UNIVERSITY OF CALIFORNIA,
IRVINE

The Memory Remains: Monetary and Social Rewards in Retroactive Enhancement of Memory

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Psychological Science

by

Kamalakannan SO M. Vijayakumar

Dissertation Committee:
Associate Professor Elizabeth A. Martin, Chair
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2024

DEDICATION

To

my family and friends

for supporting my dreams in your own way

"Every day it gets a little easier… But you gotta do it every day—that's the hard part. But it does get easier."

— Jogging Baboon from BoJack Horseman

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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VITA

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Kamalakannan, SO M. V., Blank, J.M., Lai, J., & Martin, E.A. A researcher's guide to the galaxy of social reward tasks: A scoping review (In progress)

Kamalakannan, SO M. V., Li, L.Y., & Martin, E.A. The structure, measurement invariance, and construct validity equivalence of pleasure scales (In progress) https://osf.io/bvpnz/

Kamalakannan, SO M. V., & Martin, E.A. Influence of empathy and Theory of Mind in emotion elicitation (In progress) https://osf.io/t2rq9/

Kamalakannan, SO M. V., & Martin, E.A. Role of monetary and social rewards on retroactive enhancement of memory (In progress) https://osf.io/6g2dw/

RESEARCH PUBLICATIONS

Lai, J., Snyder, M.E., **Vijaykumar, K. M**., Bailey, D. H., & Martin, E.A. Shared and unique affective abnormalities in schizotypy dimensions (2022). *PsyCh journal*, *11*(2), 149–162. https://doi.org/10.1002/pchj.506

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Dalati, N., Martinez II, J.A., Stibor A.F., Kirkorian, N.J., **Kamalakannan, SO M.V.**+, & Martin, E.A. (2024, May) Association Between Social Anhedonia & False Memories in the Presence of Social Reward [Poster session]. UROP Symposium, University of California, Irvine.

Kamalakannan, SO M. V., & Martin, E. A. (2024, April). *The Memory Remains: Effect of Monetary and Social Reward on Retroactive Enhancement of Memory* [Poster session]. 2024 Social and Affective Neuroscience Society Annual Conference.

Kamalakannan, SO M. V., & Martin, E. A. (2024, March 2). *Role of Affective Theory of Mind in Eliciting Disgust* [Poster session]. 2024 Society for Affective Science Annual Conference.

Kamalakannan, SO M. V., & Martin, E. A. (2023, March 31). *Influence of positive and negative mood on working memory capacity and prepotent response inhibition* [Poster session]. 2023 Society for Affective Science Annual Conference.

Zhang, Y., Ruiz, C., Zhou, Q., **Kamalakannan SO M. V.**+, & Martin, E.A. (2023). Role of Affective and Cognitive Theory of Mind in Eliciting Instrumental Aid in Negative Emotional States [Poster session]. UROP Symposium, University of California, Irvine. +Served as graduate mentor

Kamalakannan, SO M. V., & Martin, E. A. (2022, April 1). *Theory of Mind in emotion elicitation* [Poster Session]. 2022 Society for Affective Science Annual Conference.

Lai, J., Snyder, M. E, M. **Vijayakumar, K. S.,** Bailey, D. H., & Martin, E. A. (2022, March). Shared and unique affective abnormalities in schizotypy dimensions. Annual meeting of the Society for Affective Science and the meeting for the International Society for Research on Emotion, Los Angeles, CA.

Low, B., Phua, D., **Vijayakumar, K.**, Karnani, N., Lee, Y. S., Yap, F., Chong, M. F. F., Leutscher-Broekman, B., Rifkin-Graboi, A., Gluckman, P., Yap, S. C., Meaney, M., & Liu, J. C. (2015). *Variation in oxtr genotype is associated with early childhood adiposity.* [Oral presentation]. Neuroscience 2015.

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Social NeuroEndocrinology Research Group, Yale-NUS College **2015-2018**
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University at Buffalo **2013-2014**
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ABSTRACT OF THE DISSERTATION

The Memory Remains: Monetary and Social Rewards in Retroactive Enhancement of Memory

by

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Doctor of Philosophy in Psychological Science

University of California, Irvine, 2024

Associate Professor Elizabeth A. Martin, Chair

When an organism experiences a salient event, such as when a reward or punishment is received, it is crucial that the information pertaining to that stimulus is encoded and consolidated into memory. The memory of the salient event then allows the organism to continue seeking or avoiding that stimulus. However, it is essential that the organism is also able to recognize the events leading up to encountering the salient stimuli. Theoretically, this requires retroactive enhancement of memory. Retroactive enhancement of memory occurs when previously seemingly irrelevant memories are enhanced at a later time point due to a salient event. While there is theoretical support for the possibility of retroactive enhancement of memories, the empirical evidence in human participants has largely been mixed primarily due to methodological differences and conflation of learning paradigms. Furthermore, as prior studies that have attempted to elicit retroactive enhancement of memory using rewards have only used monetary rewards, it is unclear if social rewards could elicit the effect as well. The effect of retroactive enhancement of memory using rewards on false memories is also unclear. To address the inconsistencies and ambiguities in the literature, this dissertation examined the effects of monetary and social rewards on retroactive enhancement of memory and false memories using an operant conditioning paradigm in Study 1 and a classical conditioning paradigm in Study 2.

