

Modulating Episodic Memory Alters Risk Preference during Decision-making

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Abstract

■ When choosing between options that vary in risk, we often rely on our experience with options—our episodic memories—to make that choice. Although episodic memory has been demonstrated to be critically involved in value-based decision-making, it is not clear how these memory processes contribute to decision-making that involves risk. To investigate this issue, we tested a group of participants on a repeated-choice risky decision-making task. Before completing this task, half of the participants were given a well-validated episodic induction task—a brief training procedure in recollecting the details of a past experience—known to engage episodic memory processes, and the other half

were given a general impressions induction task. Our main finding was that risk-taking following the general impressions induction task was significantly lower than following the episodic induction task. In a follow-up experiment, we tested risk-taking in another group of participants without any prior induction task and found that risk-taking from this no-induction (baseline) group was more similar to the episodic induction than to the general impression group. Overall, these findings suggest engaging episodic memory processes when learning about decision outcomes can alter apparent risk-taking behavior in decision-making from experience. ■

INTRODUCTION

Many decisions in our daily lives—whether it is picking a restaurant for a dinner out, deciding which neighbor to invite to a concert, or selecting a stock to invest in the market—involve choosing between options that differ in risk—the predictability of the consequences associated with the choice. Because the likelihood of these consequences are typically not known, we are often inclined to draw on memories of similar experiences to help choose between the given options and make a decision (Hertwig & Erev, 2009). The ability to learn and remember past experiences in detail is supported by episodic memory (Tulving, 2002). Recently, episodic memory has been implicated in adaptive decision-making (Duncan & Shohamy, 2016; Murty, FeldmanHall, Hunter, Phelps, & Davachi, 2016). For example, a selective deficit in episodic memory resulting from brain injury results has been reported to impact performance on a temporal discounting task (Palombo, Keane, & Verfaellie, 2015) as well as impair the ability to make adaptive value-based decisions on the Iowa Gambling Task (Gupta et al., 2009; Gutbrod et al., 2006). Furthermore, there is neuroimaging evidence that episodic memory processes—particularly those supported by the hippocampus—enhance not only the association

between an experienced event and a given reward outcome but also that given reward outcome with similar experienced events (Wimmer & Shohamy, 2012).

In addition to the above-noted evidence that the use of episodic memory processes leads to more adaptive decision-making, there are hints that episodic memory may also play a pivotal role when making other types of decisions, such as risky decision-making from experience. For example, when individuals make decisions under risk, strong memories associated with extreme outcomes (e.g., large monetary gains) can override the use of other decision-making processes—as well as other learning experiences—and consequently are given more weight when choosing between options (Ludvig, Madan, & Spetch, 2014, 2015; Madan, Ludvig, & Spetch, 2014). To demonstrate this idea, Madan and colleagues had participants perform a decision-from-experience task where the expected values between the certain and risky actions were equal. One of their main findings was that extreme outcomes (e.g., a large monetary gain) were most frequently reported as the first outcome “to come to mind” for risky options. Furthermore, the researchers found that this memory salience for the extreme outcome was associated with more risk-taking in decisions (Ludvig et al., 2015; Madan et al., 2014). Consistent with the idea that memory can influence risk-taking behavior, other studies have used similar (risky) gambling tasks to reveal that initial outcomes carry a disproportionate influence on further decisions (Shteingart, Neiman, & Loewenstein, 2013), which may be attributed to better memory for events that occur at the beginning of a sequence (Tan & Ward, 2000; Murdock, 1960).

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The above studies examined the link between memory and risky decision-making by focusing on the relationship between particular memories of decision outcomes and behavior. Stemming from this research, an open question is whether a general enhancement of episodic memory processes when learning about risky outcomes can alter decisions made on the basis of these outcomes. Intriguingly, memory researchers have begun to use an episodic specificity induction technique to recruit episodic memory processes in participants as a means of examining the consequences of enhanced episodic processing upon subsequent tasks (Madore & Schacter, 2016). In short, this technique involves training participants to focus on and recall specific details from a presented scenario—engaging episodic memory processes—and then examining how this affects the ability to perform later tasks such as autobiographical remembering (Madore, Gaesser, & Schacter, 2014), problem solving (Madore & Schacter, 2014), and creative thinking (Madore, Addis, & Schacter, 2015). These studies have found that, relative to a “general impressions” (or control) induction group in which participants focus on the general impressions of a presented scenario before a given experimental task, the episodic specificity induction increases the amount of episodic content used to recall the past, imagine the future, solve problems, and enhance creative thinking (Jing, Madore, & Schacter, 2016; Madore, Jing, & Schacter, 2016; Madore et al., 2014; also see Madore & Schacter, 2016, for a review). Thus, the episodic specificity induction technique serves as an opportunity to experimentally manipulate the likelihood that episodic memory processes are being used during a subsequent behavioral task.

