Modulating episodic memory alters risks preferences during decision-making

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**Abstract**

When choosing between options that vary in risk, we often must rely on our direct experience with these actions in order to decide. While episodic memory has previously been demonstrated to be critically involved in value-based decision-making, we sought to understand how more specifically how episodic memory processes contribute to risky decision-making. To do so, we tested the effect of a well-validated episodic specificity induction—a brief training procedure in recollecting the details of a past experience and demonstrated to enhances episodic memory processes relative to an induction focusing on general impressions—on a repeated-choice risky decision-making task with constant expected value across options. We found risk-taking following the general impressions induction to be significantly lower than following the episodic condition . Interestingly, risk-taking from a no-induction condition was more similar to the general impressions than to the episodic condition. Overall, these findings suggest episodic memory processes 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 Friday dinner, deciding whether to ask a neighbor out on a date or picking a stock to invest in the market – involve choosing between options that differ in risk, in how predictable the consequences of our choices are.. Since the likelihood of these consequences are typically not known, we may draw on memories of similar experiences to help choose between 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, 1983, 2002), which has been implicated in adaptive decision-making (Murty, Feldman, Hall, Hunter, Phelps & Davachi 2016; Duncan & Shohamy, 2016). For example, research has found that a selective deficit in episodic memory resulting from brain injury results can impact temporal discounting (Palombo, Keane & Verfaellie, 2014) – and impair the ability to make adaptive value-based decisions on the Iowa Gambling Task (Gutbrod et al., 2006; Gupta et al., 2009). In line with these findings, episodic memory processes – particularly those supported by the hippocampus – are thought to not only enhance the associations between an experienced event and a given reward outcome, but also to associate the reward outcome with similar events to the event that was rewarded (Wimmer & Shohamy, 2012).

Even though episodic memory has generally been shown to lead to more adaptive decision-making, it would be interesting to know the role it plays when both options have the same value – and whether episodic memory introduces a bias towards or away from risk. In line with this idea, previous evidence has shown episodic memory processes can alter risky decision-making. Madan, Ludvig and Spetch (2013) posited an ‘extreme-outcome rule’ where extreme outcomes in risky choice are overweighed in memory (Talarico & Rubin, 2003) and consequently are given more weight when choosing from experience. To test 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, and found the extreme outcome was most frequently reported to be the first “to come to mind” when considering the risky action. This memory salience for the extreme outcome was also associated with more risk-taking in decisions from experience (Madan et al., 2013; Ludvig, Madan & Spetch, 2015). Consistent with this idea, studies using similar gambling tasks reveal that initial outcomes carry a disproportionately large influence on further decisions (Shteingart, Neiman & Loewenstein, 2013), which might possibly be due to better memory for events that occurred at the beginning of a sequence (Murdock, 1960; Tan & Ward, 2000).

A recent body of memory research has begun to use an ‘episodic specificity induction technique’ that promotes the use episodic memory processes and can be used to experimentally test the causal link between episodic memory and decision-making. In short, this technique involves training participants to focus on and recall specific details from a presented scenario and then examining how this affects the ability to perform subsequent tasks like autobiographical remembering (Madore, Gaesser & Schacter, 2014), problem solving (Madore and Schacter, 2014) and divergent thinking (Madore, Addis & Schacter, 2015). A common finding is that, relative to the control condition in which participants focus on the general impressions of a presented scenario, the episodic specificity induction increases the amount of episodic content used to recall the past, imagine the future and solve problems (Madore et al., 2014; Gaesser et al., 2011; also see Schacter & Madore, 2016 for a review). Thus, the episodic specificity induction technique is an opportunity to experimentally manipulate the likelihood that episodic memory processes are being used during a behavioral task.

Here we combined the episodic specificity induction procedure with a risky-decision making task that measures choices made from experience (following the procedure of Madan et al, 2013; Ludvig, Madan & Spetch, 2014) to shed light upon the extreme-outcome effects observed by Madan and colleagues. (2013), and to determine how enhancing episodic memory processes alters the way we learn to make risky decisions (Schacter, Welker, Schacter, & Madore, 2016). Based on prior findings, we test the specific hypothesis that episodic memory processes will spread the positive value of rewarded decisions to new and similar instances during decision-making learning (Wimmer & Shohamy, 2012), acting as a potential cause of the extreme-outcome effect. We predicted that if episodic memory processes can potentiate the observed overweighing of extreme outcomes, there would be higher apparent preference for the risky (as opposed to sure-thing) action after the episodic specificity induction than after the general impressions induction. Previous work () comparing both conditions to a (second) control suggests differences in behavior to be mainly driven by the episodic specificity induction. However, people may already naturally tend to rely on episodic memory when making decisions based on previous experiences (Duncan & Shohamy, 2016??). Hence, it would also seem plausible for the general impressions induction to bias people away from their natural tendency to use episodic memory when learning to make decisions from experience. To address these questions, we designed an experiment which requires participants to make value-based decisions learned from experience in three different conditions. Two conditions are the episodic specificity and general impressions conditions from Madore et al. (), and the third condition is a ‘baseline’ condition with no induction prior to the decision task.