First, while the data in Study 1 provided evidence of retroactive enhancement of memory for both monetary and social rewards, the data in Study 2 did not support retroactive enhancement of memory. Second, using a two-step conditioning process, results from Study 1 suggest that monetary and social rewards can exert comparable influence on memory in an operant conditioning paradigm. However, results from Study 2 demonstrated that recall in the conditioning phase of the social reward condition was significantly higher than that of the monetary reward condition using a classical conditioning paradigm. Third, in examining rates of false alarms, the data revealed no significant differences between the reward category images in Study 1. The findings of this dissertation not only add to the extant literature but also provide clarity regarding mixed findings in previous studies. Across these two studies, this dissertation provides important insights regarding one facet of memory, retroactive enhancement of memory, especially in the presence of rewards.

INTRODUCTION

Salience refers to the features of a stimulus or event that captures one's attention ((McArthur & Ginsberg, 1981; Taylor & Fiske, 1978) and has been linked to the enhancement of memory prospectively – enhancement of memory after a salient event has occurred (LaBar & Cabeza, 2006; Parr & Friston, 2017; Reisberg & Heuer, 2004). Selectively consolidating salient information in long-term memory allows an organism to predict and appropriately avoid threats or approach rewards, in turn improving its survival fitness (Nairne et al., 2008; Shohamy & Adcock, 2010). While there has been substantial research supporting the theory that emotionally salient memories are enhanced prospectively (Kensinger, 2004; Levine & Edelstein, 2010), there has been a recent advent of research on retroactive enhancement of memories. Retroactive enhancement of memory occurs when previously seemingly irrelevant memories are enhanced at a later time point due to strong stimulation, such as a salient event.

The empirical evidence for retroactive enhancement of memory, however, has been largely mixed. For example, while Patil et al. (2017) and Braun et al. (2018) found evidence for monetary rewards retroactively enhancing memory, Oyarzun et al. (2016) did not. One reason for the mixed findings could be the reward-based learning conditions used to elicit retroactive enhancement of memory. Previous studies have used "incidental encoding" and "intentional encoding" that does not account for Pavlovian-to-instrumental transfer. This Pavlovian-to-instrumental transfer occurs when learned associations between cues and rewards that are not contingent on one's response (i.e., Pavlovian conditioning), transfer to changing one's motivational salience or responses that are contingent on rewards or punishment (i.e., instrumental conditioning) (Cartoni et al., 2016; Holmes et al., 2010). Pavlovian-to-instrumental transfer could have occluded the conditions under which retroactive enhancement occurs.

Classical conditioning and operant conditioning paradigms might instead better delineate the conditions under which reward-based learning might lead to retroactive enhancement of memory.

In studies examining reward-based learning and memory processes, monetary rewards have been primarily used. Despite money not being a primary reward, robust effects have been found in studies using monetary rewards. In contrast to the vast literature on the effect of monetary reward on memory processes in general (see Miendlarzewska et al., 2016 for a review) and for retroactive enhancement of memory more specifically (Braun et al., 2018; Murayama & Kitagami, 2014; Oyarzún et al., 2016; Patil et al., 2017), it is unclear the effect social rewards have on memory processes – both prospective and retroactive enhancement of memory. Studies on social dysfunction across psychopathologies imply that there might be deficits in reinforcement learning and consolidation of social memories (Pizzagalli, 2010). As such, understanding the influence of social reward on memory processes, such as retroactive enhancement of memory, as well as prospective memory, might shed some light on understanding social dysfunction.

Furthermore, studies of reward-based learning have found that while higher reward motivation leads to higher recall, it also leads to higher rates of false alarms (i.e., indicating processing of information that was not previously presented) (Keren, 1991; Moritz et al., 2004, 2006). However, there is a lack of evidence on the retroactive effects of reward-based learning on rates of false alarms and, by extension, false memories in human participants. One implication of rewards leading to greater rates of false alarms is that there could be a greater distortion of memory and generation of false memories of the events leading up to when a reward was received.

