Creating False Rewarding Memories Guides Novel Decision-making

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Abstract

When memories of past rewarding experiences are distorted, are relevant decision-making preferences impacted? Although recent research has demonstrated the important role of episodic memory in value-based decision-making, very few have examined the role of false memory in guiding novel decision-making. The current study combined the pictorial Deese/Roediger-McDermott (DRM) false memory paradigm with a reward learning task, where participants learned that items from some related lists gained reward and items from other lists led to no reward. Later, participants' memories and decision-making preferences were tested. With three experiments conducted in three countries, we successfully created false memories of rewarding experiences in which participants falsely remembered seeing a non-presented lure picture bring them reward thereby confirming our constructive association hypothesis. Such false memories led participants to prefer the lure pictures and respond faster in a follow-up decision-making task, and the more false memories they formed, the higher preferences for the lure items they displayed (Experiment 2). Finally, results were replicated with or without a memory test before the decision-making task, showing that the impact of false memory on decision-making was not cued by a memory test (Experiment 3). Our data suggest that the reconstructive nature of memory enables individuals to create new memory episodes to guide decision-making in novel situations.

Keywords: false memory, decision-making, constructive association, reward, episodic memory

Creating False Rewarding Memories Guides Novel Decision-making

Remembering past experiences can guide people to make decisions when encountering similar situations, which has great adaptive value for human survival. For example, when people remember receiving good service from a particular airline, they tend to take that airline again for future trips. Recent research has shown the critical role of episodic memory in value-based decision-making (Gershman & Daw, 2017; Shohamy & Daw, 2015). Episodic memory enables one to encode each single rewarding experience in the memory system (Eichenbaum & Cohen, 2004; Tulving, 2002), and retrieving a specific winning or losing memory from the past can directly impact people's decisions regardless of the average winning probability (Bornstein et al., 2017). However, because memory is a reconstructive system that is susceptible to errors (Bartlett, 1932; Schacter, 2012), a natural question is: when false memories about past rewarding experiences occur, would relevant decision-making be impacted? The current study was primarily interested in answering this question.

In experience-based decision-making, people's memories of past rewarding outcomes tend to be biased in a way that they normally overestimate the extreme gains and losses, and such memory bias is found to be correlated with risk preferences (Ludvig et al., 2014; Madan et al., 2014; Mason et al., 2022). This implies that what people remember about reward outcomes is not always what they have truly experienced, suggesting the potential role of distorted memory in decision-making. Related research showed that priming memories of previous winning experiences caused people to become more risk-seeking compared to no memory priming (Ludvig et al., 2015). In another decision-making task with repeated trials, reminding a person of a past winning memory can make them repeat that action, while reminding a person of a past losing memory makes them avoid the action (Bornstein et al., 2017).

For example, a person would still choose to bet after remembering a winning trial even though the average winning probability is only 30%. By evaluating participants' choices in repeated trials, such studies have shown that samples of individual episodic memories rather than incrementally averaged reward probability can guide one's decisions.

Memory of an experience can guide people's decisions when they encounter the same situation. However, in real life, it is rare for a person to encounter the exact same choices again, and normally people are faced with novel, never experienced situations. As episodic memory can directly guide decisions (Bornstein et al., 2017; Gershman & Daw, 2017; Murty et al., 2016) and memory is reconstructive in the sense that (false) memories of non-experienced events can be formed (Howe & Otgaar, 2013; Schacter, 2012), it is possible that the reconstructive nature or flexibility of our memory system may enable an individual to "use" their reconstructed memory to guide future decision-making in completely novel situations. There is evidence showing that false memories of food history (e.g., being ill after eating egg-salad) have consequences on one's eating behavior (Bernstein & Loftus, 2009). However, so far, little research has examined the role of false memory in value-based decision-making. Hence, the current study aimed to answer the following two specific questions: (1) Can false memories of past rewarding experiences be created? (2) Would false rewarding memories impact later decision-making with novel options?

As the consequence of memory reconstruction, false memory refers to the phenomenon when someone has memories of events or details that never actually occurred (Loftus, 2005; Roediger & McDermott, 1995). False memory is a common phenomenon in daily life (e.g., mistaking a stranger for someone they know), and numerous studies have shown that people can spontaneously form false memories of words, pictures, or even rich events such as seeing footage of an airplane crash (Crombag et al., 1996; Roediger & McDermott, 1995; Wang et al., 2018). A standard paradigm to create false memories in the lab is the Deese/Roediger-McDermott paradigm (DRM; Deese, 1959; Roediger & McDermott, 1995), where lists of associatively related words such as *bus, truck, Jeep, train, tire, Ford, key,* and *garage*, are shown to the participants. Those words are all associated with a critical lure "car" and participants frequently generate a false memory of seeing the non-presented word "car", accompanied by vivid recollections and high confidence (Norman & Schacter, 1997; Roediger & McDermott, 1995).

Research further used pictorial versions of the DRM paradigm by presenting participants with pictorial representations of the list items (e.g., images of *bus, truck, Jeep, train,* etc.) and still found a robust false memory effect for non-presented lure pictures (i.e., remembering seeing an image of a car; Schacter et al., 1999; Wang et al., 2018). A recent study showed that complete, yet false *item-person-context* memory episodes can be automatically created (Wang et al., 2021a). Specifically, Wang and colleagues made a modification to the DRM paradigm such that the DRM pictures embedded within a context (e.g., a bus within a flower pattern background) were presented together with a reference person. They found that participants not only falsely recognized the lure pictures (i.e., false memory for an item), but also recalled that it was embedded in a specific context and was paired with a person (i.e., false memory for associations; see also Wang et al., 2021b). Such lure-person and lure-context false memories were termed as false episodic memories as neither was the lure picture presented nor was it ever embedded in a context or paired with a person.

Hence, these false episodic memories are essentially false associative memories, referring to misattributing the lure to a certain source.

Spreading activation theories such as the Activation Monitoring Theory (AMT; Roediger et al., 2001) and the Associative Activation Theory (AAT; Howe et al., 2009; Otgaar et al., 2018) have provided possible explanations for mechanisms underlying the false memory phenomenon. Both AMT and AAT suggest that the presentation of related list items would activate their corresponding mental representations. These activations can spread to nearby associated non-presented lure items within the episodic and semantic memory networks (see also early work by Anderson, 1983). As the left part of Figure 1 shows, seeing words or pictures of *bus*, *truck, Jeep, train, etc.* automatically activates the mental representation of the lure item “car”. Multiple activations of “car” can make participants mistake the presence of the item later. During a monitoring stage, when participants fail to distinguish whether they have seen or only thought about the “car” item, they may form a false memory of seeing the “car”.

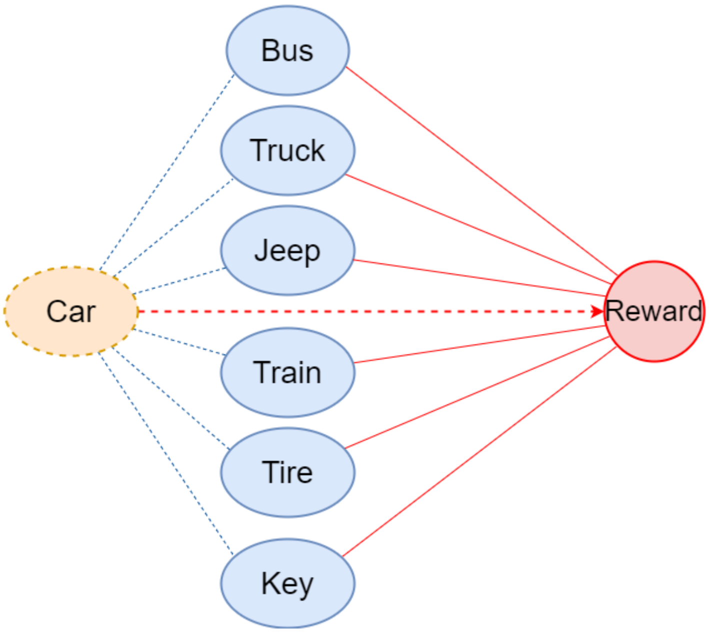


Figure 1. Hypothetical associative memory network to illustrate the constructive association mechanism (modified from Wang et al., 2021b) based on spreading activation theories (Howe et al., 2009; Roediger et al., 2001). When DRM list items (e.g., bus, truck, jeep, train, tire, and key) are paired with reward, a false association may be created between the non-presented lure item (i.e., car) and reward, creating a false memory episode of past rewarding experience. Red lines refer to the pairing of stimuli and reward during study. Blue dashed lines represent existing semantic associations among items in the memory network, and the red dashed line with arrow represents the proposed false association.

The spreading activation account is based on a preexisting memory network (Roediger et al., 2001) and describes how activation of related concepts could spread to nearby concepts leading to false memory of an item. An untouched question is whether *false associations*, such as false rewarding memories, can be automatically created to update the existing memory network and the consequences of false associations. As a supplement to the spreading activation mechanism, we propose a *constructive association hypothesis* that new memory associations between concepts could be automatically created within the memory network when mental representations of the concepts are co-activated during the encoding phase (see also Wang et al., 2021b). That is, participants can *consciously recall* a false associative memory even though they never experienced it.

This hypothesis is generated based on evidence from three lines of research. First, Roediger and colleagues (2004) presented participants with DRM lists with male or female voices and then gave them a recognition test with voice-source judgments. When DRM lists were read out by a male (or female) voice, participants frequently attributed related lures to be read out by that same male (or female) voice (see also Hicks & Starns, 2006; Payne et al., 1996). Second, in a study where participants were shown DRM lists in different locations on a computer screen, participants frequently judged the falsely recognized lures as having appeared in the same location as the corresponding DRM lists (Franks et al., 2016). Finally, a series of studies demonstrated that when related list items were paired with a person during encoding, participants would falsely remember the lure being paired with that person (Wang et al., 2021a, 2021b). Thus, when related items (e.g., *bus*, *truck*, *Jeep*, *train*, etc.) are paired with the same source, such as a voice, a context, or a person, participants frequently remember that the non-presented lure item (i.e., *car*) is also associated with that source. This is possibly because the lure item is activated in the study phase during which the source is also presented (McDermott, 1997; Meade et al., 2010; Roediger et al., 2001), thus the co-activation of the lure item and the source leads to a false association established between the lure item and the source. Based on our constructive association hypothesis, we predicted that if DRM list members were paired with a reward, participants would form false associative memories that they misremember the lure item pairing with a reward, creating false memories of past rewarding experiences (see Figure 1).