To further examine the effects of the episodic specificity induction upon learning, we fit a simple reinforcement learning (RL) model (Sutton & Barto, 1998) that quantifies the extent to which an individual participant weighs positive versus negative prediction errors (PEs) in learning the values of the two actions. In particular, we speculated that the memory bias engendered by the episodic specificity induction could be understood as an asymmetric learning process whereby positive PEs exert a disproportionately large effect on learning of values of the possible actions.

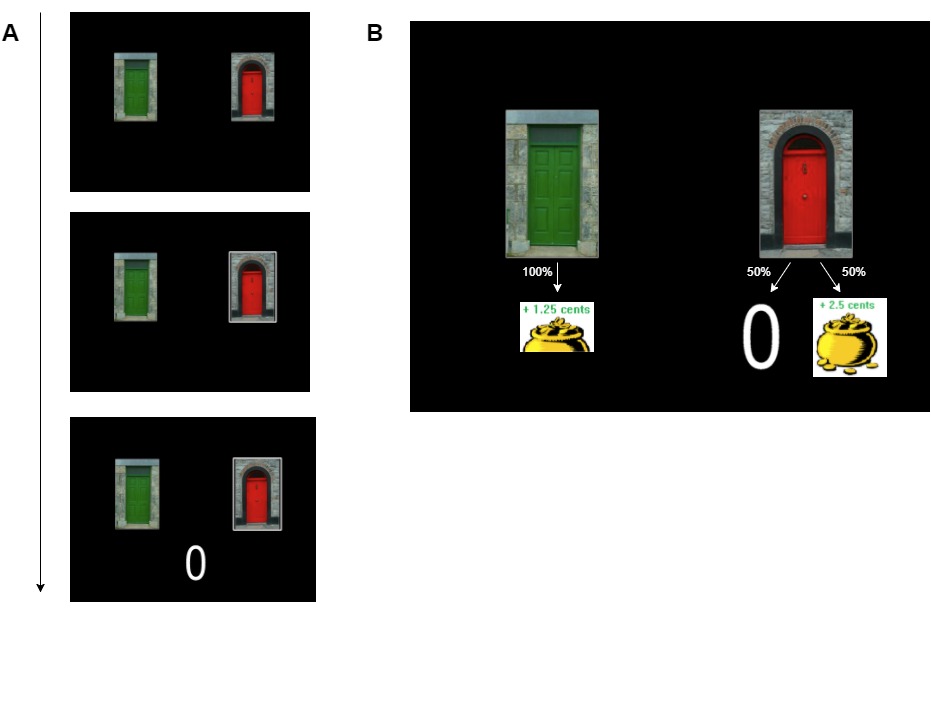
**Methods**

In Experiment 1, we used a design in which half of the tested participants were first trained to recollect specific details (episodic specificity induction) or to describe gist and general information about a viewed video (Jing, Madore, & Schacter, 2016; Madore, Szpunar, Addis, & Schacter, 2016; Madore et al., 2015; Madore & Schacter, 2014) before completing a risky decision-making task. Experiment 2 served as a (second) control condition in which a new set of participants performed the risky decision-making task without any prior induction.

For both studies, we introduced a “first outcome” manipulation that allowed us to systematically evaluate the impact of the very first outcome given on the risky decision-making task on risk preferences. 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). This “first outcome” manipulation allowed us to systematically evaluate the impact of the very first outcome on risk preferences while controlling for unrepresentative early events (Shteingart et al., 2013).

*Experiment 1*

Experiment 1 was conducted as a within-subject design, with every participant undergoing both the general impressions and episodic specificity induction procedures and then aversion of the risky decision-making task with different stimuli (Figure 1A). However, due to apparent carryover effects across the two sessions, we report only the results from the first session of the experiment. Thus, our study is effectively a between-subjects design.