Across two studies, this dissertation addresses three main issues in the current literature: 1) the confound of Pavlovian-to-instrumental transfer, 2) the type of reward (monetary vs. social), and 3) false memories relating to retroactive enhancement of memory. First, the issue with the confound of Pavlovian-to-instrumental transfer is addressed by using operant conditioning with intentional encoding in Study 1 and classical conditioning with incidental encoding in Study 2. Second, as previous studies examining the role of reward in retroactive enhancement of memory have only focused on monetary reward, this dissertation used both monetary and social reward conditions in Studies 1 and 2. Third, false memories in paradigms eliciting retroactive enhancement of memory are examined through the rates of false alarms in recognition 24 hours after the presentation of the stimuli.

Theoretical support for retroactive enhancement of memory

While there has been strong evidence for saliency enhancing memory prospectively, research on retroactive enhancement of memory in human participants has only recently gained traction amongst researchers. When an organism encounters a salient event, such as a rewarding or aversive stimulus, it is crucial that the information pertaining to that stimulus is encoded and consolidated so that the organism can continue to seek out or avoid that stimulus, respectively. This seeking of reward or avoiding aversive stimuli is known as adaptive behavior (Thorndike, 1911). In support of salient events leading to adaptive behaviors, studies have found that memory was enhanced for salient information over neutral information (Anderson & Phelps, 2001; Heuer & Reisberg, 1990; Kensinger, 2004; Reisberg & Heuer, 2004). As crucial as it is that an organism can recognize salient information, it is essential that the organism is also able to recognize the events leading up to encountering the salient stimuli. The memory of the stimulus or how salient it was alone is insufficient for an organism to learn adaptive behaviors. Otherwise, the organism can only act in the presence of the stimulus and not make predictive actions to improve the probability of encountering rewards or avoiding aversive stimuli. In turn, the organism has a lower chance of surviving and successfully reproducing. Therefore, retroactive enhancement of memory is theoretically vital for the learning of adaptive behaviors and the survival of an organism. Hippocampal replays and the synaptic tagging and capture hypothesis are two phenomena that lend theoretical support for the retroactive enhancement of memory.

Hippocampal replays in memory consolidation

Learning adaptive behaviors requires the consolidation of memories, which is known to occur during periods of rest and sleep. Studies have found that during quiescence (rested wakefulness and short-wave sleep), neurons in the hippocampus display bursts of synchronous activity known as sharp-wave ripples and are associated with replays (Atherton et al., 2015; Buzsáki, 1986; Csicsvari et al., 1999). Replays refer to the reactivation of memories that are believed to occur unconsciously and are vital in the consolidation process of memory traces (Ego-Stengel & Wilson, 2010; Girardeau et al., 2009; Girardeau & Zugaro, 2011; Middleton et al., 2018; Schapiro et al., 2018). More importantly, there has been strong evidence that rewards increase reverse replay in animals (Carr et al., 2011; Singer & Frank, 2009) and human participants (Kurth-Nelson et al., 2016; Liu et al., 2019, 2021), suggesting that rewards could retroactively strengthen weaker memory traces of neutral events preceding receiving the reward. These hippocampal replays, together with the synaptic tagging and capture hypothesis explain how weak memory traces can be strengthened, especially retroactively, in the presence of rewards.

Synaptic tagging and capture hypothesis

Due to capacity limits of cognition and memory, incoming information that is more salient is prioritized for consolidation (Kensinger, 2015; Richards & Frankland, 2017), and those that are not prioritized have weak transient "tags". However, even information not prioritized for consolidation can be consolidated retroactively in the presence of strong stimulation. The synaptic tagging and capture hypothesis delineates a two-step process that involves long-term potentiation. Long-term potentiation (LTP) is a stable, relatively long-lasting increase in synaptic strength due to high-frequency stimulation (Okuda et al., 2021; Teyler & DiScenna, 1987). This two-step process of synaptic tagging and capture explains the neuronal changes through which long-term potentiation can be achieved for even weak memory traces if there was a stronger stimulation, such as a rewarding or aversive stimulus at a later time point (Frey & Morris, 1997, 1998; K. C. Martin & Kosik, 2002; Rogerson et al., 2014).