There are other theories making hypotheses about the memory reconstruction mechanisms such as the episodic simulation hypothesis (Schacter & Addis, 2007; Schacter, 2012; Schacter et al., 2017) and the memory integration account (Biderman, Bakkour, & Shohamy, 2020; Shohamy & Daw, 2015). These theoretical accounts emphasize the recombination of different memory episodes when making inferences, but not necessarily the formation of new memory episodes. For example, Carpenter and Schacter (2018) found that after learning AB and BC pairs (where A was linked to reward), participants preferred C only after making successful inferences between A and C via recombining AB and BC episodes. Yet, such recombination process does not require the creation of a novel and false "AC" memory episode. Our constructive association hypothesis differs from existing theories critically in that we propose that a direct yet phantom memory association could be established for non-experienced stimuli, resulting in false memory episodes.

In order to test this hypothesis, we constructed a new experimental paradigm to create false rewarding memory episodes by combining the DRM paradigm with a reward learning task. Specifically, during the study phase, pictures of DRM items were paired with monetary reward or no reward. Later, in a memory test, participants' memories of the items and their reward outcomes were tested. We expected that participants would falsely remember seeing the non-presented lure pictures paired with the reward outcome. Experiment 1 served as an initial test of this hypothesis. To test whether such false rewarding memories guide decision-making with novel options, Experiments 2 and 3 added a decision-making task after the memory test, where two options of never studied pictures (e.g., a lure picture vs. another unstudied picture) were provided and participants had to make a choice to gain monetary reward. We expected that participants would prefer those lure pictures to win money. If false memory can indeed drive novel decision-making, we expected that the number of false rewarding memories should predict participants' preference for the lure pictures.

Experiment 1

Method

Participants

Based on our previous research on false associative memory (Wang et al., 2021a), we estimated a medium to large effect size (d = 0.6) of forming false rewarding memories. An a priori power analysis using the program G*Power (Faul et al., 2007) showed that at least twenty-four participants are needed to achieve a power of 0.8 (paired-samples t-test, $\alpha = .05$, two-tailed). Overall, 25 participants were tested with a mean age of 22.2 years old (*SD* = 1.66, 12 men and 13 women). Participants were exchange students who spoke English at Sungkyunkwan University, South Korea. Participants received a Starbucks voucher worth 5000 Won as compensation for their time. Ethical approval was received from the Ethical Board of the Faculty of Psychology and Neuroscience, Maastricht University as well as from Sungkyunkwan University. The experiment was pre-registered on the Open Science Framework[1] (https://osf.io/msvc8).

Materials

Ten pictorial DRM lists were used. The pictorial lists were from previous research and were normed for image and name agreement (Wang et al., 2018, 2021b). Each pictorial list contained eight pictures (e.g., *shoe, hand, toe*) that were all related

[1] The registration occurred after data collection began but before access to those data.

to a non-presented lure picture (i.e., *foot*). Therefore, participants saw 80 DRM pictures in total. Five pictorial lists were presented together with a monetary reward (i.e., a five-thousand Korean won bill, which is around 3.71 US dollars), whereas the other five pictorial lists were paired with no reward, (i.e., a gray rectangle). The ten pictorial lists were pseudo-randomly assigned to the reward and no reward conditions, and were counterbalanced in a way that each list had an approximately equal chance of appearing in the reward or no reward condition. The recognition list contained 80 pictures in total, including 10 non-studied lure pictures (one lure picture per list), 30 studied pictures (3 pictures from each list), 30 unrelated new pictures that were not related to any of the DRM lists, and an additional 10 weakly related new pictures (i.e., these items were the 9th member of the original DRM lists and thus were related to the DRM lists).

Design and Procedure

The experiment was a within-subject design, with the pictorial lists assigned to either Reward or No-reward condition. The experiment consisted of a reward learning phase and a memory test phase. Each participant was tested individually for around 25 minutes.

In the reward learning phase, participants were instructed to observe carefully and find out which pictures would win them money and which pictures would not win them money. As Figure 2 shows, the pictures were presented on a white screen, with one picture on the left and the money/gray rectangle on the right. Each pair, consisting of one DRM picture and its associated reward or the gray rectangle, was shown for 2000 ms followed by a 1000 ms blank before the next pair appeared. This phase was separated into five blocks and each block contained one rewarded DRM list and one non-rewarded DRM list. Within each block, the two pictorial DRM lists were intermixed and the presentation sequence was randomized. Each DRM list had an equal chance of appearing in the reward or no reward condition. After the reward learning phase, participants played Tetris for 5 minutes as a filler task.

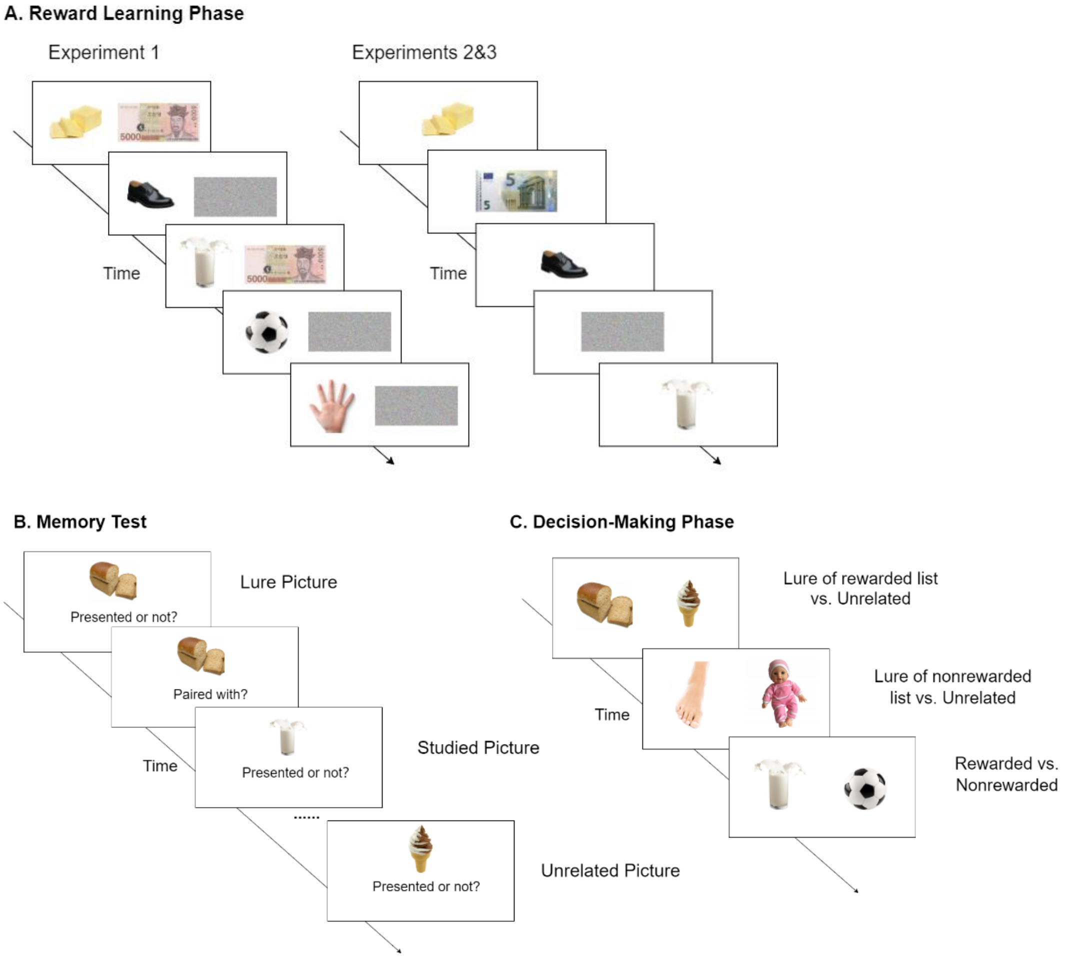


Figure 2. Schematic figure for the general procedure in three experiments. Experiment 1 consisted of a reward learning phase and a memory test, while Experiments 2 and 3 consisted of a reward learning phase, a memory test, and a decision-making phase. (A) reward learning task: participants learned that, in each block, some related items (e.g., *butter*, *milk* from the *bread* list) were paired with reward while the other items (e.g., *shoe*, *football*, *hand* from the *foot* list) paired with no reward. (B) memory test: participants had to answer a recognition question regarding whether a picture was presented in the reward learning phase and a reward source question regarding whether it was paired with a reward or no reward. Note that the recognition questions and reward source questions were asked separately in Experiment 1. (C) decision-making phase: participants needed to choose between two pictures to gain money.

Then participants' memories of the rewarding experiences were tested. The memory test phase consisted of a recognition task and a reward-source memory task. In the recognition task, a picture appeared in the middle of the screen and participants had to indicate whether the picture was new, remembered, or known (Wang et al., 2021a, 2021b; Yonelinas, 2002). Differences between the three options were thoroughly explained to the participants. If they could not recognize the picture, they chose "new"; if they recognized the picture, they chose either "remember" or "know", with the former indicating they remembered vivid details of the picture (e.g., the position, shape, paired reward) and the latter indicating that they recognized the picture but could not recall specific details. After the recognition task, their memories of reward were tested. Participants were asked, for the same pictures, whether each picture was paired with money or not. They could also answer the picture was "not presented" or "cannot remember" whether the picture was rewarded/not rewarded. Thus, participants had a second chance to respond "not presented" in this question.

Results

Before examining our hypothesis that participants would generate false memories of rewarding experiences, we first had to make sure that participants falsely recognized the lure pictures as presented. We first report false recognition data and false rewarding memories, and then true recognition rates and true rewarding memories.