Figure 1: Example of stimuli shown to participants during the gambling task (Panel A) and possible outcomes (Panel B).

*Participants*

We collected data from 47 participants who were recruited through McGill’s classified ads system. 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 outliers who were at least3 standard deviations away from the mean of their group. . In experiment 1, we excluded 2 participants with insufficient levels of early exploration, 1 participant with insufficient overall risk experience and 2 participants with both. We also excluded 1 outlier from the general impressions condition who chose the risky option 94% of the time past trial 24. Of the remaining 41 participants, 21 participants were randomly assigned to the episodic induction condition, and 20 participants were randomly assigned to the control induction condition. 22 participants were randomly assigned to the first-win condition, and 19 participants to the second-win condition. Participants were compensated $10 CAD for one hour, and received an average bonus of $1.24 CAD, (*SD*= 0.069) for each of the two sessions. We administered the Positive and Negative Affect Schedule (PANAS; Watson, Clark & Tellegen, 1988) both at the beginning of the experimental session and at the end, and the OSIQ questionnaire (Vannucci, Cioli, Chiorri, Grazi, & Kozhevnikov, 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 (REB).

*Episodic specificity induction*

The experimental procedure began with an episodic specificity or control (“general”) induction, following the procedure 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 specificity and control induction conditions begin with the participants watching a 4-minute 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 the content of the video. In the episodic specificity condition (Jing et al., 2016; Madore 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 control condition, 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 9 to 12 minutes.

*Risky decision-making test*

Immediately after the induction procedure, participants performed the gain-version of the risky decision-making task used by Madan et al. (2014). In general, 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, while 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 (see figure 1B). 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.

*Memory Recall*

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 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 with a paper and pencil and label the colors.

*Data Analysis*

*Risk preference measurements*

To compare risk preferences across induction groups (episodic versus control), we computed the mean level of risk excluding the first 24 trials (Madan et al., 2013; Ludvig et al., 2014). Excluding early trials allowed us to compare decisions that were made after having sufficient prior experience with the task; the number of early trials excluded is the same than on the gain version of the task used by Madan et al. (2013). Risk preferences across groups were compared by conducting ANOVAs upon proportions of risky choices. Learning effects were tested using mixed-effects logistic regressions with random intercepts and slopes for each participant. This was done using the lme4 package (Pinheiro & Bates, 2000) for the R programming language.

*Reinforcement learning (RL)*

Following basic formulations of RL models (Gershman, 2015; Sutton & Barto, 1998), this model operates by developing and updating expected reward values for each option, *aj,* on each trial, *t.* these *Q-values* aredenoted here and elsewhere as *Q(aj, 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:

(1)

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

On each trial the option that is chosen () is updated for the next trial (*t*+1) based on a simple incremental updating rule:

(2)

(3)

In Equation 2 above and are learning rate parameters for positive and negative prediction errors (PE), and *r*(*t*) is the reward received from the chosen option on trial *t*. As these learning rate parameters approach 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.

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. To avoid estimates at parameter range boundaries, we imposed a ‘pseudo-prior’ over parameters, which for the learning rates, took the form of a beta distribution with *a* = *b* = 2, and for the inverse temperature parameter ()*,* a gamma distribution with *k*=1 and *θ*=3.

*Experiment 2*

Experiment 2 was comprised of a second “control” condition to assess people’s baseline levels of risk-taking. In this condition, 24 participants completed the gambling 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 were randomly assigned to the first-win condition and 11 were assigned to the second-win condition. Participants were paid $8 CAD for approximately 20 minutes of their time, plus a bonus averaging $1.24 CAD (*SD* = 0.076). The gambling task and memory recall procedures were identical to that of Experiment 1 except that they were performed in the absence of an episodic or control impressions induction. The Positive and Negative Affect Scale was not administered prior to 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.

**Results**

*Experiment 1*

*Risky decision-making* *behavior*

We first sought to determine if apparent risk preferences differed across induction groups. Since the main effect of first-outcomes was far from significant across all conditions (F(1,62) = 0.107, p = 0.745) and within each memory condition, further analyses were conducted by collapsing across these two conditions. Upon examining the mean level of risky choices for each participant after trial 24 (Madan et al., 2013; Madan et al., 2014), we found that risk-taking in the episodic induction group (*M* = 0.479, *SD*=0.173) was significantly higher than in the control induction group (M = 0.34, SD = 0.122; F(1, 39) = 8.8, p = 0.0051; see figure 2A).

