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# Reaching reveals that best-versus-rest processing contributes to biased decision making

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ABSTRACT

The study of human decision making has revealed many contexts in which decisions are systematically biased. These biases are particularly evident in risky decisions, characterized by choice outcomes that are probabilistic. One recently explored bias is the extreme-outcome rule: the tendency for participants to overvalue both the best and worst outcome when they learn about choice probabilities through trial and error (aka experience). Here we aimed to test whether the extreme-outcome rule arises in part from a disproportionate subjective weight on extreme values. Participants reached to choose between two options in a riskless task where each choice option always produced the same result. In contrast to the idea that the overvaluing of extreme outcomes results from participants overestimating the underlying choice probabilities (e.g. treating a 50% "worst" outcome as though it occurred 60% of the time), we find overvaluation of extreme outcomes even when they are not probabilistic. Particularly, we find strong evidence for overvaluation of the best outcome relative to all other outcomes in *how* participants enact their decision (reaction times and reaching movements), but no evidence for such overvaluation in participants' choice accuracy. Compared to the extreme-outcome rule, these results are more simply characterized in a framework where the "best" option is given a boost in processing relative to the "rest" of other available options.

## 1. Introduction

In decisions from experience, people tend to overweight extreme outcomes (Ludvig, Madan, & Spetch, 2014; Madan, Ludvig, & Spetch, 2014). That is, when learning about the possible outcomes of decisions by experiencing them over multiple choices, they seem to put added weight on the best and worst outcomes they have experienced. This "extreme-outcome rule" drives choice behavior toward options where the best outcome has been experienced, and away from options associated with the worst experienced outcome, more than is to be expected from traditional economic models (Ludvig et al., 2014; Madan et al., 2014). The extreme-outcome bias additionally manifests itself in better memory for these extreme outcomes (e.g., Madan, Fujiwara, Gerson, & Caplan, 2012; Madan & Spetch, 2012; Madan et al., 2014). Overall, a growing body of research suggests that people are disproportionally drawn toward the best option and away from the worst option relative to more intermediate alternatives.

This overvaluing of extreme outcomes has also been seen in recent investigations of how people integrate dynamically streaming information during the decision-making process (Tsetsos, Chater, & Usher, 2012). In these experiments, numbers at two spatial locations are presented rapidly before participants are asked to make a decision, which involves monitoring decision information as it evolves throughout a trial. People overweight the extreme outcomes observed (e.g., a high number in a stream of numbers) and their decisions (identifying which stream has the higher numerical average) are biased toward the information stream with the highest individual exemplars. However, in both risky decisions where all decision information is presented at once (Ludvig et al., 2014; Madan et al., 2014), and dynamic integration decisions (Tsetsos et al., 2012), it is unclear exactly what aspect of an extreme outcome is being overvalued. Specifically, in both cases, the expected value of any individual option is a conjunction of its actual value (outcome) and the likelihood of receiving that value (probability) – two components of value that we have shown are separable and weighted differently by each individual (Chapman, Gallivan, & Enns, 2015). To take a prototypical risky decision example, the expected value of an option that gives 20 points 100% of the time is the same as the expected value of an option that gives 40 points 50% of the time

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and 0 points 50% of the time. Here, the bias toward an extreme outcome (e.g., 40 points 50% of the time) plays out in a disproportionate number of choices for the 50/50 (e.g. risky) option. What is unclear is whether the "50% of 40 points" extreme outcome is overvalued because participants experience its actual value as somehow higher than 40 points, or, because participants experience its actual probability as > 50%. In risky decisions from experience, experiments that have asked participants to report both the first-to-mind value and their experienced probabilities find it is more likely that the probability is being overestimated (Madan et al., 2014).

Here we aimed to test whether the extreme-outcome bias observed in risky decision making from experience would continue to persist in riskless decision making. That is, we tested participants in a decision from experience task where every option always produced its associated outcome. In these circumstances, expected value is equivalent to outcome value (i.e., there are no probabilities to consider). To accomplish our experimental objective, we had two groups of participants make repeated decisions between two choice options (outlined shapes), providing feedback each trial such that they would learn through experience the value of each option. Critically, the six choice options were presented in pairs such that the value difference between options in every pair was identical (5 cents, see Fig. 1). On the surface, this task therefore appears almost trivial – within each pair, one option always dominates the other option since it has the higher value. In fact, most previous experiments (Brown et al., 2013; De Martino, Kumaran, Seymour, & Dolan, 2006; Ludvig et al., 2014; Madan et al., 2014; Shenhav & Greene, 2010) use these types of unequal value trials as catch trials, with the underlying assumption being that participants who cannot detect the better option (e.g., choose the low-value option > 40% of the time) are not performing the task correctly. But implicit in this assumption are two important aspects. First, this assumes that because outcome value does not fluctuate on a trial-to-trial basis like outcome probability, outcome value is not nearly as susceptible to biases like the extreme-outcome bias. For example, knowing the probability of receiving 40 points requires interpolating outcomes across multiple trials in the past. In contrast to outcome probability, receiving a 40-point outcome value every winning trial is explicitly visible, and may therefore account for less variability in decision making. Second, relying on "trivial" decisions (e.g., 100% of 5 points vs 100% of 10 points) as a screening measure in part assumes that choice percentages are sufficient to measure decision biases. As we have outlined, we are theoretically motivated to test whether the extreme-outcome bias is in part due to exaggerating the size of the extreme value, or solely due to exaggerating the frequency of occurrence of the extreme value. In addition, we aim to add to a large literature showing that the dynamics of behavior leading up to a decision can reveal important aspects about decision biases, such as the extreme-outcome bias.