False Memory

False Recognition. When participants responded "remember" or "know" (i.e., old) to a non-presented lure picture in the recognition task, it was classified as a false recognition (see Yonelinas, 2002). The false recognition rate was calculated as the number of false recognitions divided by the total number of lure pictures. On average, participants falsely recognized 42% (95%CI [0.32, 0.53]) of the lure pictures in the reward condition, which was statistically significantly higher than the mean false recognition rate of unrelated new pictures (M = 0.04, 95%CI [0.02, 0.05]), $t(24)$ = 7.85, $p < .001$, d = 1.57. The mean false recognition rate for lure pictures in the no reward condition was 41% (95%CI [0.30, 0.52]) which was also statistically higher than the mean false recognition rate of unrelated pictures, $t(24) = 7.24$, $p < .001$, d = 1.45. False recognition rates did not differ significantly in the reward and no reward conditions, $t(24) = 0.32$, $p = .75$, $d = 0.06$. These results suggest that we have successfully evoked false memories of lure pictures in both rewarding conditions.

False Rewarding Memory. A false rewarding memory was defined as when participants falsely remembered that a non-presented lure picture was paired with money. For example, when a participant recognized a picture in the recognition question AND responded that the picture was paired with money in the reward memory question, it was categorized as a false rewarding memory. The false rewarding memory rate was calculated as the number of false rewarding memory (i.e., “money” responses in the reward memory question) divided by the total number of lures. Indeed, in the reward condition, participants falsely remembered 37% (95%CI[0.26, 0.48]) of the total lure pictures paired with money (see Table 1), being statistically higher than the chance of misremembering an unrelated picture paired with money (M = 0.007, 95%CI[0.001, 0.01]), $t(24) = 6.87$, $p < .001$, d = 1.37. These results suggest that we have successfully induced false memories of rewarding experiences. When a participant recognized a picture in the recognition question and responded that the picture was paired with no money, it was categorized as a false non-rewarding memory. False non-rewarding memory rate was calculated as the number of false non-rewarding memory divided by the total number of non-rewarded lures. In the no reward condition, participants formed false non-rewarding memories instead of false rewarding memories that they falsely remembered 43% (95%CI[0.32, 0.54]) of the lure pictures pairing with no reward.

Table 1. Mean rates of false rewarding memory and false nonrewarding memory for lure pictures, related pictures, and unrelated pictures in Experiments 1, 2, and 3 (Means with 95% Confidence Intervals).

	False Rewarding Memory	False Nonrewarding Memory
Experiment 1		
Lure Picture	0.37 [0.26, 0.48]	0.43 [0.32, 0.54]
Related Picture	0.19 [0.12, 0.26]	0.13 [0.07, 0.19]
Unrelated Picture	0.007 [0.001, 0.01]	0.04 [0.01, 0.07]
Experiment 2		
Lure Picture	0.32 [0.25, 0.39]	0.33 [0.25, 0.41]
Related Picture	0.09 [0.03, 0.14]	0.03 [0.007, 0.05]
Unrelated Picture	0.005 [0.0005, 0.01]	0.004 [0.0006, 0.008]
Experiment 3		
Lure Picture	0.38 [0.31, 0.46]	0.37 [0.30, 0.42]
Related Picture	0.08 [0.04, 0.12]	0.07 [0.04, 0.11]
Unrelated Picture	0.005 [-0.001, 0.01]	0.01 [0.003, 0.02]

True Memory

True Recognition. True recognition rate was calculated as the number of “remember” and “know” (i.e., old) responses divided by the total number of studied pictures in the recognition test. Overall, participants correctly recognized 88% (95%CI[0.79, 0.96]) of the studied pictures in the reward condition, which was statistically higher than the mean recognition rate in the no reward condition (M = 0.74, 95%CI[0.65, 0.83]), $t(24) = 3.99$, $p < .001$, $d = 0.80$.

True Rewarding Memory. When participants correctly remembered that a studied picture was paired with money, it was classified as a true rewarding memory. Participants formed true rewarding memories for 73% (95%CI[0.62, 0.83]) of the total studied pictures in the reward condition. In the no reward condition, participants correctly remembered that 48% (95%CI[0.39, 0.58]) of the studied items were paired with a gray rectangle (i.e., no reward). Paired samples t-test showed that participants remembered the rewarding episodes better than the non-rewarding experiences, $t(24) = 5.39$, $p < .001$, $d = 1.08$.

Remember/Know Responses

We further analyzed whether the rewarding condition (i.e., reward vs. no reward) would affect the percentage of memory component (i.e., remember vs. know) of false and true memories, respectively. As can be seen in Table 2, paired samples t-test showed that participants had statistically higher percentage of remember responses to lure pictures in the reward condition than in the no reward condition, $t(24) = 3.44$, $p = .002$, $d = 0.69$, while participants had statistically lower Know response rates in the reward condition than in the no reward condition, $t(24) = 3.44$, $p = .016$, $d = 0.52$. Hence, reward could enhance participants' phantom recollection experiences of the non-presented lure pictures.

Table 2. Mean percentage of Remember and Know responses in Reward and No Reward conditions for lure pictures and studied pictures (Means with 95% Confidence Intervals).

	Lure Pictures		Studied Pictures	
	Remember	Know	Remember	Know
Reward	0.21 [0.14, 0.28]	0.22 [0.13, 0.30]	0.74 [0.62, 0.85]	0.14 [0.06, 0.22]
No Reward	0.07 [0.009, 0.14]	0.34 [0.22, 0.45]	0.50 [0.41, 0.59]	0.24 [0.17, 0.31]

We found similar results on remember and know percentages of studied pictures. Participants had more remember responses in the reward condition relative to the no reward condition, $t(24) = 4.44$, $p < .001$, $d = 0.89$, suggesting that reward boosts the memory of rewarded pictures. Meanwhile, participants had fewer know responses in the reward condition than in the no reward condition, $t(24) = 2.44$, $p = .022$, $d = 0.49$.

Discussion

In Experiment 1, we have successfully created false memories of rewarding (and non-rewarding) experiences, confirming our constructive association hypothesis. With a false memory paradigm incorporated within a reward learning procedure, participants not only falsely recognized the lure pictures as presented but also falsely remembered that the lure pictures had been paired with reward. Participants on average generated false rewarding memories for 37% of the total lure pictures. Results on Remember/Know responses further showed that reward has increased the phantom recollection of the lure pictures in that participants reported more Remember responses to lure pictures of the rewarded lists than those of the non-rewarded lists.

Reward also increased true recognition as well as the true rewarding memories of rewarded pictures. These results were consistent with previous research showing the reward-enhanced memory effect (Shohamy & Adcock 2010; Miendlarzewska et al., 2016; Knowlton & Castel, 2022). That is, people normally remember items with high value better than those with low value, which shows how reward can shape one's memory. It is also adaptive for individuals to prioritize valuable information in daily life. In particular, our experiment revealed that reward increased true memory via increasing Remember responses or the recollection component of memory, so participants were more likely to retrieve specific details of rewarded pictures. Bui et al. (2013) found that reward can boost false memory formation, but we did not find any effect of reward on false memory formation here. The reason might be that previous research used word DRM lists, whereas the current study used pictorial DRM lists that have higher distinctiveness than word lists. According to the Fuzzy-trace Theory (FTT, Brainerd & Reyna, 2002), retrieving verbatim traces (e.g., sensory details) can inhibit false memory production. Our results showed that reward can enhance verbatim traces for studied items as measured by increased Remember responses, so enhanced verbatim traces might have canceled out the reward-enhanced effect on false memory production for pictorial lure items.

The rewarding learning task in Experiment 1 was passive that participants merely viewed the stimulus-reward pairs. The task also measured intentional memory because participants were asked to remember the pictures and their corresponding reward before encoding. However, in real-life experiences, reward learning is usually incidental (e.g., people walk into a restaurant and find the food delicious). In Experiment 2, we changed the reward learning task into an active learning task as in typical reward learning research (e.g., Bornstein et al., 2017). That is, participants saw a DRM picture and had to bet whether it would win them money or not. After they made a choice, either reward or no reward was presented. In this way, participants actively gained rewarding experiences instead of passively remembering the rewards.

Furthermore, one limitation of Experiment 1 was that the recognition test and reward memory test were separated. Participants had seen the lure pictures once in the recognition test when taking the reward memory test, which might boost their false rewarding memories. Hence, in Experiment 2, the recognition test and the reward-source memory test were combined in one memory test. For each picture, participants first answered a recognition question and then answered the reward memory question immediately after the recognition question.

Having established that false rewarding memories could be created in Experiment 1, we examined the consequences of the false rewarding memories via adding a decision-making task in Experiment 2. Specifically, after the reward learning phase and the memory test, participants had to choose between two pictures to win money (i.e., a value-based decision-making task, Shohamy & Daw, 2015). Previous research showed that decision preference can be a reliable indicator for memory-based decision-making (Weilbächer et al., 2020). Of interest was that participants needed to choose between a lure picture and another new picture. Due to findings in Experiment 1 that participants could generate false rewarding memories of lure pictures being rewarded, we hypothesized that participants would exhibit preferences for lure pictures of the rewarded DRM lists relative to a random new picture. Moreover, if false memory can indeed cause decision preferences to the lure pictures, more false rewarding memories would lead to more preferences. Hence, we also expected that the level of false memory would positively predict the level of decision preferences to lure pictures.

Experiment 2

Experiment 2 followed a similar procedure as in Experiment 1 but had the following differences. First, in the reward learning phase, participants needed to predict whether the presented DRM picture could win them money or not. Second, the recognition question and reward memory question were asked consecutively for each picture in one memory test. Finally, a decision-making task was added after the memory test.

Method

Participants

Our new paradigm showed a large effect (d = 1.37) of inducing false rewarding memories in Experiment 1, but no research existed on the effect of false rewarding memories on decision-making. We made a conservative estimation of medium effect size (d = 0.5) on the interested effect. An a priori power analysis (using G*Power) showed that at least 34 participants were needed to achieve a power of 0.80 (α= .05; two tailed). Experiment 2 was not pre-registered. In total, thirty-nine participants (36 women and 3 men) completed the experiment. Participants' age ranged from 17 years old to 23 years old, with a mean age of 19.79 (*SD*= 1.56). Participants were recruited at Maastricht University, The Netherlands, and received 1 course credit for their participation.