In the first step of the synaptic tagging and capture hypothesis (i.e., early-LTP), weak transient "tags" occur at the synaptic level even to information not prioritized for consolidation. In the presence of stronger stimulation, plasticity-related proteins are synthesized and bind to these transient tags, inducing late-LTP, which strengthens the weak transient tags (Moncada & Viola, 2007; Redondo & Morris, 2011). Through tetanization or strong stimulation of dopamine D1/D5 receptors, plasticity-related products are translated from mRNA in the neurons that have been tagged (Okuda et al., 2021; Redondo & Morris, 2011). This late-LTP results in retroactive enhancement of the previously seemingly irrelevant information. In support of the theoretical framework laid by hippocampal replays and the synaptic tagging and capture hypothesis, empirical evidence of retroactive enhancement of memory has been found in animal models (Quintanilla et al., 2021; Redondo & Morris, 2011; Wang et al., 2010; Yamasaki & Takeuchi, 2017). For example, Quintanilla et al. (2021) exposed male rats to odor cups and replaced one cup with a novel odor. Upon introducing the novel odor cup, the rats' behavior (i.e., sampling time spent investigating) indicated that they recognized that the odor in the cup was novel. However, the rats did not discriminate between the odor cups at 24 hours, indicating that the novelty of the odor wore off during that interval. In contrast, male rats that were immediately introduced to a salient stimulus (i.e., bedding of a female rat or strobing light) after exploring the novel odor retained greater odor memory (as measured by sampling time spent investigating) 48 hours later than the control rats exposed to only clean bedding. The memory of the novel odor was retroactively enhanced in the male rats from the exposure to a salient stimulus.

Conflicting findings for retroactive enhancement of memory

Retroactive enhancement of memory has been largely studied in animal models (Quintanilla et al., 2021; Redondo & Morris, 2011; Wang et al., 2010; Yamasaki & Takeuchi, 2017). While there has been a recent advent of research on retroactive enhancement of memory in human participants, the findings have been largely mixed. Using incidental encoding through a fear-based (shock) classical conditioning paradigm, Dunsmoor et al. (2015) found category-specific retroactive enhancement of memory. There was a greater recognition for images in the category paired with the shock – including those viewed before the conditioning – even 24 hours after the initial viewing of the images. However, Kalbe and Schwabe (2021) tried to replicate these findings over four studies but failed to find evidence for retroactive enhancement of memory. In a similar vein, Murayama and Kitagami (2014) and Braun et al. (2018) examined the influence of reward and found that incidental encoding of monetary reward led to retroactive enhancement of memory. Patil et al. (2017) found that intentional (as opposed to incidental) encoding of monetary reward through operant conditioning led to retroactive enhancement of memory. However, using incidental encoding of monetary reward, Oyarzun et al. (2016) found that enhancement only occurred for images seen after conditioning (prospectively) and not images seen before conditioning. There are a few possible reasons for the mixed findings across these studies. One of these reasons is the conflation of reward learning paradigms.

Conflated reward learning paradigms

One possible confound leading to the mixed findings regarding retroactive enhancement of memory could be the conflation of learning paradigms used in the studies. First, confusion may arise between the constructs of *incidental encoding* and *classical conditioning. Incidental encoding* involves the participant receiving no explicit instructions but instead learning implicitly through associations. *Classical or Pavlovian conditioning* is the learning of associations between cues and stimuli that elicit a response. Therefore, while all classical conditioning paradigms involve incidental encoding, not all incidental encoding paradigms involve classical conditioning. Second, *intentional encoding* and *operant conditioning* are another set of constructs that are often confused. *Intentional encoding* involves clear instructions on encoding. An example of intentional encoding would be explicitly asking participants to learn a set of images they would be required to recall later. *Operant or instrumental conditioning* is the process by which the frequency of specific behaviors is altered through rewards and punishments. As such, operant conditioning without explicit instructions would be an incidental encoding paradigm instead. By exploring a maze and receiving rewards in some arms of the maze but shocks in other arms, mice might learn which arms to approach and which to avoid. This example illustrates incidental encoding with operant conditioning.

Incidental encoding paradigms may also result in a transfer from classical conditioning to operant conditioning in a process called *Pavlovian-to-instrumental transfer*. *Pavlovian-to-*

instrumental transfer occurs when learned associations between cues and rewards that are not contingent on one's response (i.e., Pavlovian conditioning) transfer to changing one's motivational salience or responses that are contingent on rewards or punishment (i.e., instrumental conditioning) (Cartoni et al., 2016; Holmes et al., 2010). For example, if rats are provided with rewards when placed in a cage in which the floor is green, the rats learn to associate green with rewards through classical conditioning. When released in a maze, the rats then spend more time exploring the arms of the maze in which the floor is green, with the expectation of rewards. This behavior illustrates Pavlovian-to-instrumental transfer as the learned associations between cues and rewards not contingent on the rats' behavior, transfers to motivating them to seek rewards actively instead (i.e., motivational salience).