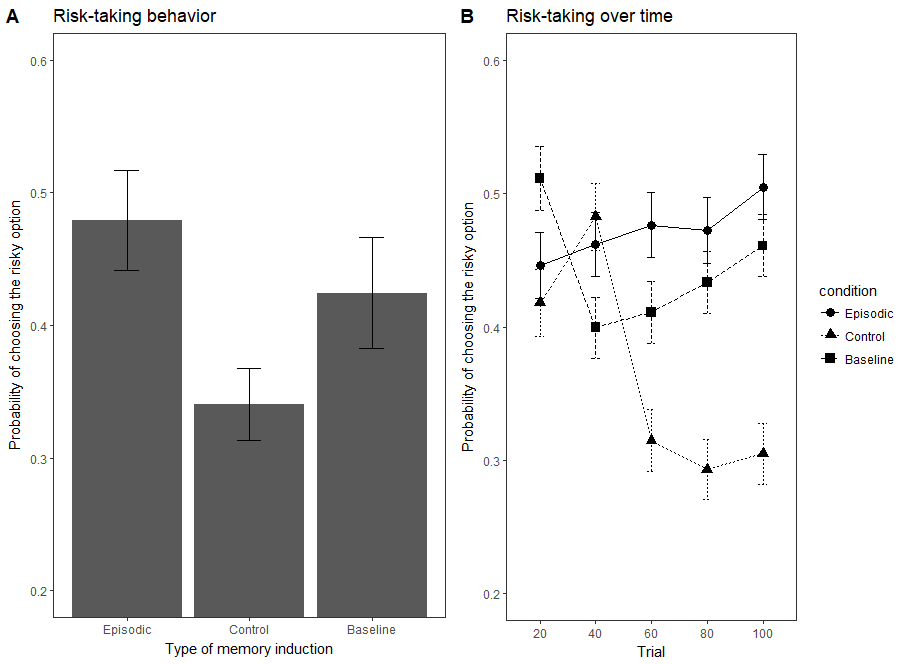


Figure 2: Panel A depicts the proportion of risky choices for the three induction conditions (Episodic, Control and Baseline) from trial 24 to 100. Panel B depicts the time course of risky preferences over 20-trial blocks in the three conditions: Episodic, Control and Baseline (Experiment 2)

Examining choice behavior across blocks, we found that risk-taking developed differently over time in the episodic specificity and control induction groups (Figure 2B). A mixed-effects logistics regression revealed that participants in the control induction group became significantly more risk-averse over time than participants in the episodic induction group (group X trial interaction; *β* = 1.25, SE = 0.349, *p*= 0.000346). Thus, the two groups exhibited apparent differences in their time courses of apparent risk preference. Put another way, risk-taking tended to decrease over time in the control condition (*β* = -1, SE = 0.253, p = 0.0000767) but did not significantly change over time in the episodic condition (*β =* 0.222, SE = 0.241, p = 0.36).

*Memory for Outcomes*

When asked which outcome first comes to their mind, participants in the episodic induction group were marginally significantly more likely to report the positive outcome, χ2(1, N = 21) = 3.86, p= 0.0495 (Figure 3A). This was not the case for the control induction group χ2 (1, N = 20) = 0.2, p= 0.655. However, the episodic condition did not significantly report the positive outcome more than the control condition χ2(1, N = 21) = 1.96, p = 0.16. The first outcome that came to mind was not significantly correlated with risky behavior across the episodic and control induction condition groups F(1,39) = 0.637, p = 0.43.