Materials, Design and Procedure

Experiment 2 used the same materials from Experiment 1. Ten pictorial DRM lists were assigned to the Reward or No reward condition. As Figure 2 shows, Experiment 2 followed a similar procedure as in Experiment 1 except for the following.

In the reward learning phase, a DRM picture was presented at the center of the screen and participants had to guess whether the picture would lead to a monetary reward or not. If they expected money, they should press the "Y" button, and if they expected no money, they should press the "N" button. After participants' response, a five-euro image or a gray rectangle appeared, indicating gaining five euros or no reward. Participants were told that their accuracy of prediction would be recorded, and their responses would not impact the rewarding result of each picture. There were five blocks in the reward learning phase and each block consisted of one rewarded DRM list and one non-rewarded list. The two lists were intermixed and the sequence of the pictures was randomized. Stimuli in the reward and no reward conditions were counterbalanced.

After playing Tetris for 10 minutes, participants' memories for previous rewarding experiences were tested. For each picture in the memory test, a recognition question was asked first that participants had to answer if the picture was presented or not in the learning phase. Then a reward-source memory question followed where participants responded whether they remembered the picture bringing reward or no reward by choosing one of the four options: Rewarded, Not Rewarded, Cannot Remember, and Not presented (see Figure 2). In the last vividness question, participants rated the vividness of their reward or non-reward memory on an 8-point Likert-like scale with 1 indicating no memory at all and 8 indicating clear and complete memory (Otgaar et al., 2013).

Immediately after the memory test, participants went through the decision-making phase (Wimmer & Shohamy, 2012; Wang et al., 2019a). In each trial, two pictures appeared left and right on the screen. Participants were told to try to earn as much money as possible by choosing the left or right picture that they thought could win them money. Participants did not see any reward feedback immediately after each trial to avoid re-learning, but they were told that the reward would accumulate and be shown to them by the end of the task. Critically, we tested participants' preferences to the lure pictures such that they had to choose between a lure picture and an unrelated picture, both of which were not presented in the reward learning phase but appeared in the memory test. Note that we did not ask participants to choose between two lure pictures from a rewarded list and a nonrewarded list because it was difficult to judge whether the decision was based on false rewarding or nonrewarding memory. For example, if a participant chose "car" over "foot", it is unknown whether they made the choice because they misremembered car being rewarded or they avoided "foot" because they misremembered that "foot" did not bring reward. We also tested participants' reward learning performance by asking them to choose between a rewarded picture and a nonrewarded picture. There were 5 lures from the rewarded lists and 5 lures from the nonrewarded lists, hence there were 10 *lure vs. unrelated* picture pairs and 5 *rewarded vs. nonrewarded* picture pairs in total. Each picture pair was repeated four times with each picture appearing on the left or right side equally (see Wimmer & Shohamy, 2012), leading to 60 trials (15 pairs *4 times) in total.

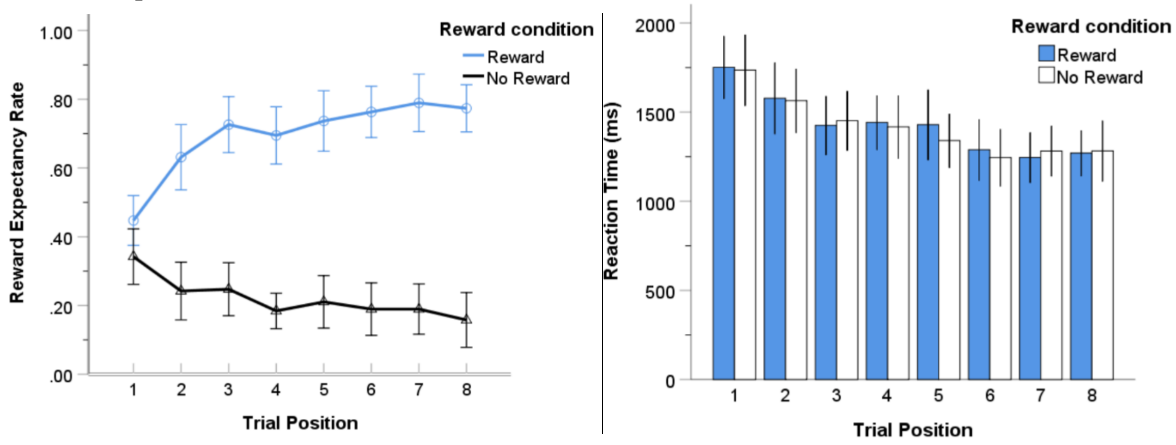
Results

We will first report data in the reward learning phase to show participants' reward learning performance. Then we will report false memory and true memory data in the memory test. Finally, data from the decision-making task will be reported to test our main hypotheses concerning whether participants would show decision preferences to the lure pictures of rewarded DRM lists and whether false memory levels could predict such preferences.

Reward Learning Performance

We examined whether participants had successfully learned the reward rather than making random responses in the reward learning phase. One participant's data in the reward learning phase were not recorded due to technical issues, leaving thirty-eight participants' data in total. There were five learning blocks and each block contained eight rewarded pictures (i.e., one rewarded DRM list) and eight nonrewarded pictures (i.e., one nonrewarded DRM list). For a single trial, if the participant predicted monetary reward by responding "Y", the reward expectancy was 100%; if they responded "N", the expectancy was 0. We collapsed data across five blocks and calculated participants' mean reward expectancy rate (i.e., percentage of "Y" responses) for each trial position (1-8) in each reward condition. A 2 × 8 repeated measures ANOVA was conducted, and Greenhouse-Geisser correction was applied when the sphericity assumption was not met. As Figure 3 shows, an interaction between reward condition and trial position was found on the mean expectancy rate, $F(4.78, 176.81) = 15.36$, $p < .001$, partial $\eta^2 = .29$. Simple main effect analysis indicated that as trials progressed, participants' expectancy rates of reward for pictures belonging to the rewarded DRM list increased, *F*(7, 259) = 15.90, *p* < .001, whereas their expectancy of reward for pictures in the non-rewarded DRM list decreased, *F*(7, 259) = 3.89, *p* < .001. The results suggest that participants successfully differentiated the two DRM lists in each block and learned the associations between reward and the pictures.

A. Experiment 2



B. Experiment 3

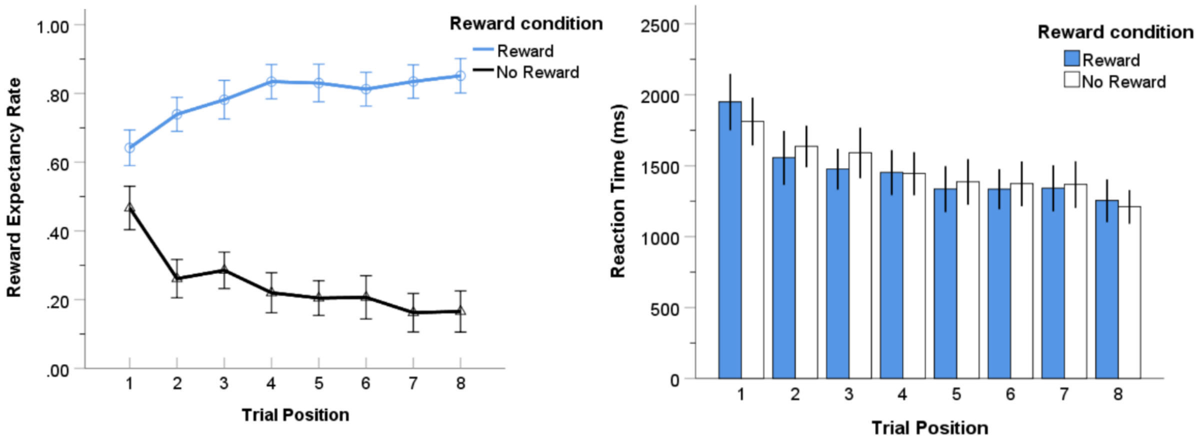


Figure 3. Reward expectancy rates and reaction times across different trial positions in the Reward and No Reward conditions in Experiments 2 and 3. Error bars represent 95%CI.

We also analyzed the reaction times participants took when responding to the pictures. Following our previous research (Wang et al.,2019b), only reaction times between 300 ms and 8,000 ms were included into analysis, which was consistent with general rules in reaction time tasks such as the implicit memory test (Greenwald, Nosek, & Banaji, 2003). We did not find a significant interaction effect between reward condition and trial position, $F(5.34, 197.55) = 0.41$, $p = .85$, partial $\eta^2 = .01$. The effect of trial position was statistically significant, $F(4.70, 173.82) = 18.10$, $p < .001$, partial $\eta^2 = .32$, indicating that participants responded faster as trials emerged (see Figure 3A). The effect of reward condition was not significant, $F(1, 37) = 0.23$, $p = .64$, partial $\eta^2 = .01$, suggesting that the average stimuli exposure times did not differ for rewarded and nonrewarded pictures.

False Memory

Participants falsely recognized 44% (95%CI [0.36, 0.52]) of the lure pictures in the reward condition, and falsely recognized 45% (95%CI [0.37, 0.52]) of the lure pictures in the no reward condition. The two means did not differ significantly, $t(38) = 0.12$, $p = .91$, $d = 0.02$. Importantly, participants formed false rewarding memories in the reward condition that they remembered 32% (95%CI [0.25, 0.39]) of the lure pictures had brought them money, while they falsely remembered that 33% (95%CI [0.25, 0.41]) of the lure pictures in the no reward condition had brought them a gray rectangle. The mean vividness score for false rewarding memories ($M = 5.17$, 95%CI [4.58, 5.76]) did not differ significantly from that for false nonrewarding memories ($M = 4.76$, 95%CI[4.20, 5.32]), $t(30) = 1.60$, $p = .12$, $d = 0.29$.

