect of rare events in risky choice. *Psychological Science, 15,* 534–539. http://dx.doi.org/10.1111/j.0956-7976.2004.00715.x

Hertwig, R., & Erev, I. (2009). The description-experience gap in risky choice. *Trends in Cognitive Sciences, 13,* 517–523. http://dx.doi.org/10 .1016/j.tics.2009.09.004

Hsee, C. K. (1996). The evaluability hypothesis: An explanation for preference reversals between joint and separate evaluations of alternatives. *Organizational Behavior and Human Decision Processes, 67,* 247–257. http://dx.doi.org/10.1006/obhd.1996.0077

Hunt, R. R., & Worthen, J. B. (2006). *Distinctiveness and memory.* Oxford, UK: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/ 9780195169669.001.0001

Jou, J. (1997). Why is the alphabetically middle letter in a multiletter array so hard to determine? Memory processes in linear-order information processing. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1743–1763. http://dx.doi.org/10.1037/0096-1523 .23.6.1743

Jou, J. (2011). Two paradigms of measuring serial-order memory: Two different patterns of serial-position functions. *Psychological Research, 75,* 202–213. http://dx.doi.org/10.1007/s00426-010-0297-0

Kahneman, D., Fredrickson, B. L., Schreiber, C. A., & Redelmeier, D. A. (1993). When more pain is preferred to less: Adding a better end. *Psychological Science, 4,* 401–405. http://dx.doi.org/10.1111/j.1467- 9280.1993.tb00589.x

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47,* 263–292. http://dx.doi.org/10 .2307/1914185

Kellen, D., Pachur, T., & Hertwig, R. (2016). How (in)variant are subjective representations of described and experienced risk and rewards? *Cognition, 157,* 126–138. http://dx.doi.org/10.1016/j.cognition.2016.08.020

Khaw, M. W., Glimcher, P. W., & Louie, K. (2017). Normalized value coding explains dynamic adaptation in the human valuation process. *Proceedings of the National Academy of Sciences of the United States*

of America, 114, 12696–12701. http://dx.doi.org/10.1073/pnas.1715293114

Konstantinidis, E., Taylor, R. T., & Newell, B. R. (2017). Magnitude and incentives: Revisiting the overweighting of extreme events in risky decisions from experience. *Psychonomic Bulletin & Review.* Advance online publication. http://dx.doi.org/10.3758/s13423-017-1383-8

Kunar, M. A., Watson, D. G., Tsetsos, K., & Chater, N. (2017). The influence of attention on value integration. *Attention, Perception & Psychophysics, 79,* 1615–1627. http://dx.doi.org/10.3758/s13414-017-1340-7

Lacouture, Y. (1997). Bow, range, and sequential effects in absolute identification: A response-time analysis. *Psychological Research, 60,* 121–133. http://dx.doi.org/10.1007/BF00419760

Lakshminarayanan, V. R., Chen, M. K., & Santos, L. R. (2011). The evolution of decision-making under risk: Framing effects in monkey risk preferences. *Journal of Experimental Social Psychology, 47,* 689–693. http://dx.doi.org/10.1016/j.jesp.2010.12.011

Lim, R. G. (1995). A range-frequency explanation of shifting reference points in risky decision making. *Organizational Behavior and Human Decision Processes, 63,* 6–20. http://dx.doi.org/10.1006/obhd.1995.1057

Ludvig, E. A., Madan, C. R., Pisklak, J. M., & Spetch, M. L. (2014a). Reward context determines risky choice in pigeons and humans. *Biology Letters, 10,* 20140451. http://dx.doi.org/10.1098/rsbl.2014.0451

Ludvig, E. A., Madan, C. R., & Spetch, M. L. (2014b). Extreme outcomes sway risky decisions from experience. *Journal of Behavioral Decision Making, 27,* 146–156. http://dx.doi.org/10.1002/bdm.1792

Ludvig, E. A., Madan, C. R., & Spetch, M. L. (2015). Priming memories of past wins induces risk seeking. *Journal of Experimental Psychology: General, 144,* 24–29. http://dx.doi.org/10.1037/xge0000046

Ludvig, E. A., & Spetch, M. L. (2011). Of black swans and tossed coins: Is the description-experience gap in risky choice limited to rare events? *PLoS ONE, 6,* e20262. http://dx.doi.org/10.1371/journal.pone.0020262

Madan, C. R., Ludvig, E. A., & Spetch, M. L. (2014). Remembering the best and worst of times: Memories for extreme outcomes bias risky decisions. *Psychonomic Bulletin & Review, 21,* 629–636. http://dx.doi.org/10.3758/s13423-013-0542-9

Madan, C. R., Ludvig, E. A., & Spetch, M. L. (2017). The role of memory in distinguishing risky decisions from experience and description. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 70,* 2048–2059. http://dx.doi.org/10.1080/17470218.2016.1220608