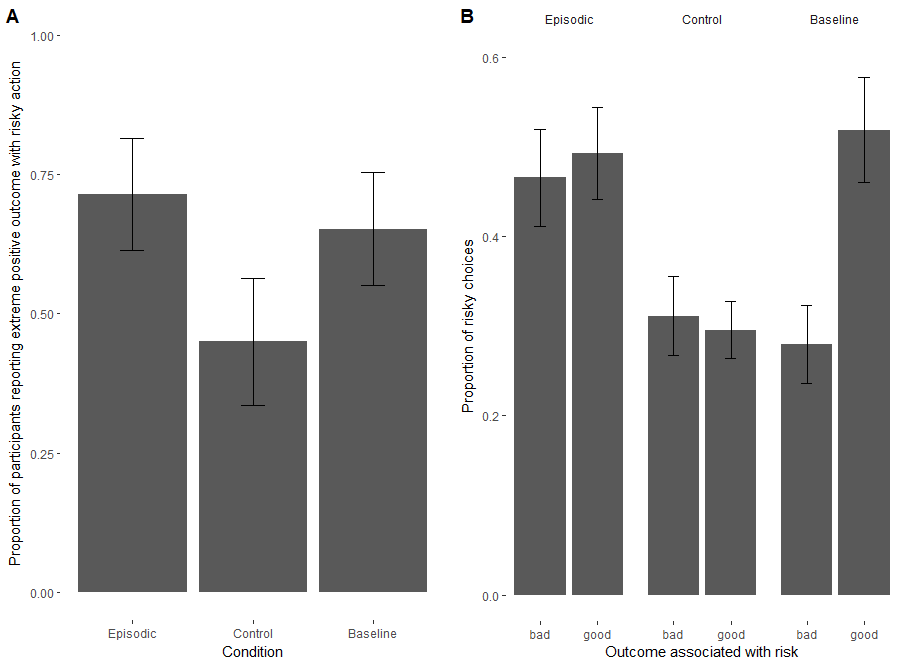


Figure 3: Panel A depicts the proportion of participants reporting that the extreme positive outcome in the first-outcome question. Panel B represents average risk-taking (without the first 24 trials) as a function of the first outcome that comes to mind when thinking of the risk option, in different groups.

*Effects of Episodic Specificity Group on RL Model Parameters*

The best-fitting RL model parameter estimates are reported in Table 1. Considering the entire sample, we found a significant main effect of PE valence (positive versus negative PEs) such that negative PE learning rates were significantly larger than positive PE learning rates (mixed-effects regression *β* = -0.15, *SE=*0.05, *p* = 0.026). Indeed, this observation corroborates previous observations of a ‘negativity bias’—a tendency to weigh negative PEs more strongly than positive PEs— in RL updating in similar tasks (Christakou et al., 2013; Gershman, 2015; Niv, Edlund, Dayan, & O’Doherty, 2012).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Condition** | **Learning Rate (Positive PE)** | **Learning Rate (Negative PE)** | **Inverse Temperature** | **Mean Log Likelihood** |
| *Episodic* | 0.385 | 0.395 | 2.776 | -60.371 |
| *Control* | 0.242 | 0.401 | 3.759 | -56.223 |
| *Baseline (Experiment 2)* | 0.309 | 0.357 | 2.847 | -61.283 |

Table 1: Positive and negative learning prediction error rates for the episodic, control and baseline conditions.

However, examining the Episodic and Control induction groups separately, we found that positive and negative PE learning rates exhibited less asymmetry in the Episodic Specificity induction condition than in the Control induction condition (Figure 4). In other words, participants who underwent the Episodic specificity induction appeared to weigh positive and negative prediction errors more equally than participants who underwent the Control induction. The later exhibited the typical negativity bias in learning rates (condition × PE type interaction *β* = .16, *SE=*0.06, *p* = 0.017).

../../../Downloads/pe_lr_v3.pdf

Figure 4: Best-fitting learning rate parameters for positive prediction errors and negative prediction errors, by condition. Error bars depict standard error of the mean.

*Experiment 2*

*Risky decision-making* *behavior*

We analyzed the baseline condition the same way as in the episodic and control induction groups. Upon examining the mean level of risky choices for each participant after trial 24 (Madan et al., 2013; Madan et al., 2014), we found that risk-taking in the episodic induction group (*M* = 0.479, *SD*=0.173) was not significantly different than in the baseline group (M = 0.424, SD = 0.199; F(1,42) = 0.94, p = 0.337) and that risk-taking in the baseline group was not significantly higher than in the general impressions induction group, even though the difference was trending (M = 0.34, SD = 0.122; F(1, 41) = 2.7, p = 0.108; Figure 2A). A mixed-effects logistic regression revealed that learning of risk preferences over time (condition X trial interaction) in the episodic and baseline conditions were not significantly different from each other (Figure 2B*; β* = 0.41, SE = 0.531, p = 0.42). This interaction between the control and baseline conditions was not significant either but trending (*β* = 0.86, SE = 0.53, p = 0.11).

*Memory for Outcomes*

Participants in the baseline group were not significantly more likely to report the positive outcome as the first one to come to mind χ2(1, N = 23) = 2.13, p= 0.144 (see Figure 3A). Within the baseline condition, participants with positive recall were more likely to choose the risky option after trial 24 (F(1,21) = 9.33, p = 0.006; Figure 3B).