True Memory

Participants correctly recognized 94% (95%CI[0.92, 0.97]) of the studied pictures in the reward condition, which was not statistically different from the mean recognition rate in the no reward condition ($M = 0.93$, 95%CI[0.90, 0.95]), $t(38) = 1.30$, $p = .20$, $d = 0.21$. Participants formed true rewarding memories for 70%

(95%CI[0.63, 0.77]) of the total studied pictures in the reward condition. In the no reward condition, participants correctly remembered that 71% (95%CI[0.65, 0.76]) of the studied items were paired with no reward. In Experiment 2, participants remembered the rewarding experiences and non-rewarding experiences to a similar extent, $t(38) = 0.16$, $p = .88$, $d = 0.03$. However, the mean vividness score for true rewarding memories ($M = 6.16$, 95%CI[5.85, 6.47]) was significantly higher than that for non-rewarding memories ($M = 5.76$, 95%CI[5.39, 6.14]), $t(38) = 4.26$, $p < .001$, $d = 0.69$.

Decision-making Preference

First, we needed to make sure that reward learning was successfully transferred to decision-making by examining participants' preferences to rewarded pictures in the decision-making task. Decision preference was calculated as the percentage of choosing a target picture in all trials involving that picture. In trials of choosing between a rewarded picture and a nonrewarded picture, the average preference or choosing rate of rewarded pictures ($M = 0.79$, 95%CI[0.72, 0.85]) was statistically higher than the chance level (i.e., 50%), $t(38) = 9.39$, $p < .001$, $d = 1.50$, suggesting a preference to previously rewarded pictures. Then we analyzed participants' preferences to lure pictures belonging to the rewarded DRM lists. To control for stimuli exposure, we asked participants to choose between lure pictures and unrelated pictures, both of which have neither been presented nor rewarded. Participants' average decision preference of lure pictures ($M = 0.76$, 95%CI[0.67, 0.84]) was statistically higher than the 50% chance level, $t(38) = 6.19$, $p < .001$, $d = 0.99$, which supported our hypothesis that participants preferred lure pictures from the rewarded DRM lists to gain money. As a control condition, we also asked participants to choose between lure pictures from non-rewarded DRM lists and unrelated pictures.

Participants did not show preference to the lure pictures from non-rewarded DRM lists (M = 0.50, 95%CI[0.41, 0.60]) as the average decision preference was not different from the chance level, $t(38) = 0.09$, $p = .93$, $d = 0.02$.

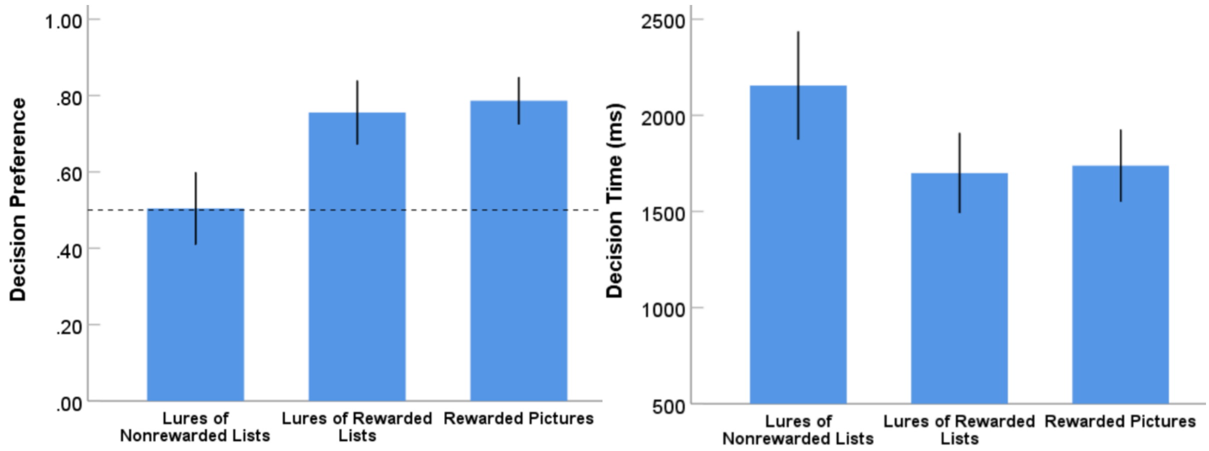


Figure 4. Mean decision preferences (left) and decision times (right) for lure pictures and rewarded pictures in the decision-making task. The dashed line in the left figure represents the 50% chance level. Error bars represent 95%CI.

As Figure 4 shows, we made multiple comparisons among the three types of decision trials correcting for family-wise error. The mean decision preference of lure pictures in the reward condition was significantly higher than the mean preference rate of lure pictures in the no reward condition, $t(38) = 4.12$, $p < .001$, $d = 0.94$, while the former did not differ significantly from decision preferences for rewarded pictures, $t(38) = 0.10$, $p = .98$, $d = 0.16$. This indicates that participants preferred lure pictures of rewarded DRM lists as often as rewarded pictures. We found a similar pattern of results when comparing decision times in the three types of decision trials, $F(1.22, 46.18) = 10.37$, $p = .001$, $\eta^2 = .21$. Post-hoc analysis with Bonferroni correction showed that, decisional reaction times to lure pictures from nonrewarded lists (M = 2155.22, 95%CI[1873.81, 2436.64]) were statistically longer than reaction times to lure pictures from rewarded lists (M = 1699.79, 95%CI[1492.15, 1907.43]), p

= .01, *d* = 0.51, and reaction times to rewarded pictures (*M* = 1737.78, 95%CI[1550.79, 1924.77]), *p* = .002, *d* = 0.60. The latter two did not differ significantly from each other, *p* ≈ 1.00, *d* = 0.10.

False Memory and Decision-Making

Individuals had different susceptibilities to forming false rewarding memories. We examined whether the false memory level could predict decision preference to lure pictures. False rewarding memory rate statistically predicted the decision preference to lure pictures of rewarded DRM lists, *r* (37) = 0.39, *p* = .01, suggesting that the more false rewarding memories generated, the more decision bias participants had for corresponding lure pictures (see Figure 5). False recognition rate in the reward condition could also predict decision preference to lure pictures, *r* (37) = 0.36, *p* = .02. For true memory, true rewarding memory rate statistically predicted preference to rewarded pictures, *r* (37) = 0.59, *p* < .001, however true recognition rate could not predict decision preference of rewarded pictures, *r* (37) = 0.18, *p* = .28.

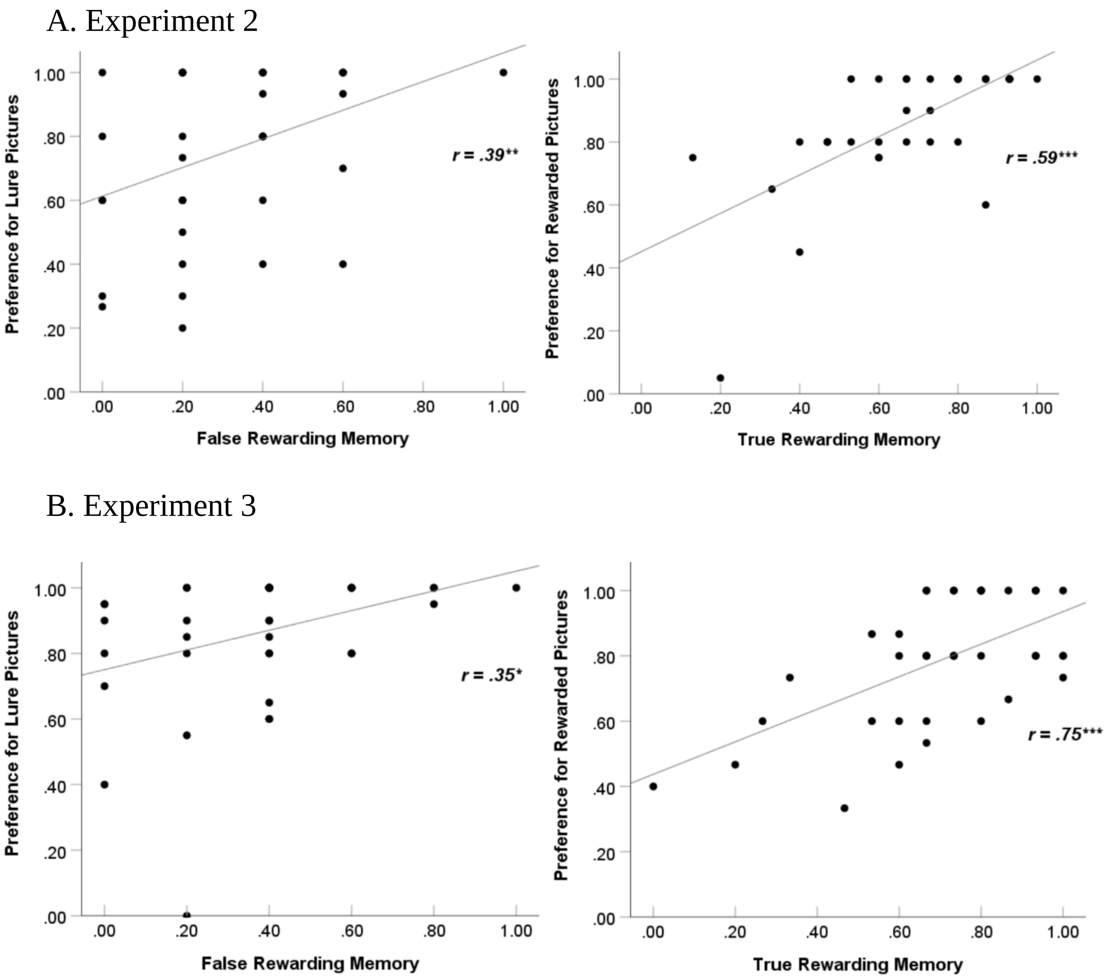


Figure 5. Scatter plots with fitting regression lines illustrating positive correlations between false rewarding memory and decision preference for lure pictures (left panels) and positive correlations between true rewarding memory and decision preference for rewarded pictures (right panels) in Experiments 2 and 3 (**p* <.05, ***p* < .01, ****p* <.001) .