To shed light upon the role of episodic memory in risky decision-making, we combined the episodic specificity induction technique with a risky decision-making task that measures choices made from experience (following the procedure of Madan et al., 2014). Specifically, we used this induction technique to investigate the role of episodic memory when continually learning about and using decision outcome information—which, notably, deviates from prior studies using the technique to investigate the role of episodic memory in retrieval-based tasks (e.g., recalling a past event; retrieving creative solutions).

With this design, we tested two alternate hypotheses for how episodic memory will affect risky choice behavior. One hypothesis is that if episodic memory processes spread a positive value of rewarded decisions to new and similar instances during decision-making learning (Wimmer & Shohamy, 2012), alongside with an extreme outcome effect (Ludvig et al., 2014; Madan et al., 2014), then an enhanced use of episodic memory processes during learning will result in more risky behavior. That is, decision-makers should have a larger apparent preference for the risky (as opposed to sure-thing) action after an episodic specificity induction than after a general impressions induction.

An alternative possibility—based on findings that individuals are naturally inclined to rely upon episodic memory

processes when making decisions from experience (Duncan & Shohamy, 2016; Murty et al., 2016)—is that recruiting episodic memory processes during risky decision-making will not have an effect on performance. Rather, reducing the recruitment of episodic processes (i.e., via the general impressions induction) will bias people away from this default tendency to use episodic memory when learning (Madore et al., 2014) and lead to lower levels of risk-taking. To test these hypotheses, our study compared the effects of three separate groups—after an episodic specificity induction, after a general impressions induction (Madore, Jing, et al., 2016; Madore et al., 2014), and a third “baseline” group with no prior induction procedure—on choice behavior and subsequent memory for outcomes in a risky decision task.

As the risky decision task required learning about the options’ values from experience with outcomes as well as making decisions across trials, we can further examine the effect of modulating episodic memory processes upon trial-by-trial learning using a simple reinforcement learning (RL) model (Sutton & Barto, 1998). In doing so, we can assess the impact of prediction errors (PEs)—the mismatch between expected and received outcomes, which are believed to underpin value learning from experience (Kable & Glimcher, 2009)—upon the evaluation of the options and parameterize how trial-to-trial learning of the options’ values may differ as a function of episodic memory engagement.

METHODS

In Experiment 1, we used a design in which half of the tested participants were first given the episodic specificity induction procedure (i.e., they were trained to recollect specific details from a learned event) and half of the participants were first given the general impressions induction procedure in which they were trained to describe gist and general information from a learned event (Jing et al., 2016; Madore, Szpunar, Addis, & Schacter, 2016; Madore et al., 2014, 2015; Madore & Schacter, 2014). Afterwards, all participants completed a risky decision-making task. Although this experiment was initially conducted as a within-subject design, with every participant completing both induction groups and then a version of the risky decision-making task with different stimuli, there were large carryover effects across the two sessions that rendered the effects of the within-subject manipulation uninterpretable. Thus, we report this experiment effectively as a between-subject design. In Experiment 2, a new set of participants performed the risky decision-making task without any prior induction to serve as a baseline control group.

For both experiments, we introduced a “first outcome” manipulation that allowed us to systematically evaluate the impact of the very first outcomes on risk preference while controlling for unrepresentative early events (Shteingart et al., 2013). Approximately half of the participants were given a “first-win” trial order (win-loss-win-loss), and

the other half were given a first-loss trial order (loss-win-loss-win).

Experiment 1

Participants

Forty-seven participants were recruited through McGill University's classified ads system. Participants were compensated \$10 CAD for 1 hr and received an average bonus of \$1.25 CAD ($SD = 0.716$) for each of the two sessions. We administered the Positive and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988) both at the beginning and at the end of the experimental session and the Object Spatial-Imagery Questionnaire (Blajenkova, Kozhevnikov, & Motes, 2006) at the end of the experimental session; however, these questionnaire data are not reported in the following analyses. This study was approved by McGill's Research Ethics Office.

Of the tested participants, we excluded participants who had insufficient levels of early exploration (i.e., 10% of risky choices or less during the first 30 trials), participants who experienced risk 10% of the time or less, and participants who were identified as outliers for performing at least three standard deviations away from the mean of their group. In Experiment 1, we excluded two participants with insufficient levels of early exploration, one participant with insufficient overall risk experience, and two participants with both. One outlier was identified from the general impressions group—this outlier chose the risky option 96.7% for the analyzed trials. Of the remaining 41 participants, 21 participants were randomly assigned to the episodic induction group, and 20 participants were randomly assigned to the general induction group. Among the episodic induction group, 12 participants received the first-win order, and 9 participants received the second-win order. In the general group, 10 participants received the first-win order, and 10 participants the second-win order.