Conflating incidental encoding with classical conditioning and intentional encoding with operant conditioning could occlude the influence of motivational salience (from Pavlovian-to-instrumental transfer) on the conditions under which retroactive enhancement of memory is elicited. As such, it is important to clearly delineate the conditions under which retroactive enhancement of memory occurs. This can be achieved by using 1) an operant conditioning paradigm using intentional encoding involving explicit instructions and 2) a classical conditioning paradigm with incidental encoding that does not involve explicit instructions. Doing so will account for the confound of Pavlovian-to-instrumental transfer that might occur in reinforcement learning paradigms that use incidental encoding but do not distinguish classical conditioning from instrumental conditioning. Other reasons for the mixed findings relating to retroactive enhancement of memory in human participants could be the sensitivity of factors relating to conditioning.

Sensitivity of factors relating to conditioning

Based on the works of Kalbe and Schwabe (2021) and Dunsmoor et al. (2019), there is evidence that retroactive enhancement of memory might be sensitive to factors relating to conditioning. As the various studies that have examined retroactive enhancement of memory (Braun et al., 2018; Dunsmoor et al., 2015, 2019; Hennings et al., 2021; Kalbe & Schwabe, 2021; Murayama & Kitagami, 2014; Oyarzún et al., 2016; Patil et al., 2017) used different methodologies, it is difficult to determine the factors that were vital in eliciting the effect. Kalbe and Schwabe (2021) attempted to replicate the findings of Dunsmoor et al. (2015) – shocks elicited retroactive enhancement of memory – over four studies but could not replicate them. In their discussion, Kalbe and Schwabe (2021) identified two possible explanations for being unable to elicit retroactive enhancement of memory. These are the timing of the presentation of the unconditioned stimulus (shock) with the neutral stimulus (image) to form the conditioned stimulus, and stimulus typicality (i.e., features of one member that generalize to other members of the same category).

Firstly, while Dunsmoor et al. (2015) presented shocks that co-terminated with the presentation of the images, Kalbe and Schwabe (2021) had shocks that started at the end of the stimulus presentation instead. This difference in timing could have led to different processes, such as trace and delay conditioning (Kochli et al., 2015; J. McLaughlin et al., 2002). Secondly, Dunsmoor et al. (2015) kept stimulus typicality constant across all phases of their study. Typical exemplars are examples of a category with features that apply to other members of the category (Dunsmoor & Murphy, 2014). For example, typical exemplars of birds would include crows and pigeons, whereas atypical exemplars would include penguins and ostriches. To prevent the confound of stimulus typicality when eliciting retroactive enhancement of memory in human participants, it is essential that the images used in the stimuli set have similar stimulus typicality.

As research in retroactive enhancement in humans is still relatively new and the findings are mixed, much is not well understood. To better understand the mechanism behind retroactive enhancement of memory, it is essential to learn from previous studies and delineate the conditions under which retroactive enhancement of memory is elicited. This can be achieved through study designs that use appropriate learning paradigms delineating the influence of motivational salience and accounting for Pavlovian-to-instrumental transfer. The timing of reward or punishment, as well as the typicality of stimulus, should be carefully controlled as they are factors that may influence the elicitation of retroactive enhancement of memory.

Social reward

Of the published studies that have attempted to use rewards to elicit retroactive enhancement of memory, monetary reward has been primarily used (Braun et al., 2018; Murayama & Kitagami, 2014; Oyarzún et al., 2016; Patil et al., 2017). *Rewards* are defined as environmental stimuli that can elicit approach responses (White, 1989). Monetary reward is an abstract concept that is not a primary reward with direct survival implications (e.g., food). Therefore, money is a secondary reward that signals primary rewards instead (Astur et al., 2016; Delgado et al., 2011; Grahn, 2017). Nonetheless, money has proven to be a robust reward. It has been shown to influence various psychological and physiological processes compared to non-rewards (Lea & Webley, 2006; Pessiglione et al., 2007).

In contrast, one domain of reward that has had little attention in behavioral paradigms examining memory in human participants is social reward. In human participants, indicators of social approval such as smiling faces, positive feedback, and viewing of attractive faces have served as social reward cues (Bhanji & Delgado, 2014; Davey et al., 2010; Fehr & Camerer, 2007; Syal et al., 2015). These social reward cues have been primarily used in studying the anticipation and consumption of rewards (Gu et al., 2019; Martins et al., 2021). Of note, the "Social Incentive Delay" task (Spreckelmeyer et al., 2009), a variation of the "Monetary Incentive Delay" task (Knutson et al., 2000), has been widely used. The Social Incentive Delay task uses faces (e.g., smiling face) to signal social approval and has been shown to produce smaller effect sizes compared to the monetary reward but greater than neutral images (Barman A et al., 2015; Gossen A et al., 2014; Rademacher L et al., 2010; Spreckelmeyer et al., 2009). Social rewards, as used in the Social Incentive Delay task, have also been found to elicit approach responses through the activation of brain regions similar to non-social rewards such as money (Gu et al., 2019; Martins et al., 2021). Adaptive behaviors in social situations are contingent on the encoding and consolidation of social rewards (Fehr & Camerer, 2007). As such, activation levels of brain regions corresponding to approach responses in the presence of social rewards may serve as a signal of social dysfunction (Porcelli et al., 2019; Tamir & Hughes, 2018; Xie et al., 2014).