Discussion

Experiment 2 had three major findings. First, we replicated the results in Experiment 1 with a reinforcement reward learning task showing that participants can still generate false rewarding memories about non-presented lure pictures bringing them reward. Participants formed false rewarding memories for 32% of the lure pictures, which is very close to the percentage (37%) in Experiment 1. Second, participants showed high decision preferences and fast decision times to the lure pictures belonging to rewarded DRM lists when encountering novel decision options. Finally, participants' level of false rewarding memories positively predicted their decision preferences to lure pictures.

As we expected, when asked to choose between a lure picture belonging to a rewarded DRM list and an unrelated picture to win money, participants chose the lure picture for 79% of the times, which was statistically higher than the chance level. Both the lure pictures and the unrelated pictures were novel to participants in that they did not have any prior reward experience for either picture. If participants indeed had no preference or bias over the two pictures, they should exhibit an equal chance (50%) to choose either picture. However, false rewarding memories of the lures guided them to choose the lure pictures more often than the unrelated pictures, as we also found that the more false memories participants had, the higher preference rates for the lure pictures. The 50-50 chance level was observed in trials when participants had to choose between a lure picture from a nonrewarded DRM list and an unrelated picture, suggesting that participants had no decision preference to lure pictures in the no reward condition. This is probably because for lure pictures from nonrewarded DRM lists, participants did not form any false rewarding memories and hence they did not show preference to those lure pictures. The faster decision times for lure pictures of rewarded lists also show that false memory can facilitate the decision-making process, an effect similar to the priming effect of false memory on problem solving (e.g., Howe et al., 2011). These results together support the important role of false rewarding memory in guiding novel decision-making.

Data from true memory support the role of true episodic memory in decision-making as well. We found that true rewarding memory rate statistically predicted participants' decision preference for rewarded pictures. When participants remembered more about their reward experiences, they exhibited more preference to rewarded pictures. Note that participants' true memories were very high (> 0.9) on average, and such ceiling effect with low variability may bring caution when interpreting the correlational results. Nonetheless, data in Experiment 2 have supported the general role of true and false episodic memory in reinforcement decision-making.

Some might argue that the current results could be explained by a mechanism similar to categorical or semantic generalization, which refers to an effect that participants generalize the learned reward to items belonging to the same category or semantic continuum (e.g., Biderman et al., 2020). For example, after learning that dog, cat, goat, etc. bring reward, people will expect reward for other four-footed animals even though they have no false memories for them. However, if decision preference to lure pictures was merely due to categorical learning, we would not find the positive correlation between false memory rate and preference for lure pictures. Nevertheless, to further examine the possibility of categorical/semantic generalization, we constructed picture pairs consisting of an unrelated item and a related non-presented picture (e.g., *bicycle*) from a DRM list (e.g., with the lure *car*) in the decision-making task of Experiment 3. Categorical generalization would predict preference to the related picture because the picture belongs to a rewarded DRM list. Meanwhile, false memories for related items are much lower than false memories for lure pictures (see Table 1). If false memory indeed plays a role in decision-making, we expected that preference for lure pictures would be significantly higher than preference for related pictures.

Another unsolved question in Experiment 2 was whether decision-making preference to lure pictures was due to a memory cuing effect. That is, it is possible that the memory test explicitly activated participants' false rewarding memories and hence participants showed preferences to the lure pictures. Research showed that test may boost false memory under certain conditions (Marsh et al., 2004; Marsh & Dolan, 2007). To examine this question, a memory test was either included or not included before the decision-making phase in Experiment 3. Note that research has already shown that false memories from the DRM paradigm are formed during the study phase (McDermott, 1997; Meade et al., 2010), so the formation of false memory does not depend on the memory test. Similarly, false memory priming of problem solving depends solely on false memory formation during storage and is not influenced by performance on subsequent recognition tests (see Howe et al., 2016; Otgaar et al., 2015). Another purpose of Experiment 3 was to test whether a memory test is needed for false memory to influence decision-making, just as in daily life people do not usually receive a memory test before they make decisions.

Experiment 3

Method

Participants

Experiment 3 tested 76 participants in total based on the sample size of Experiment 2 that we doubled the sample size of Experiment 2 as we had a memory test group and a no memory test group. Experiment 3 was not pre-registered. We conducted a sensitivity analysis in G*Power and found that with the current sample size, the smallest effect size we could reliably detect was a medium effect (f = 0.26). Participants were randomly assigned to the memory test group (n = 41) and no memory test group (n = 35). The mean age in the memory test group (M = 20.90, SD

= 2.21, 17-26 years old) did not statistically differ from the mean age in the no memory test group (*M* = 20.51, *SD* = 1.98, 18-25 years old), $t(74) = 0.80$, $p = .43$, $d = 0.18$. There were 20 men (48.78%) in the memory test group and 16 men (45.71%) in the no memory test group. The gender ratio in these two groups did not differ significantly, $\chi2(1) = 0.07$, $p = .79$, $\Phi = 0.03$. All participants were native Chinese speakers and were recruited at Fudan University, Shanghai, China. Participant fee was determined by their performance in the decision-making task (ranging from 20 to 40 RMB). The study was approved by the Ethical Committee at Department of Psychology, Fudan University.

Materials, Design, and Procedure

The same materials from Experiment 2 were used in Experiment 3. However, before conducting the experiment, we checked the materials for potential culture-sensitive contents (e.g., a typical garage in China might be different from a typical garage in Western countries). We replaced a few ($n = 4$) pictures and normed the Image Agreement Rating (Snodgrass & Vanderwart, 1980) in a Chinese sample ($N = 54$). We asked participants to rate how well the picture represented the DRM concept on a Likert scale from 1 (no agreement) to 5 (high agreement). The mean rating for the ten DRM pictorial lists was 4.50 (*SD* = 0.12), ranging from 4.34 to 4.67.

The procedure was identical to the procedure in Experiment 2 except that, for the no memory test group, participants skipped the memory test and took the decision-making task immediately after the filler task that followed the reward learning phase. Furthermore, we added two types of decision trials in the decision-making task: *studied versus unrelated* picture trials where participants needed to choose between a studied picture and an unrelated picture to win money, and *related versus unrelated* picture trials where participants chose between a related picture of a DRM list and an unrelated picture. Note that participants received actual money from the decision-making task and that 10% of their total earnings would be their participation fee (e.g., 35 RMB out of 350 totally earned). The former type of trials was one way to assess reward learning and the latter was to assess decision bias to pictures that were related to DRM lists but with a much lower false memory rate. As a result, extra 40 trials (2 types * 5 pairs * 4 times) were added to the original 60 trials in Experiment 2, making 100 decision trials in total in Experiment 3. Participants were explicitly told that their gains in the decision-making task determined their final participation fee.

Results

Reward Learning Performance

We compared the reward learning performance in the memory test and no memory test groups. A 2 (Memory test: yes, no) × 2 (Reward condition: reward, no reward) × 8 (Trial position: 1, 2, 3, 4, 5, 6, 7, 8) repeated measures ANOVA on mean reward expectancy rate was conducted, with the Memory test being a between-subjects variable. Participants in the two Memory test groups did not differ in their mean expectancy rate for the pictures, $F(1, 73) = 0.23$, $p = .64$, partial $\eta^2 = .003$, nor did Memory test interact with Reward condition or Trial position (ps > .05), which suggests that participants in each memory test group had a similar level of reward learning performance. Like results in Experiment 2, a significant interaction between Reward condition and Trial position was found, $F(5.43, 396.22) = 36.71$, $p < .001$, partial $\eta^2 = .34$, and no other interaction was found. As Figure 4 shows, after collapsing data from the yes/no memory test groups, participants' expectancy rates for pictures of the rewarded list increased significantly as trials progressed, $F(7, 511) = 14.29$, $p < .001$, but their expectancy rates for pictures of the non-rewarded list decreased significantly as trials progressed, $F(7, 511) = 25.10$, $p < .001$.

Data on reaction times replicated results in Experiment 2 as well. A 2 (Memory test) × 2 (Reward condition) × 8 (Trial position) ANOVA showed only a significant effect of Trial position on reaction times, $F(5.33, 388.94) = 26.03$, $p < .001$, partial $\eta^2 = .26$, indicating that participants responded faster as trials emerged (see Figure 4). No significant main effect of Memory test was found, $F(1, 73) = 1.17$, $p = .28$, partial $\eta^2 = .02$, and no main effect of Reward was found either, $F(1, 73) = 0.21$, $p = .65$, partial $\eta^2 = .003$. No significant two-way or three-way interaction effect was found, *p*s > .05. Hence, for both Memory test groups, stimuli exposure times to rewarded and nonrewarded pictures were similar.

False Memory

For the group with a memory test, participants falsely recognized 57% (95%CI[0.50, 0.64]) of the lure pictures in the reward condition and 58% (95%CI[0.51, 0.65]) of the lure pictures in the no reward condition, showing no statistical difference, $t(40) = 0.24$, $p = .81$, $d = 0.04$. The mean false rewarding memory rate in the reward condition was 0.38 (95%CI[0.31, 0.46]) and the mean false nonrewarding memory rate in the no reward condition was 0.37 (95%CI[0.30, 0.42]). The mean vividness rating of false rewarding memories ($M = 4.17$, 95%CI[3.67, 4.68]) was significantly higher than that of false nonrewarding memories ($M = 3.73$, 95%CI[3.27, 4.18]), $t(40) = 2.21$, $p = .03$, $d = 0.34$. The average false recognition rate for related but non-presented pictures ($M = 0.09$, 95%CI [0.05, 0.14]) was statistically lower than the mean false recognition rate of lure pictures in the reward condition, $t(40) = 11.33$, $p < .001$, $d = 1.77$. The mean false rewarding memory rate of related pictures ($M = 0.08$, 95%CI [0.04, 0.12]) was also statistically lower than that of lure pictures, $t(40) = 8.03$, $p < .001$, $d = 1.26$.