Episodic Specificity Induction

Participants were randomly assigned to an experimental procedure that began with either an episodic specificity or general impressions induction. As outlined in Madore et al. (2014), the episodic specificity induction is an experimental manipulation based on an established eyewitness interview technique known to enhance the number of details people can recall from witnessed events (Memon, Meissner, & Fraser, 2010). In short, both the episodic specificity and general impressions groups begin with the participants watching a 4-min long video involving actions of people in everyday settings (here we used clips of "Mr. Bean"). They were told to pay close attention to the video. After the video ended, participants were interviewed about its content. In the episodic specificity group (Jing et al., 2016; Madore, Jing, et al., 2016), participants were asked to get a strong mental image of

the video in mind and then describe as many specific details from that video in terms of the surroundings/setting, the physical appearances of the participants in the scene, and the actions in the video. In the general impressions group, participants were instructed to describe the video using adjectives referring to the setting/people/actions; that is, provide their general impressions of the video and not describe any specific details. Both induction procedures lasted approximately 8–11 min.

Risky Decision-making Task

Immediately after the induction procedure, participants performed the gain version of the risky decision-making task used by Madan et al. (2014). Over 100 trials, participants were presented with two doors that both yielded real monetary rewards. One of the doors was considered "safe" and always yielded a reward of 1.25 cents, whereas the other door was designated as the "risky" door and had a 50% chance to give a higher reward in the context of the experiment (2.5 cents) and a 50% chance to yield no reward. After choosing a door, participants were shown the reward they received from that door on that trial. Participants were not told beforehand the possible outcomes associated with each door. Thus, the participants had to learn the outcomes associated with each door as they made decisions during the task.

Risky Decision-making: Memory Test

Immediately after the risky decision-making task, participants were asked to report the first outcome that came to their mind when thinking about the doors, following the procedure from Madan et al. (2014). Participants were shown each of the two doors, in random order, and were asked to indicate the first outcome that came to mind when seeing each door. This manipulation allowed us to examine the influence of participants' explicit memory of the outcomes they received in the task on behavior. After reporting these outcomes, participants were instructed to draw the two doors to the best they could remember. However, these drawings were not analyzed in this report.

Experiment 2

Participants

Experiment 2 was composed of a baseline "control" group to assess standard levels of risk-taking. Twenty-four participants completed the risky decision-making task without any prior induction. One participant was excluded from the analysis for having insufficient levels of early exploration (i.e., less than 10% of risky choices during the first 30 trials). Of the remaining 23 participants, 12 received the first-win order, and 11 received the second-win order. Participants were paid \$8 CAD for approximately 20 min of their time, plus a bonus averaging \$1.24 CAD ($SD = 0.076$). The risky decision-making and associated memory

tests were identical to that of Experiment 1. The Positive and Negative Affect Scale was not administered before the experiment, neither did we ask participants to draw the doors or to complete the Object Spatial-Imagery Questionnaire after the risk decision-making task. The same data analysis and modeling procedure from Experiment 1 was used.

Data Analysis

For Experiment 1, to compare risk preference across induction groups (episodic vs. general impression), we computed the mean level of risk (proportions of risky choices) excluding the first 40 trials (Ludvig et al., 2014; Madan et al., 2014). We excluded early trials to ensure that risk preference was being established after participants had sufficient prior experience with the task and based our choice of excluding the first 40 trials (the first two blocks out of five) on the methods used by Madan et al. (2014). We then compared how risk preference changed across the trial blocks between the groups using mixed-effects logistic regressions (random intercepts and slopes on participants) with risky versus sure action as the outcome variable, using the lme4 package (Pinheiro & Bates, 2000) for the R programming language.

RL Model

We fit two simple RL models: a dual learning rate model, which allows for unequal weighting of positive versus negative PEs in learning the values of the two actions, and a single learning rate model, which weights positive and negative PEs equally (Gershman, 2015). Following basic formulations of RL models (Sutton & Barto, 1998), this model operates by updating expected reward values for the chosen action, a_j on each trial, t . These Q values are denoted here and elsewhere as $Q(a_j, t)$. The Q values for each option (in the present task there are two options) are used to determine the model's probability for selecting each option via a softmax decision rule,

$$P(a_i) = \frac{\exp(\gamma \cdot Q a_i, t)}{\sum_{j=1}^2 \exp(\gamma \cdot Q a_j, t)} \quad (1)$$

Here γ is an exploitation parameter that determines the degree to which the option with the highest Q value is chosen. As γ approaches infinity, the highest valued option is chosen more often, and as γ approaches 0, all options are chosen equally often.

On each trial, the Q value of the chosen action (a_i) is updated for the next trial ($t + 1$) based on the PE, denoted δ_t , between the Q value for that action and the obtained reward,

$$\delta_t = r(t) - Q(a_i, t) \quad (2)$$

where $r(t)$ is the reward received from the chosen option on trial t . In the reduced (single learning rate) model, a single learning rate was used to perform updates on

Q values, regardless of the sign of the PE, on a simple incremental updating rule,

$$Q(a_i, t + 1) = Q(a_i, t) + \alpha \cdot \delta_t \quad (3)$$

where α is a learning rate parameter. As α approaches 1, greater weight is given to the most recent rewards in updating Q values indicative of more active updating of Q values on each trial, and as the learning rate parameters approach 0, recent rewards are given less weight.