**Discussion**

We examined how inducing an episodic specificity state — which is thought to bias participants towards using episodic memory processes— bears upon risk preferences in a risky decision-making task. This was achieved by combining an episodic induction (Madore et al., 2014) with a gambling task in which risk is learned from experience (Madan et al., 2013). We found much lower apparent risk-taking in the general impressions than in the episodic specificity induction (figure 2A). It seems this difference is mainly driven by the general impressions induction lowering risk-taking, since risk-taking in the baseline condition is more similar to the episodic specificity than to the general impressions condition. . Further, the difference in risk preferences between these two induction techniques grew over time: while the episodic and baseline conditions appeared to engender relatively stable their risk-preferences over time, participants in the general impressions condition became progressively more risk-averse in their choices after an apparent initial period of exploration (Figure 2B). However, this isn’t perfectly clear since the differences in means and slopes between the general impressions and baseline conditions are only marginal. Even so, the episodic and baseline conditions are consistent with findings reported from Madan et al. (2013) and Ludvig et al. (2014) who used the same risky decision-making task, and found that in the gains conditions, risk-taking did not significantly change over time. In light of these findings, 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 (see figure 3A). We suggest individuals may naturally approach risk-taking behavior through an ‘episodic lens’, thus when biased towards non-episodic recall, risk choice is altered. Learning choices from experience already requires and induces episodic memory to a certain extent, and the episodic specificity induction might not have been able to enhance the use of episodic memory much beyond that point. Even though the control induction group was meant as a control against which to compare the episodic specificity induction group, it requires participants to recall information in a general manner. Previous work (insert appropriate Madore citation here) has suggested the general impressions induction to act as a proper control condition in recall tasks. However, episodic memory has been shown to be important when encoding the association between items and rewards (Wimmer & Shohamy, 2012). In the present study, both encoding and recall take place after the induction. It is therefore possible that the general impressions induction could dampen the normal use of episodic processes in encoding information learned from experience (Madore & Shacter, 2014; but see Madore et al., 2014)—that is, if the decision-making from experience task by itself brings to bear episodic processes which increases 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. (2013), whose observed risk-taking levels were closer to the baseline and the episodic groups than to the general impressions condition in the present study. Further, participants in the episodic specificity but not in the control induction condition were more likely to recall the positive extreme outcome when asked about the risky action, suggesting a memory bias whereby these extreme positive outcomes are overweighed—indeed, the true rate of positive and negative outcome occurrences was 50/50. This could possibly be due to the role of episodic memory in enhancing associations between experienced events and their associated outcomes (Wimmer & Shohamy, 2012). Regarding recall, we could replicate overweighing of the positive outcome in memory for the episodic induction condition but not for the baseline condition (Madan et al., 2013; see figure 3A). However, this difference was trending in the baseline condition, but not in the control induction condition. This is consistent with the idea that episodic memory processes strengthen memory for extreme outcomes. The tendency for participants who reported the positive outcome to be more risk-seeking could be observed in the baseline condition (Madan et al., 2013), but not in the episodic and general imp conditions (see figure 3B). This suggests the episodic specificity induction procedure might possibly override the relationship between risk preferences and the reported first outcome that comes to mind by having participants report the positive outcome in the episodic condition, or the negative outcome in the general impressions condition, independently of their actual behavior on the task.

Applying an RL model-based analysis to choice behavior, we revealed the episodic specificity induction to attenuated the typical ‘negativity bias’—whereby negative PEs are more strongly weighted than positive PEs (Christakou et al., 2013; Gershman, 2015)—which was observed in the control induction. Similarly, participants in the control induction condition were risk-averse but not so much in the episodic induction condition (see figure 2). Since episodic memory contributes to adaptive decision-making (Murty et al., 2016; Duncan & Shohamy, 2016), it is possible that episodic memory plays a role in reducing inherent bias against risk.

Taken together, these results suggest that episodic memory processes play a critical role in establishing risk preferences from direct experience. More specifically, it seems people naturally tend to use episodic memory when learning to make decisions from experience. We have also found that detracting people from their natural tendencies to use episodic memory significantly reduces risky behavior, as suggested by both the behavioral and RL model-based analysis. A possible mechanism for this is how episodic memory spreads rewards to similar instances to the one which was rewarded (Wimmer & Shohamy, 2012), reducing the inherent bias against risk observed in decisions from decision between gains (citation?). An alternative viewpoint is that episodic memory might enhance the extreme-outcome effect observed by Madan et al. (2013). Both possible mechanisms are supported by the tendency to recall the positive outcome in the episodic condition and the negative outcome in the general impressions condition.

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