True Memory

As for true recognition, participants correctly recognized 87% (95%CI[0.83, 0.92]) of the rewarded pictures in the reward condition and 89% (95%CI[0.85, 0.93]) of the nonrewarded pictures in the no reward condition. Reward had no statistical impact on true recognition, $t(40) = 0.88$, $p = .38$, $d = 0.14$. The mean true rewarding memory rate in the reward condition was 0.70 (95%CI[0.63, 0.77]) and the mean true nonrewarding memory rate in the no reward condition was 0.73 (95%CI[0.67, 0.80]). Vividness for true rewarding memories ($M = 6.28$, 95%CI[5.94, 6.62]) was statistically higher than vividness for true nonrewarding memories ($M = 5.79$, 95%CI[5.36, 6.21]), $t(40) = 0.88$, $p = .38$, $d = 0.14$.

Decision-making Preference

We first assessed whether reward learning was successfully demonstrated in the decision-making phase. When asked to choose between rewarded pictures and nonrewarded pictures, the memory test group ($M = 0.83$, 95%CI [0.77, 0.90]) showed statistically higher preference for the rewarded pictures than the 50% chance level, $t(40) = 10.42$, $p < .001$, $d = 1.63$, so did the no memory test group ($M = 0.88$, 95%CI [0.83, 0.93]), $t(34) = 16.30$, $p < .001$, $d = 2.76$. The two groups did not differ significantly in the mean decision preferences for rewarded pictures, $t(74) = 1.07$, $p = .29$, $d = 0.25$, suggesting that the memory test did not impact normal reinforcement decision-making.

The key question was whether including a memory test would significantly impact decision-making. Figure 6 shows the decision preferences for various types of pictures in the memory test group and the no memory test group. We conducted a 2 (Memory test: yes, no) × 4 (Picture type: lures of nonrewarded lists, lures of rewarded lists, rewarded pictures, related pictures) repeated measures ANOVA on decision preferences in the decision-making task, with the Memory test being a between-subjects variable. No significant main effect of Memory test was found, F (1, 74) = 0.02, p = .89, partial η^2 < .001, and no interaction effect between Memory test and Picture type was found, F(2.14, 158.64) = 0.17, p = .86, partial η^2 = .002, suggesting that with or without a memory test, decision-making preference was not impacted. A statistical main effect of Picture type emerged, F(2.14, 158.64) = 108.39, p < .001, partial η^2 = .59. Post-hoc analysis with Bonferroni correction showed that preference to lure pictures of rewarded lists was significantly higher than participants' preference to lure pictures of nonrewarded lists, p < .001, d = 1.63, and the former did not differ from preference to rewarded picture, $p \approx 1.00$, d = 0.12, replicating results in Experiment 2. Moreover, decision bias to lure pictures of rewarded lists was significantly higher than related pictures of rewarded lists, p < .001, d = 0.99, and the latter was not statistically different from the chance level, t(75) = 1.53, p = .13, d = 0.18. As Figure 6 illustrates, preferences to the other three picture types were all significantly different from the chance level, ps < .001.

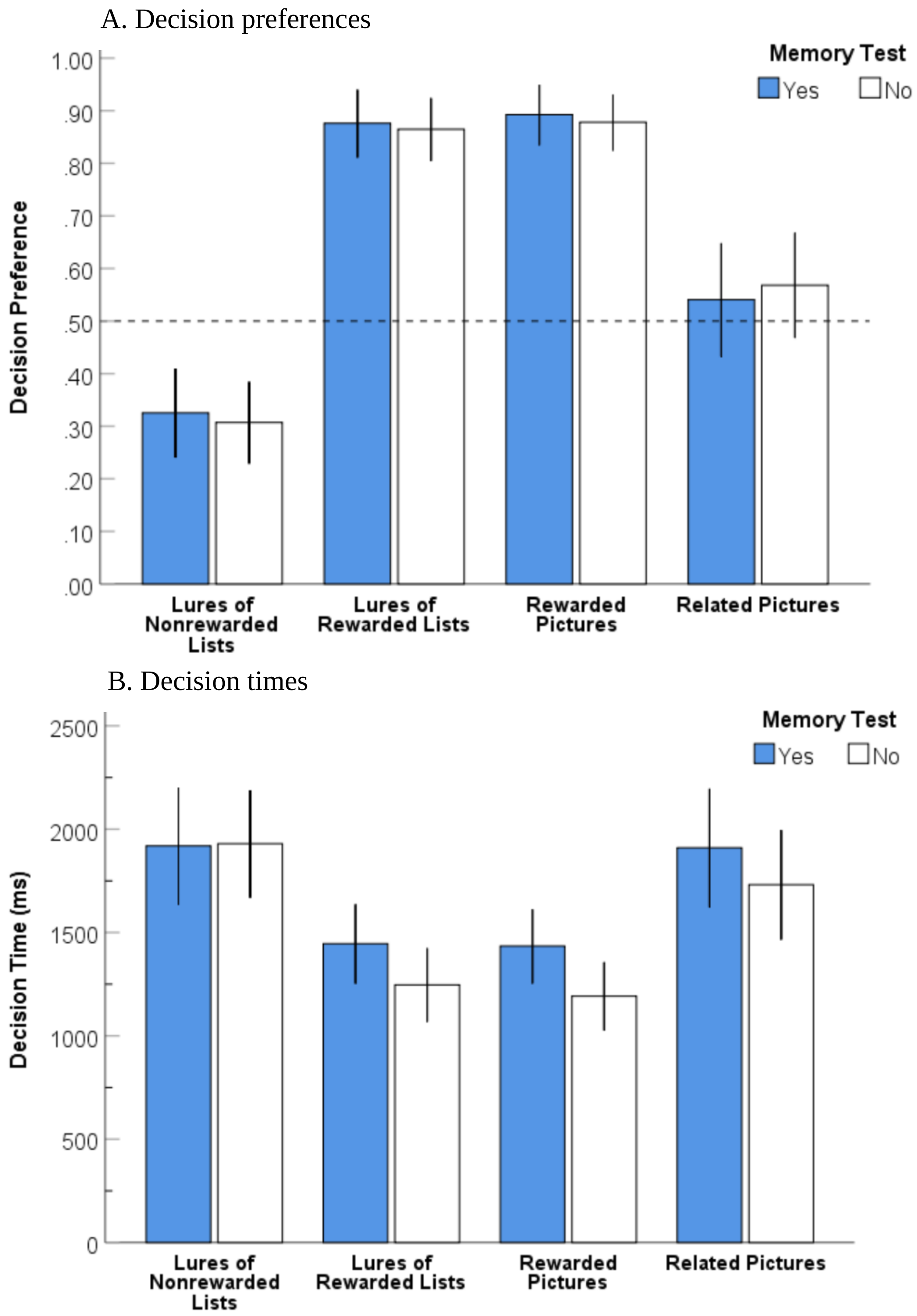


Figure 6. Mean decision preferences and decision times for lure pictures, rewarded pictures, and related pictures in Experiment 3. Error bars represent 95%CI.

We then conducted a 2 (Memory test: yes, no) × 4 (Picture type: lures of nonrewarded lists, lures of rewarded lists, rewarded pictures, related pictures) repeated measures ANOVA on decision times in the decision-making task. Again, we found no significant effect of Memory test on decision times, $F(1, 74) = 1.37$, $p = .25$, partial $\eta^2 = .02$, nor an interaction effect between Memory test and Picture type, $F(2.35, 174.09) = 0.96$, $p = .40$, partial $\eta^2 = .01$. Hence, data on decision times also support no effect of memory test on decision-making. We found a significant main effect of Picture type, $F(2.35, 174.09) = 30.75$, $p < .001$, partial $\eta^2 = .29$. Post-hoc analysis with Bonferroni correction showed that decision times for lure pictures of rewarded lists were statistically lower than decision times for lure pictures of nonrewarded lists, $p < .001$, $d = 0.80$, and the former did not differ from decision times for rewarded pictures, $p \approx 1$, $d = 0.09$. Decision times for lure pictures of rewarded lists were also statistically lower than that for related pictures of rewarded lists, $p < .001$, $d = 0.66$.

False Memory and Decision-Making

Because memory data should be obtained with a memory test, the link between false memory and decision-making was examined only in the memory test group. Consistent with Experiment 2, the level of false rewarding memory significantly predicted decision preference to lure pictures of rewarded lists, r (39) = 0.35, $p = .02$, and decision times for lure pictures of rewarded lists, r (39) = -0.49, $p = .001$. The results suggest that the more false rewarding memories participants formed, the higher their preference for the corresponding lure pictures and the faster decision times. Meanwhile, false recognition rate of lure pictures from rewarded lists did not significantly predict decision preference to the lure pictures, r (39) = -0.10, $p = .53$, suggesting mere false recognition (e.g., without rewarding memory) may not be enough to guide decision-making. These results together have demonstrated the link between false rewarding memory and novel decision-making.

For the relation between true memory and decision-making, true rewarding memory (*r* (39) = 0.75, $p < .001$) as well as true recognition memory (*r* (39) = 0.38, $p = .02$) of rewarded pictures both significantly predicted participants' preference for choosing rewarded pictures to win money. Hence, the more rewarded pictures and rewarding experiences they remembered, the higher their preference for these pictures.

Discussion

Experiment 3 showed that the memory test did not interfere with the effect of false memory on decision-making. With or without a memory test, participants showed a comparable level of preferences to lure pictures of rewarded DRM lists, which were consistent with results in Experiment 2. Including a memory test before decision-making did not impact decision times as well. Participants who had a memory test made decisions as fast as those who did not go through a memory test before the decision-making task. These results imply that the influence of false memory on decision-making is not due to a memory cuing effect. The results have also confirmed that false rewarding memories are probably formed during the study phase instead of during the memory test, because otherwise we should not observe decision bias to lure pictures without a memory test.

Experiment 3 again showed the role of false rewarding memory in guiding preferences during novel decision-making. Besides replicating results in Experiment 2, Experiment 3 found that participants' preferences to lures of rewarded lists were significantly higher than preferences to related items of the same rewarded lists, and participants did not prefer the related items at all to gain reward. This might be because participants had very few false rewarding memories for related items, while they generated significantly more false rewarding memories for lure pictures. Data on decision times support this explanation as well. Participants were significantly faster in trials involving lure pictures of rewarded lists than in trials involving related pictures or lure pictures of nonrewarded lists.