There have been robust links drawn between social dysfunction and psychopathology (Keltner & Kring, 1998; Y. Wang et al., 2018). One example of social dysfunction is social anhedonia, characterized by a reduced motivation for social interaction, diminished pleasure from social contact, and dysfunctional social reward learning (Gooding & Pflum, 2022; Kwapil et al., 2009). Social anhedonia, as measured by the Social Anhedonia Scale ((Eckblad et al., 1982), identified individuals at risk of developing schizophrenia-spectrum disorders (Kwapil, 1998). Indeed, lower levels of social support and social functioning have been reported in those with higher levels of social anhedonia (Blanchard et al., 2011). Those with social anhedonia predict social interactions as unpleasant but have been found to momentarily enjoy social interactions (Gooding & Pflum, 2022; E. A. Martin et al., 2019; Moore et al., 2019). This finding might indicate deficits in reinforcement learning and consolidation of social memories (Pizzagalli, 2010). Understanding the influence of social reward on retroactive enhancement of memory and even prospective memory might shed some light on understanding social anhedonia and, by extension, social functioning deficits.

False memory

False memories (sometimes referred to as memory errors) refer to the recall of inaccurate information or events that never occurred (Roediger & McDermott, 1995). These false memories can be attributed to several causes, including errors in the storage or retrieval of information (Loftus, 2003). False memory in the lab is elicited using explicit suggestions (e.g., misinformation paradigm) (Loftus, 2003) and without using explicit suggestions (e.g., Deese–Roediger–McDermott [DRM] paradigm; Roediger & McDermott, 1995). The DRM, one paradigm without explicit suggestions, involves participants being presented with a list of words and later asked to recall words they had seen. However, during the recall, participants often identify words not presented during the task but semantically related to some of the presented words (i.e., lures). These lures are considered "false alarms". False alarms in paradigms such as the DRM, are then generalized as indicators of false memories in the literature. In paradigms that involve rewards and declarative memory, not only are cues that signal reward recalled to a greater degree than neutral cues, but even unrelated information presented after the reward cue is recalled to a greater extent (Adcock et al., 2006; Kuhl et al., 2011; Wittmann et al., 2008, 2011). Taken together, these findings suggest that measuring rates of false alarms in paradigms such as the DRM gives researchers insight into the intrusion of false memories and can be used in reward-based learning paradigms to examine their relation to retroactive enhancement of memory.

One mechanism through which rewards influence declarative memory is reward generalization. Reward generalization occurs when the reward value of a conditioned stimulus spreads to a stimulus that is not conditioned. This is especially true when the stimuli share some perceptual characteristics (Bhatt et al., 1988; Honig & Urcuioli, 1981). In instances where stimulus typicality is high, the reward generalization is also expected to be high. For example, Swirsky et al. (2020) found that reward anticipation led to enhanced gist-level encoding over detail-level encoding, suggesting greater reward generalization. Moreover, reward consumption would lead to positive emotions like contentment (Fredrickson, 2001), which in turn signal a safe environment. This safety signal promotes more heuristic processing (Schwarz, 1990). Indeed, studies have found that higher reward motivation leads to higher recall but also higher false alarms (i.e., indicating processing of information that was not previously presented) and, therefore, poorer accuracy of memories (Keren, 1991; Moritz et al., 2004; Moritz, et al., 2006).

Accuracy of memories has been found to be impacted in those with psychopathology. For example, increased memory confidence despite significant memory errors has been found in those with schizophrenia, while confidence in accurate memories has been slightly poorer compared to healthy controls (Bhatt et al., 2010; Gawęda et al., 2012; Moritz et al., 2004, 2006, 2008; Moritz & Woodward, 2006; Peters et al., 2013). It has also been argued that this bias for overconfidence in false memories might play a role in the development and maintenance of positive symptoms in schizophrenia. There is a lack of evidence on the retroactive effects of reward-based learning on rates of false alarms and, in extension, false memories. Understanding the role rewards play in the distortion of memories and the generation of false memories might shed some light on the mechanisms that lead to aberrant learning and recall of memories.