In the dual learning rate model, separate learning rates govern the Q -value updates made for positive and negative PEs,

$$Q(a_i, t + 1) = \begin{cases} Q(a_i, t) + \alpha_{\text{pos}} \cdot \delta_t, & \delta_t > 0 \\ Q(a_i, t) + \alpha_{\text{neg}} \cdot \delta_t, & \delta_t < 0 \end{cases} \quad (4)$$

where α_{pos} and α_{neg} are learning rate parameters for positive and negative PEs, respectively (Gershman, 2015; Christakou et al., 2013; Niv, Edlund, Dayan, & O'Doherty, 2012).

Our model fitting procedure used the Nelder–Mead optimization algorithm to find parameter values that maximized the likelihood of participants' choices given their previous rewards and choices (Nelder & Mead, 1965). To compare goodness of fit between the two models while appropriately penalizing model complexity (i.e., number of free parameters), we used the Akaike information criterion (AIC; Akaike, 1974). As resultant model parameter estimates are often nonnormally distributed, we log-transformed the estimated learning rates to reduce skew before being entered into regressions.

RESULTS

Experiment 1

Risky Decision-making Behavior

We first sought to determine if apparent risk preference differed across induction groups using an ANOVA with taking our two manipulations—Memory induction and First outcome—as between-subject factors. Upon examining the mean level of risky choices for each participant after Trial 40 (Ludvig et al., 2014; Madan et al., 2014), we found the main effect of Induction to be significant, $F(2, 58) = 5.2, p = .00835$, across all three groups. However, because the main effect of First outcome, $F(1, 58) = 0.0689, p = .794$, and the interaction between Induction groups and First outcome, $F(2, 58) = 0.877, p = .421$, were far from significant, we conducted our main analyses of interest (Memory induction) by collapsing across the first-outcome manipulation, finding that risk-taking in the episodic induction group ($M = 0.485, SD = 0.179$) to be significantly higher than in the general impressions induction group ($M = 0.304, SD = 0.123; t = 3.78, p = .00058$; see Figure 1A).

Next, we examined choice behavior (i.e., risk preference) across blocks and found that risk-taking developed

differently in the episodic specificity and general impressions groups. Confirming the pattern of results depicted in Figure 1B, a mixed-effects logistics regression revealed that participants in the general impressions induction group became significantly more risk-averse over time than participants in the episodic induction group (Group \times Trial interaction; $\beta = 1.25$, $SE = 0.349$, $p = .000346$). Thus, the two groups exhibited apparent differences in their time courses of apparent risk preference, such that risk-taking tended to decrease over time in the general impressions group ($\beta = -1$, $SE = 0.253$, $p = .0000767$) but did not significantly change over time in the episodic specificity group ($\beta = 0.222$, $SE = 0.241$, $p = .36$).

Memory for Outcomes

When asked which outcome first comes to their mind, participants in the episodic induction group were significantly more likely to report the positive outcome than the negative outcome, $\chi^2(1, n = 21) = 3.86$, $p = .0495$ (Figure 2A). This was not the case for the general impressions induction group, $\chi^2(1, n = 20) = 0.2$, $p = .655$. However, comparing across the groups, the episodic specificity group did not significantly report the positive outcome more than the general impressions group, $\chi^2(1, n = 21) = 1.96$, $p = .16$. Participants who reported the positive outcome as first to mind were not significantly

different in risk-taking than participants who reported the negative outcome as first to mind in either the episodic ($t = 0.364$, $p = .721$) or the general ($t = 0.29$, $p = .776$) group.

Experiment 2

Risky Decision-making Behavior

We analyzed the baseline group the same way as in the episodic and general impressions induction groups. Upon examining the mean level of risky choices for each participant after Trial 40 (Ludvig et al., 2014; Madan et al., 2014), we found that risk-taking in the episodic induction group ($M = 0.485$, $SD = 0.179$) was not significantly different than in the baseline group ($M = 0.435$, $SD = 0.226$; $t = 0.807$, $p = .424$) and risk-taking in the general impressions group ($M = 0.304$, $SD = 0.123$) was significantly lower than in the baseline induction group ($t = -2.41$, $p = .0214$; Figure 1A). A mixed-effects logistic regression did not reveal a change in risk preference over time in the baseline group (Group \times Trial interaction; $\beta = -0.2$, $p = 0.666$). Learning of risk preference over time did not significantly differ between the episodic and baseline groups (Figure 1B; $\beta = 0.41$, $SE = 0.531$, $p = .42$), or between the general impression and baseline groups ($\beta = 0.86$, $SE = 0.53$, $p = .11$).