Interestingly, participants avoided choosing lure pictures from nonrewarded DRM lists in the decision-making task. This is probably because participants formed false nonrewarding memories for the lure pictures that those items did not bring them reward in the past, hence they avoided choosing the lure items in the decision-making task. Participants in Experiment 3 showed higher false memory rates for non-rewarded lures than those in Experiment 2. It is possible that high level of false memory leads to avoidance of lures for non-rewarded lists in Experiment 3 but not in Experiment 2. Nonetheless, such results are consistent with our general hypothesis that false memory can guide novel decision-making. Results in Experiment 3 did not support a categorical generalization mechanism for the decision-making. According to the generalization mechanism, participants would show preferences to related items of rewarded DRM lists. However, we found that participants did not show any preference to related items of rewarded DRM lists and the relevant decision times were significantly slower than decision times for lure pictures.

General Discussion

The current experiments examined the role of false memory in value-based decision-making. In Experiment 1, we constructed a new paradigm that combined the DRM paradigm with a reward learning task, and induced robust false memories of past rewarding (and non-rewarding) experiences. Experiment 2 further examined the impact of these false rewarding memories on value-based decision-making. False rewarding memories of lure pictures led participants to prefer choosing these lure pictures to gain reward. Experiment 3 replicated and extended results of Experiment 2 that false memory guided novel decisions no matter if a memory test was included or not before the decision-making task, showing that the impact of false memory on decision-making does not depend on memory cuing. These data together provide direct support for the important link between false memory and novel value-based decision-making.

Constructive Association

Across three experiments, false memories of past rewarding experiences could be successfully created in lab settings. After participants learned that some related items brought them monetary reward, they usually falsely remembered seeing an associated but non-presented lure picture bringing them a reward, creating false rewarding memories. False memories for nonrewarding experiences can be created as well: when DRM list items were paired with no reward, participants falsely remembered that lure pictures were paired with no reward.

The current results have supported our constructive association hypothesis. False rewarding or nonrewarding memories are essentially false associative memories. Lure pictures were never presented during the study phase, nor were they associated with reward or no reward. According to the constructive association hypothesis which is generated from the spreading activation theories (Howe et al., 2009; Roediger et al., 2001; Wang et al., 2021), new associations between concepts could be created when mental representations of the related concepts are co-activated. In the study phase of our experiments, participants' mental representations of the lure items (e.g., *bread*) were automatically activated after participants saw related items to the lures (e.g., *butter, milk, dough, jam*, etc.). Meanwhile, mental representation of the reward was also activated when participants learned the reward, hence the co-activation of the reward and the lure item led participants to form a false association between the lure picture and the reward.

Some might argue that the lure-reward false association is established during the memory test instead of the study phase. For example, previous research showed that the transfer of value to novel items can only be successful after an inference associative test (Carpenter & Schacter, 2018). It could be that participants first formed false memories of the lure pictures in the study phase, and then when asked about the reward source in the memory test, they made a reference that the lure pictures should have brought reward thus forming a false association. However, results in Experiment 3 did not support this explanation. Without a memory test, participants still showed preferences to lure pictures of rewarded DRM lists. This suggests that participants already formed false rewarding memories during the study phase, otherwise they should not exhibit preferences to the lure pictures of rewarded DRM lists while showing avoidance to lure pictures of nonrewarded lists. Of course, the current study did not examine any monitoring processes that might prevent the formation of false associations. Further research can investigate potential factors that might impact the formation and retrieval of false associative memories.

False Memory and Novel Decision-Making

Having established that false rewarding memories can be reliably created, we examined our core research question concerning whether false memories can guide novel decision-making. Experiments 2 and 3 consistently showed that reconstructed false memories of past rewarding experiences play an important role in guiding decision-making with novel options. First, when participants had false rewarding memories for lure pictures, they preferred to choose these non-presented lure pictures to gain reward, even though they had no prior reward experiences with the lures.

However, when they had false nonrewarding memories for lure pictures in the no reward condition, they did not prefer these lure pictures to gain reward. Participants' mean preference rate of lure pictures from rewarded lists was equivalent to their preference rate of rewarded pictures, as if they had *truly experienced* the false rewarding memories.

Second, both experiments found that false memories of rewarding experiences can guide participants to make faster decisions. Third, data consistently showed that the more false rewarding memories participants formed, the higher preference to the relevant lure pictures, suggesting the direct impact of false memory on novel decision-making. Fourth, when participants had significantly lower false rewarding memories for related items than for lure pictures, they also showed significantly higher preference rates for lure pictures than for related items. The results suggest that higher false memory rates lead to higher preference rates of lure items. The above results together have provided compelling evidence for the crucial role of false memory in novel decision-making.

One potential mechanism underlying how false memory impacts novel decision-making might be the spreading activation (Anderson, 1983; Roediger et al., 2001) or associative activation (Morewedge & Kahneman, 2010) mechanism of memory. The basic principle of this mechanism is that a stimulus can evoke a coherent activation of its related concepts in the memory network. For example, seeing "thirst" will automatically activate the concept "water" as "thirst" and "water" are associated in the memory network. After participants form a false association between the lure item "car" and reward, as Figure 1 illustrates, when participants see the "car" in a decision trial, activation of the "car" activates the mental representation of reward. Hence, participants will prefer the lure picture "car" to gain reward although the picture is novel to them. Such a process illustrates how constructed (false) associative memory can guide novel value-based decision-making.

An alternative mechanism can be provided by the Fuzzy-trace Theory (FTT; Brainerd & Reyna, 2002). FTT proposes that memories are stored in two parallel memory traces: verbatim traces and gist traces, for which the latter can support false memory for a non-presented but gist-familiar item. When participants encode a DRM list with reward in the learning phase, participants might extract the gist of the list (i.e., the critical lure), attaching rewarded value to the gist and forming false rewarding memories. Thus, in a subsequent decision-making task, participants favor the lure items due to their false rewarding memories. Having established the effect of false memory on decision-making, it would be interesting to further manipulate the level of false memories via affecting the monitoring process to examine how decision-making would be impacted. False memories are known to be reduced by pre-warnings or divided attention as these manipulations impact the monitoring process (Dewhurst et al., 2007; Watson et al., 2004). Future research may focus on how to mitigate the effect of false memory on decision-making.

Implications for the Adaptive Function of Memory in Decision-Making

We consistently found that true rewarding memories can guide decision preferences to rewarded pictures in Experiments 2 and 3. The more accurate participant's memories about past rewarding experiences, the more preference to the rewarded pictures. Previous studies mostly used reward learning tasks with repeated trials (e.g., Balleine, 2018; Bornstein et al., 2017; Ludvig et al., 2015), but our study has used a trial-unique reward learning task and shown that episodic memory can indeed guide value-based decision-making. Such results have provided additional evidence to support the role of episodic memory in reinforcement decision-making (see Gershman & Daw, 2017), suggesting that one of memory's functions is to allow people to use episodes directly from prior experiences to guide their behavior.

The most important finding of the current study is that we have found the role of false memory in guiding decision-making with completely novel options. Our study has shown that memory is reconstructive by creating new yet false associations. A recent study also found that people may not exhibit veridical recall but confabulate rewarded outcomes in experienced-based decision tasks (Mason et al., 2022). One might ask, why would our memory spontaneously construct false associations involving novel stimuli? We argue that these phenomena nicely illustrate a less discussed adaptive function of memory, that is, the ability to reconstruct new memory episodes to guide decision-making in novel situations in the future.

In the literature so far, memory researchers have already discussed the adaptive function of memory distortion, but false memory is viewed as a by-product of efficient memory functioning such as gist extraction, and false memory can occasionally have positive consequences (Howe, 2011; Schacter et al., 2011). For example, false memories of words generated from the DRM paradigm can prime problem-solving of related puzzles (Howe et al., 2011; Wang et al., 2017), but the function of false memory in guiding human behavior is not clear. In the decision-making literature, researchers have mostly focused on the function of true episodic memory in decision-making and how humans can make inferences or recombine distinct experiences to guide decisions (Biderman et al., 2020). However, none has considered the adaptive function of false memory in value-based decision-making.

Another perspective on the adaptive function of memory, which has gained increasing empirical support, is the constructive episodic simulation hypothesis (Schacter & Addis, 2007; Schacter, 2012; Schacter et al., 2017). It proposes that the function of constructive episodic memory is to allow individuals to flexibly retrieve and combine elements from distinct episodic memories to construct imaginary events. This idea emphasizes the flexible combination of different episodic elements in *future simulation*, or imagining the future, but not the flexible combination in *remembering the past*. For example, if participants learn overlapping associations AB and BC, the simulation account suggests that participants would make inferences of the relationship between A and C via B but actually no memory association is constructed for AC (Carpenter & Schacter, 2017, 2018). Our experiments, however, suggest that participants might construct memories of A and C being directly associated. In reality, people might not always simulate or imagine scenarios before making a decision as the simulation hypothesis suggests. The current study has demonstrated that the memory system has the ability to spontaneously construct novel associations to non-experienced stimuli while remembering.

Here, we argue that the function of reconstructive memory might be to generalize individuals' memories of past experiences such as learned associations (e.g., stimuli-reward association) to novel stimuli (e.g., lure-reward association), and thus to predict possible situations in the future. That is, the memory system itself can create new episodic memories of novel stimuli. What people will encounter in the future is not necessarily the same as what they have experienced. If non-experienced (thus novel) episodes/scenarios can be spontaneously retrieved from memory after experiencing similar scenarios, it is beneficial for organisms to cope with novel situations. Due to the reconstructive nature of the memory system, memory might already be prepared for possible future scenarios before encountering actual situations. A memory system that is flexible enough to generalize or extend memories of learned associations to novel stimuli would be efficient and beneficial. Evidence from the current study has extended the role of episodic memory in decision-making, contributing to a more complete picture regarding the function of memory.

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