Current Project

Based on hippocampal reverse replay and the synaptic tagging and capture hypothesis, there is strong theoretical support for reward paradigms eliciting retroactive enhancement of memory. Furthermore, although largely mixed, researchers have found greater success eliciting retroactive enhancement of memory in studies using rewards (Braun et al., 2018; Murayama & Kitagami, 2014; Patil et al., 2017) than aversive stimuli (Dunsmoor et al., 2019; Hennings et al., 2021; Kalbe & Schwabe, 2021). Since one reason for the mixed findings from prior studies could be the confound of Pavlovian-to-instrumental transfer, I attempted to disentangle the conflicting findings by using an operant conditioning paradigm with intentional encoding and a classical conditioning paradigm with incidental encoding. As there is a lack of evidence regarding the influence of social rewards on memory, it is unclear if social rewards are salient enough to elicit the retroactive enhancement of memory. Understanding the influence of social reward on retroactive enhancement of memory and even prospective memory might shed some light on understanding social anhedonia and, by extension, social functioning deficits. Therefore, the current dissertation used not only monetary rewards but social rewards as well to elicit retroactive enhancement of memory. Another aim of this dissertation was to examine the retroactive effects of reward-based learning on rates of false alarms, as this might inform us of mechanisms relating to the distortion of memories and false memories involving rewards.

Taking these factors into consideration, two studies were conducted as part of this dissertation to further understand the effect of rewards on retroactive enhancement of memory and the conditions in which it may be elicited. Specifically, Study 1 (1) examined the effects of

(a) monetary reward and (b) social reward on retroactive enhancement of memory and (2) investigated the influence of (a) monetary reward and (b) social reward on false memories using an operant conditioning paradigm with intentional encoding. Study 2 had similar aims to Study 1 but used a classical conditioning paradigm with incidental encoding instead. The findings from these two studies add to the growing body of literature on retroactive enhancement of memory. As the mixed findings in previous studies could be due to factors affecting reinforcement learning, these two dissertation studies delineate conditions that may elicit the effect and investigate false memories under such conditions. The findings of this dissertation may shed light on psychopathology involving memory and reward systems.

Study 1

The Effect of Monetary and Social Reward on Retroactive Enhancement of Memory in Operant Conditioning Paradigm

Instrumental or *operant conditioning* is a process of learning through which frequencies of specific behaviors are shaped using rewards and punishments. Desired behaviors are reinforced by administering rewards or punishments to increase or reduce frequencies of those behaviors respectively. In contrast, *Pavlovian* or *classical conditioning* is the process of learning associations between a neutral stimulus and an unconditioned response (UR) to an unconditioned stimulus (US), such as an appetitive reward or an aversive stimulus. The previously neutral stimulus then becomes the conditioned stimulus (CS), eliciting a conditioned response (CR). In classical conditioning, the presentation of both the neutral and the unconditioned stimuli is not contingent on the subject's behavior. Conversely, instrumental or operant conditioning requires active participation (Thorndike, 1911) from the subject. This participation in reinforcement learning of salient stimuli in operant conditioning reflects goal-directed behavior or motivational salience. However, the role of motivational salience in eliciting retroactive enhancement of memory in previous studies might have been occluded due to the conflation of learning paradigms used, thus leading to mixed findings.

Incidental encoding and intentional encoding are two learning paradigms used in previous studies to investigate retroactive enhancement of memory. However, when there is no distinction between operant conditioning and classical conditioning in incidental encoding paradigms, there is a possibility of Pavlovian-to-instrumental transfer occurring. In incidental encoding, no specific instructions on learning and forming associations are provided; instead, free exploration leads to the discovery of rewards or aversive stimuli. Conversely, specific instructions are given in intentional encoding, and rewards are awarded to increase the frequency of preferred behavior. Not accounting for this Pavlovian-to-instrumental transfer means that it is difficult to determine the role of motivational salience in eliciting retroactive enhancement of memory. Instrumental conditioning paradigms could use incidental or intentional encoding depending on whether clear instructions on learning the items in the task were provided (McLaughlin, 1965).

Previous studies that have used rewards to elicit retroactive enhancement of memory have mainly used incidental encoding without specifically using an operant or classical conditioning paradigm (Braun et al., 2018; Murayama & Kitagami, 2014; Oyarzún et al., 2016). Furthermore, these studies have only used monetary rewards. Only Patil et al. (2016) employed intentional encoding with operant conditioning using monetary rewards to elicit retroactive enhancement of memory. As such, there is a lack of evidence regarding the role motivational salience plays in the elicitation of retroactive enhancement of memory. By using operant conditioning with intentional encoding, we can better understand the role motivational salience plays in eliciting retroactive enhancement of memory and untangle Pavlovian-to-instrumental transfer from the previous studies. Thus, Study 1 used operant conditioning with intentional encoding for (monetary and social) rewards to disentangle motivational salience from Pavlovian-to-instrumental transfer and elicit retroactive enhancement of memory.