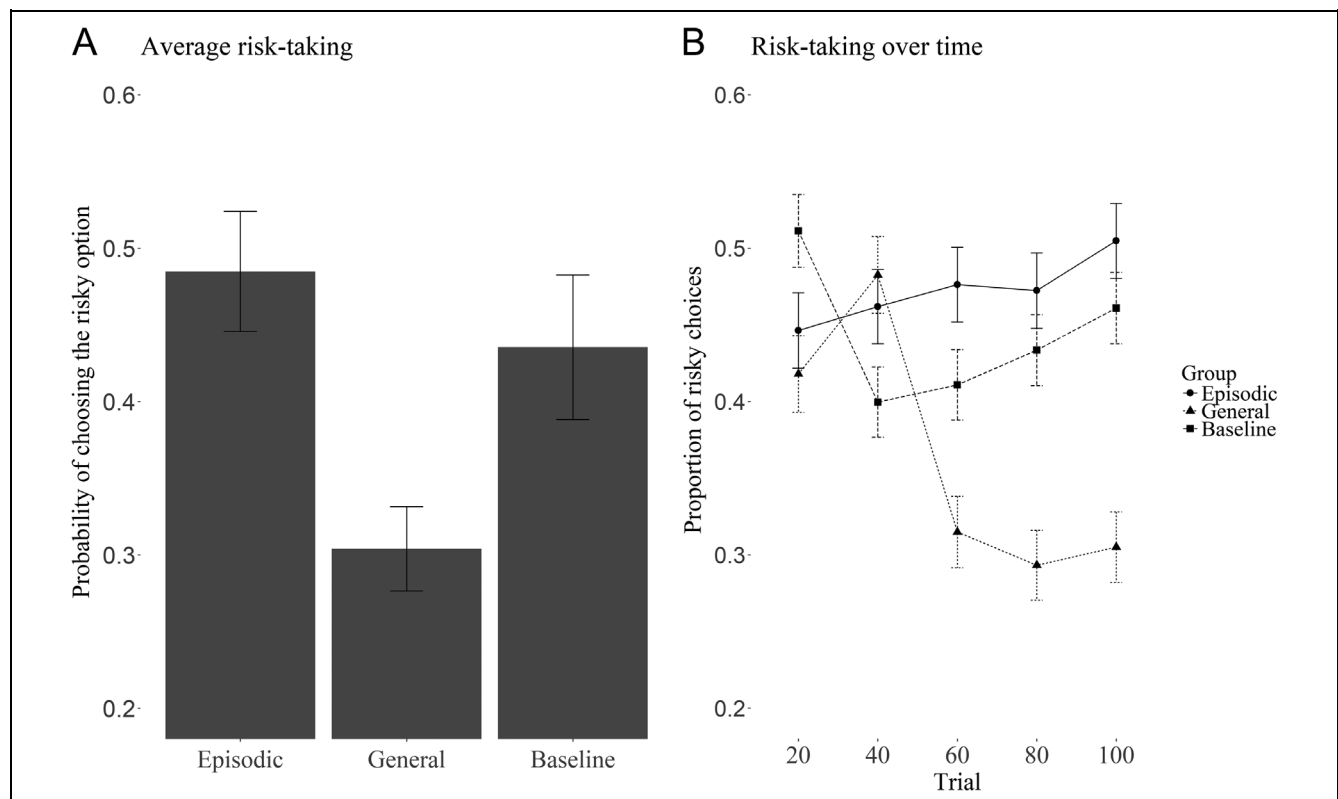


Figure 1. (A) Proportion of risky choices for the three induction groups (Episodic, General Impressions, and Baseline) from Trials 40 to 100. (B) Time course of risk preference over 20-trial blocks in the three groups: Episodic, General Impressions, and Baseline (Experiment 2).