Madan, C. R., & Spetch, M. L. (2012). Is the enhancement of memory due to reward driven by value or salience? *Acta Psychologica, 139,* 343–349. http://dx.doi.org/10.1016/j.actpsy.2011.12.010

Marsh, B., & Kacelnik, A. (2002). Framing effects and risky decisions in starlings. *Proceedings of the National Academy of Sciences of the United States of America, 99,* 3352–3355. http://dx.doi.org/10.1073/pnas.042491999

Miller, G. A. (1956). The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81–97. http://dx.doi.org/10.1037/h0043158

Moon, J. A., Fincham, J. M., Betts, S., & Anderson, J. R. (2015). End effects and cross-dimensional interference in identification of time and length: Evidence for a common memory mechanism. *Cognitive, Affective & Behavioral Neuroscience, 15,* 680–695. http://dx.doi.org/10.3758/s13415-015-0348-5

Murdock, B. B., Jr. (1962). The serial position effect of free recall. *Journal of Experimental Psychology, 64,* 482–488. http://dx.doi.org/10.1037/h0045106

Murty, V. P., FeldmanHall, O., Hunter, L. E., Phelps, E. A., & Davachi, L. (2016). Episodic memories predict adaptive value-based decision-making. *Journal of Experimental Psychology: General, 145,* 548–558. http://dx.doi.org/10.1037/xge0000158

Neath, I., Brown, G. D., McCormack, T., Chater, N., & Freeman, R. (2006). Distinctiveness models of memory and absolute identification: Evidence for local, not global, effects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 59,* 121–135. http://dx.doi.org/10.1080/17470210500162086

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2015). How does the hippocampus shape decisions? *Neurobiology of Learning and Memory, 125,* 93–97. http://dx.doi.org/10.1016/j.nlm.2015.08.005

Parducci, A. (1965). Category judgment: A range-frequency model. *Psychological Review, 72,* 407–418. http://dx.doi.org/10.1037/h0022602

Ratcliff, R., & Smith, P. L. (2004). A comparison of sequential sampling models for two-choice reaction time. *Psychological Review, 111,* 333–367. http://dx.doi.org/10.1037/0033-295X.111.2.333

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

Shohamy, D., & Daw, N. D. (2015). Integrating memories to guide decisions. *Current Opinion in Behavioral Sciences, 5,* 85–90. http://dx.doi.org/10.1016/j.cobeha.2015.08.010

Simonson, I., & Tversky, A. (1992). Choice in context: Tradeoff contrast and extremeness aversion. *Journal of Marketing Research, 29,* 281–295. http://dx.doi.org/10.2307/3172740

Stewart, N. (2009). Decision by sampling: The role of the decision environment in risky choice. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 62,* 1041–1062. http://dx.doi.org/10.1080/17470210902747112

Stewart, N., Chater, N., & Brown, G. D. A. (2006). Decision by sampling. *Cognitive Psychology, 53,* 1–26. http://dx.doi.org/10.1016/j.cogpsych.2005.10.003

Stewart, N., Reimers, S., & Harris, A. J. (2014). On the origin of utility, weighting, and discounting functions: How they get their shapes and how to change their shapes. *Management Science, 61,* 687–705. http://dx.doi.org/10.1287/mnsc.2013.1853

Suter, R. S., Pachur, T., & Hertwig, R. (2016). How affect shapes risky choice: Distorted probability weighting versus probability neglect. *Journal of Behavioral Decision Making, 29,* 437–449. http://dx.doi.org/10.1002/bdm.1888

Tobler, P. N., Fiorillo, C. D., & Schultz, W. (2005). Adaptive coding of reward value by dopamine neurons. *Science, 307,* 1642–1645. http://dx.doi.org/10.1126/science.1105370

Tsetsos, K., Chater, N., & Usher, M. (2012). Salience driven value integration explains decision biases and preference reversal. *Proceedings of the National Academy of Sciences of the United States of America, 109,* 9659–9664. http://dx.doi.org/10.1073/pnas.1119569109

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

Tversky, A., & Simonson, I. (1993). Context-dependent preferences. *Management Science, 39,* 1179–1189. http://dx.doi.org/10.1287/mnsc.39.10.1179

Weber, E. U., & Johnson, E. J. (2006). Constructing preferences from memories. In S. Lichtenstein & P. Slovic (Eds.), *The construction of preference* (pp. 397–410). New York, NY: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511618031.022

Wimmer, G. E., & Shohamy, D. (2012). Preference by association: How memory mechanisms in the hippocampus bias decisions. *Science, 338,* 270–273. http://dx.doi.org/10.1126/science.1223252

Wulff, D. U., Mergenthaler-Canseco, M., & Hertwig, R. (2018). A meta-analytic review of two modes of learning and the description-experience gap. *Psychological Bulletin, 144,* 140–176. http://dx.doi.org/10.1037/bul0000115