Specifically, regarding choice percentages, it is quite possible that all the information about the decision is not captured by the end result (e.g., what the person chooses). Rather, decision making is most often conceptualized as a dynamic process whereby choice options compete for selection until one eventually wins out (Chapman et al., 2010; Cisek & Kalaska, 2010; Gold & Shadlen, 2007; Ratcliff & Rouder, 1998; Spivey & Dale, 2006; Vickers, 1970). That is, even if the same option is ultimately selected, how a person arrives at that decision may be totally different. The most common tool used to assess these differences is reaction time, where more difficult choices take longer in time. Recently, however, another tool has emerged showing even greater sensitivity to choice demands. We, and others, have shown the unique power of analyzing how the hand (or a hand-proxy like a mouse or pointer) moves to select a target to indicate decision processes (Chapman, Gallivan, & Enns, 2015; Chapman, Gallivan, Wong et al., 2015; Chapman et al., 2010; Freeman, Dale, & Farmer, 2011; Gallivan et al., 2011; McKinstry, Dale, & Spivey, 2008; Resulaj, Kiani, Wolpert, & Shadlen, 2009; Song & Nakayama, 2009) with more difficult choices leading to slower, and more curved trajectories. In one study, trajectories curved more toward an incorrect option under conditions of increased conflict, even when the correct option was ultimately chosen (Travers, Rolison, & Feeney, 2016). Therefore, we suggest that even in a simple task like the one tested here, decision biases may be present in choice dynamics (reaction times and reach trajectories) while appearing absent in the choice percentages. In order to assess if exaggeration of value for extreme options is present, we look to reaction time and trajectories to reveal if a choice is disproportionately easy to participants (i.e., if one option is disproportionately preferred relative to its

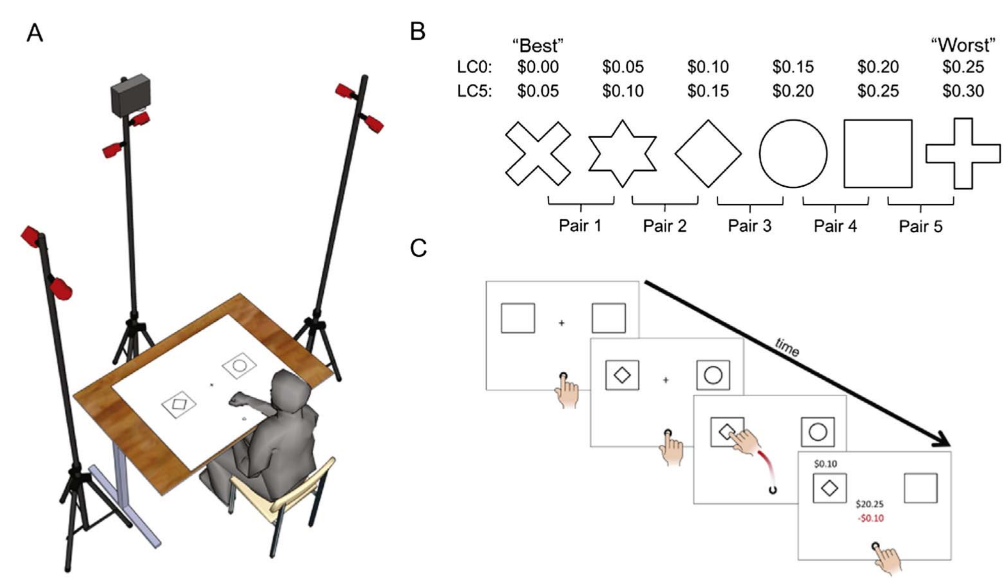


**Fig. 1.** Illustration of the experimental setup, stimuli and trial sequence. A) Participants sat at a table onto which stimuli were projected from overhead. They wore a reflective marker on their right index finger whose position was monitored by 6 Optitrak infrared cameras, rendering the table touch interactive. B) Participants made choices between two shapes paired such that they always differed in value by 5-cents over a 25 cent range, resulting in 5 shape pairs. Shapes ranged in price from 0 (best) to 25 (worst) cents for the low-cost-zero group (LC0) and 5 (best) to 30 (worst) cents for the low-cost-five group (LC5). Note the price-to-shape mapping in the figure illustrates only one of the possible mappings that were assigned randomly to each participant. C) Participants started each trial by placing their right index finger on a start circle. 1 to 2 s later, they heard a beep and the two shapes appeared. Participants then reached to touch the shape they wanted to purchase on that trial. After selecting a shape, its price was presented above its box and participants' total bank account was then shown, with that trial's deduction indicated.