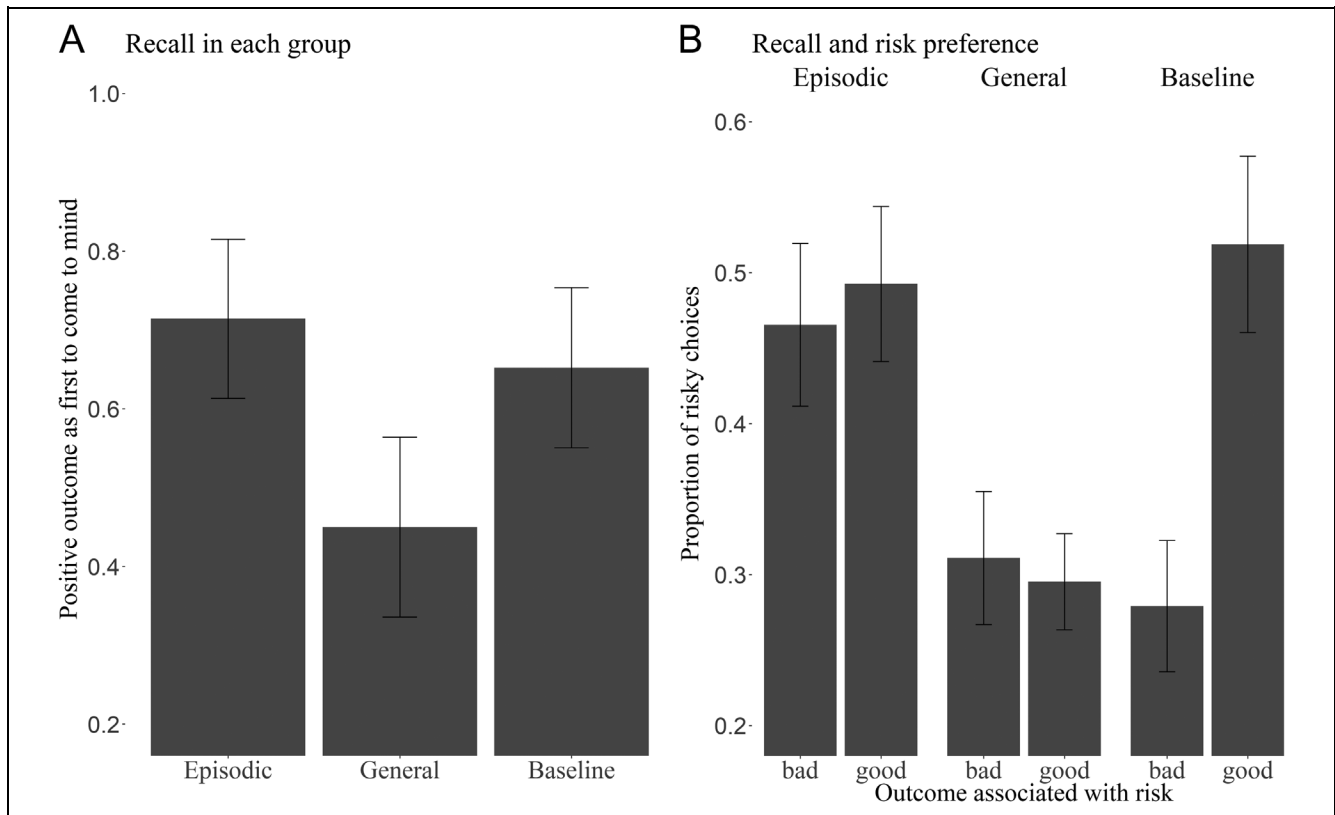


Figure 2. (A) Proportion of participants reporting the extreme positive outcome in the first outcome to come to mind question. (B) Average risk-taking (without the first 40 trials) as a function of the first outcome that comes to mind when thinking of the risky option, in different groups.

Memory for Outcomes

Participants in the baseline group were not significantly more likely to report the positive than the negative risky outcome as the first one to come to mind, $\chi^2(1, N = 23) = 2.13$, $p = .144$ (Figure 2A). However, contrarily to the two other groups, positive recall was associated with more risk-taking in the baseline group, ($t = 3.29$, $p = .0035$) (Figure 2B).

RL Model Analysis

Our model-based analysis fits two different RL models that make different assumptions about how participants

learn from PEs: a single learning rate model that learns equally from positive and negative PEs and a dual learning rate model that allows different rates of learning for positive versus negative PEs. The best-fitting RL model parameter estimates for the dual learning rate model and AIC scores for the two different models are reported in Table 1. Collapsing across groups, participants had significantly lower AIC scores for the dual learning rate model than for the single learning rate model ($t = 3.78$, $p < .001$), indicating that the dual learning rate model better characterized the choice behavior than the single learning rate model. Importantly, the AIC scores of the

Table 1. Best-fitting Parameter Estimates for the Dual Learning Rate Model and Goodness-of-fit Statistics for the Episodic Specificity, General Impressions, and Baseline Groups

Group	Learning Rate (Positive PE)	Learning Rate (Negative PE)	Inverse Temperature	Mean AIC (Single Learning Rate Model)	Mean AIC (Dual Learning Rate Model)	Best Fit by Dual Learning Rate Model
Episodic (Experiment 1)	0.451	0.408	3.179	124.242	122.350	52.17%
General (Experiment 1)	0.203	0.313	5.877	119.057	111.836	73.91%
Baseline (Experiment 2)	0.336	0.358	3.919	129.623	123.278	58.33%
All participants	0.330	0.360	4.319	124.383	119.214	62.9%

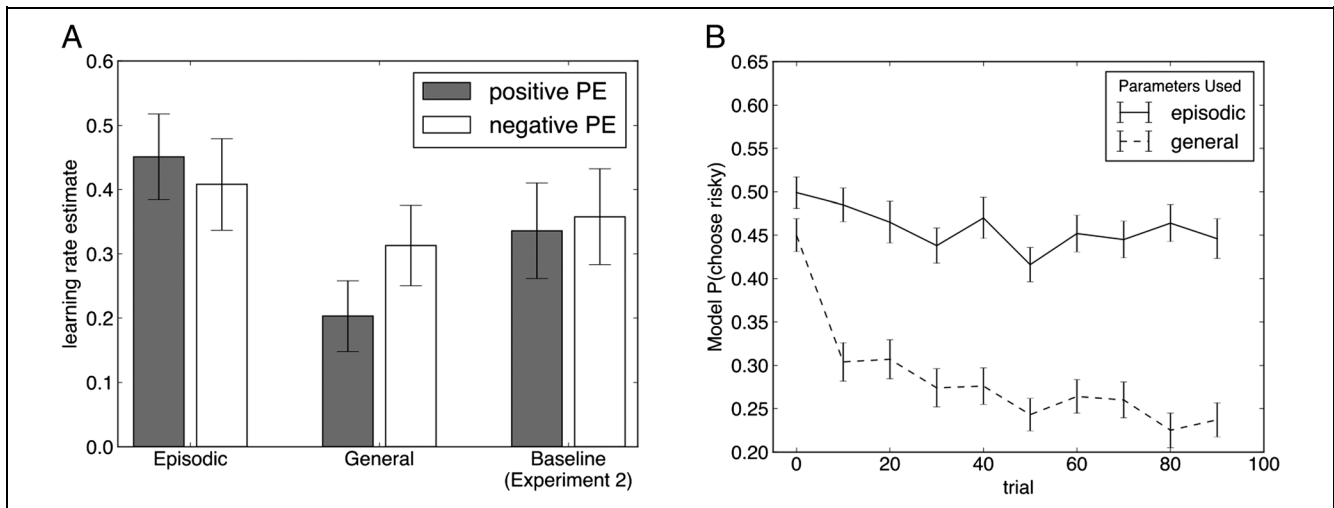


Figure 3. (A) Estimated positive and negative PE learning rates for the dual learning rate model, by group. (B) Predicted time course of risky choices obtained from simulating the dual learning rate model under the best-fit parameter for the episodic and general impressions groups. Error bars depict standard error of the mean.

dual learning rate model did not differ significantly across groups, $F(2, 61) = 1.41, p = .25$.

Next, we turned to analyzing positive and negative learning rates by experimental condition (Figure 3A). Examining the episodic and general induction groups separately, we found that positive and negative PE learning rates were less asymmetric in the episodic specificity induction condition than in the general impressions induction condition (Condition \times PE type interaction $\beta = 2.83, SE = 1.01, p = .001$). In other words, participants who underwent the general impressions induction appeared to weigh positive and negative PEs more unequally than participants who underwent the episodic specificity induction. This parameter difference did not differ significantly between the episodic specificity induction group (Experiment 1) and the baseline group (Experiment 2; Condition \times PE type interaction $\beta = 0.583, SE = 0.124, p = .779$), nor between the general impression induction and the baseline group ($\beta = -1.02, SE = 0.112, p = .365$).

To examine whether the best-fitting dual learning rate model predicts different levels of apparent risk-taking under different sets of parameter values, we conducted model simulations using two sets of parameter values estimated separately from participants in the episodic specificity and general impressions groups (Table 1). The time courses of simulated choice behavior, plotted analogously as we did for participants (Figure 3B), reveal that the observed differences in best-fitting parameter values capture the observed differences in risk-taking behavior across the groups. As only the risky door engenders PEs, the larger weighting of negative PEs—evidenced by participants in the general impressions induction group—will cause the RL model to develop a preference away from the risky option (and toward the safe option) as its estimated action value will decrease below the safe option’s estimated action value.

DISCUSSION

Here we examined how modulating the use of episodic memory processes affected risky decision-making from experience. To do this, we performed a memory induction manipulation—which promoted reliance upon specific episodic details versus general “gist”-like impressions (Jing et al., 2016; Madore, Jing, et al., 2016; Madore et al., 2014, 2015; Madore & Schacter, 2014)—and then examined risk-taking behavior in subsequent gambling task in which the options’ values are learned from direct experience over a series of trials (Madan et al., 2014). Our key finding was that there were lower levels of risk-taking following the general impressions induction than following episodic specificity induction (Figure 1A). Subsequent analyses revealed that this difference was mainly driven by the general impressions induction “reducing” levels of risk-taking rather than the episodic specificity induction “increasing” levels of risk taking, as risk-taking levels in a group in which no induction was given appeared more similar to the episodic specificity than to the general impressions group. Our finding that the general impressions group differed from the episodic specificity and control group is at odds with the established effect of the episodic induction procedure. There are several reports that the episodic specificity induction procedure improves performance above a general impressions and baseline control procedure on tasks ranging from recalling the past to imagining the future to solving creativity problems (Jing, Madore, & Schacter, 2017; Jing et al., 2016; Madore, Jing, et al., 2016; Madore & Schacter, 2016; Madore et al., 2014, 2015). The selective enhancement from episodic specificity in these works would also argue against interpreting the current data set as evidence that the general impressions group were less likely to recruit episodic memory processes. However, there are some critical differences between our study and

these prior reports that may account for the disparate findings. First, there are methodological differences. Of note, our study took a between-subject design, whereas other studies using the episodic induction task have implemented a within-subject design. A larger difference between our study and others is the processing requirements of the task given after the induction procedure. The enhancing effects of episodic specificity induction have been documented on retrieval-based tasks (see references above); however, our task required both encoding and retrieval memory mechanisms for successful performance—participants had to learn to make decisions across a series of trials. The reliance on encoding these decisions across trials may have inadvertently made the task already episodic in nature, which could explain why our pattern of results deviates from what has been consistently reported in the literature. In fact, this apparent difference in risk preference increased over time: Although the episodic and baseline groups appeared to engender relatively stable their risk preference over time, participants in the general impressions group became progressively more risk-averse in their choices after an apparent initial period of exploration (Figure 1B). The effect of modulation of episodic memory processes upon subsequent risk preference provides compelling evidence for a specific role of memory processes in the extreme outcome effect revealed by Madan et al. (2014) and Ludvig et al. (2014).

An interesting pattern emerged when we applied an RL model-based analysis to the risk preference behavior. We found the general impressions induction engendered a “negativity bias” in their learning rates, whereby negative PEs were more strongly weighted than positive PEs in learning estimates of the two options’ values (Gershman, 2015; Christakou et al., 2013). In contrast, participants who underwent the episodic specificity induction and participants in the baseline group both exhibited a more equal weighting of positive and negative PEs (Figure 3A), further supporting the possibility that the general impressions induction moves participants away from a default episodic specificity state and altered learning from positive versus negative PEs. We further demonstrated using model simulations that this sort of negativity bias manifests in apparent risk-averse choice behavior (Figure 3B). Based on findings that episodic memory contributes positively to adaptive decision-making (Duncan & Shohamy, 2016; Murty et al., 2016), it is possible that these effects are because episodic memory—engaged in both the specificity induction group and also, by default, in the baseline group—reduced inherent bias against risk in our tested sample.

Previous research that has used the induction technique implemented in our study has focused on how this technique alters subsequent retrieval tasks—such as autobiographical recall (Madore et al., 2014), problem solving (Madore & Schacter, 2014), and creativity (Madore et al., 2015). In our study, however, we examined how the tested inductions affect behavior on a decision-making

task that requires both retrieving rewards from previous trials but also encoding the presented associations between items and rewards (Murty et al., 2016; Wimmer & Shohamy, 2012). That is, in our study we tested the effects of the induction on both encoding (i.e., learning about outcomes associated with the options) and retrieval (i.e., reporting outcomes associated with the options) processes. This difference could explain our pattern of results. It is possible that the general impressions induction dampened the normal use of episodic processes in encoding information learned from experience, which is inherent in the risky decision-making task we used (Madore & Schacter, 2014; but see Madore et al., 2014). That is, if the decision-making task by itself brings to bear episodic processes, which increase risk-taking, the general impression induction might have counteracted that effect by reducing the use of episodic memory. This pattern of results dovetails with those found by Madan et al. (2014), whose observed risk-taking levels were closer to the baseline and the episodic induction groups than to the general impressions group in this study. Also in line with this thought is the finding that participants in the episodic specificity but not in the general impressions group were more likely to recall the positive extreme outcome when asked about the risky option, suggesting a form of episodic memory bias whereby these positive outcomes are overweighed—indeed, the true rate of positive and negative outcome occurrences was 50:50.

Thus, it seems the general impressions induction tends to detract people from choosing the risky option after a certain period of exploration, possibly because they differently remember previous outcomes (Figure 2A). Moreover, our findings suggest that individuals naturally approach risk-taking behavior through an “episodic lens,” thus when biased toward nonepisodic recall, risk choice is altered. To the extent that experience-based decision-making already requires (and may in itself induce) episodic memory processing, the episodic specificity induction might not have been able to further enhance the use of episodic memory processes. Interestingly, the tendency for participants who reported the positive outcome as first to come to mind to be more risk-seeking was observed in the baseline group (Madan et al., 2014), but not in the episodic and general impressions induction groups (see Figure 2B). We take this as evidence that the episodic specificity induction procedure might possibly override the relationship between risk preference and the reported first outcome that comes to mind.

In conclusion, we have shown the general impressions induction to reduce risk-taking behavior relative to both the episodic specificity induction and a baseline control. Together, these results suggest that episodic memory processes play a critical role in establishing risk preference from direct experience—more specifically, it appears that individuals, by default, tend to use episodic memory when learning to make decisions from experience and that attenuating these episodic processes through the use of

a general impressions induction reduces apparent risk preference, and this is corroborated by both the overall rates of choice and RL model-based analysis. Future research should assess the generalizability of these episodic memory processing modulations under different levels of outcome saliency and different outcome probabilities as well as when choices are made in the losses rather than the gains domain.

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