Social Reward

While monetary rewards have been widely used to understand the role that rewards play in memory processes, few studies have used social rewards. Indeed, all four previously published studies that have used rewards to elicit retroactive enhancement of memory used only monetary reward (Braun et al., 2018; Murayama & Kitagami, 2014; Oyarzún et al., 2016; Patil et al., 2017). Studies on social dysfunction across psychopathologies imply that there might be deficits in reinforcement learning and consolidation of social memories (Pizzagalli, 2010). For example, individuals with social anhedonia – a symptom associated with several psychopathologies – might have impairment in the consolidation of memories relating to social rewards. Individuals with social anhedonia are more likely to predict social interactions as unpleasant despite momentarily enjoying them (Gooding & Pflum, 2022; Martin et al., 2019; Moore et al., 2019). This finding indicates that the consolidation of social memories and cues leading up to social rewards might be impaired. Therefore, it is crucial to understand the role of motivational salience and operant conditioning in retroactive enhancement of memory using not only monetary but social rewards as well.

False Alarms

Studies of reward-based learning have found that while higher reward motivation leads to higher recall, it also leads to higher rates of false alarms (Keren, 1991; Moritz et al., 2004, 2006). False alarms are a type of false positive and reflect instances in which a stimulus that was not presented is identified as having been presented (Festini & Katz, 2021). The implication is that there could be a greater distortion of memory and generation of false memories leading up to when rewards are received. The two studies (Dunsmoor et al., 2019; Hennings et al., 2021) that examined false alarms relating to retroactive enhancement of memory used shocks in an incidental encoding with classical conditioning paradigm. As such, the role of reward-based reinforcement learning – both monetary and social rewards – on false memories in paradigms eliciting retroactive enhancement of memory is unclear. Understanding the role of rewards in false alarms, especially when retroactive enhancement of memory is elicited, will improve our understanding of reward-based reinforcement learning. This understanding would also allow us to clarify contexts in which false alarms arise in the presence of rewards.

Extrinsic vs. Intrinsic Reward in Operant Conditioning

In reward-based reinforcement learning, cues of rewards may serve as performance feedback instead of serving as cues of the rewards themselves. Thus, it is unclear if the reward or merely performance feedback elicits retroactive enhancement of memory. When extrinsic rewards are given, individuals engage in compensatory behaviors such as post-error slowing and error correction. Rabbitt (1966, 1968) found that participants also monitor task performance and exhibit compensatory behaviors such as post-error slowing and error correction when extrinsic rewards were not provided. This finding illustrates that intrinsic rewards can result in behaviors similar to extrinsic rewards. Furthermore, studies have found that intrinsic motivation moderated exploration despite the lack of extrinsic rewards (Baranes et al., 2014). These findings suggest that intrinsic rewards might be sufficient for spontaneous error correction and performance modulation. In fact, neural networks recruited during intrinsic motivation mirror structures recruited during the processing of extrinsic rewards (Kang et al., 2009; Lee et al., 2012; Murayama, 2022; Murayama et al., 2010; Satterthwaite et al., 2012; Schouppe et al., 2014; Ulrich et al., 2014). Therefore, as Study 1 used operant conditioning, it was crucial to examine if intrinsic reward from performance feedback might be salient enough to elicit retroactive enhancement of memory compared to extrinsic rewards (e.g., monetary and social rewards).

Current Study

Taken together, the role of reward-based learning in retroactive enhancement of memory is unclear. One reason for the mixed findings from prior studies could be that the confound of Pavlovian-to-instrumental transfer may have been introduced in using incidental conditioning without specifically using classical conditioning. The confound of Pavlovian-to-instrumental transfer occludes the conditions under which retroactive enhancement of memory might occur. As such, Study 1 used operant conditioning with intentional encoding to elicit retroactive enhancement of memory to disentangle motivational salience from Pavlovian-to-instrumental transfer. Furthermore, there is a lack of evidence on the effect social reward has on retroactive enhancement of memory using an operant conditioning paradigm. Understanding the effect of social reward reinforcement learning on prospective and retroactive enhancement of memory can provide insight into aberrant learning of social cues. Examining rates of false alarms in conditions that elicit retroactive enhancement of memory will also add to our understanding of the distortion of memories and false memories through reward reinforcement. To address these gaps, Study 1 aimed to (1) examine the effects of (a) monetary reward, (b) social reward, and (c) intrinsic reward on retroactive enhancement of memory and (2) investigate the influence of (a) monetary reward, (b) social reward, and (c) intrinsic reward on false memories of images using an operant conditioning paradigm.

Hypotheses

Aim 1. Role of Rewards in Eliciting Retroactive Enhancement of Memory.

Hypothesis 1.1: *d'* (standardized mean difference between the distribution of correct hits and false alarms) will be greater for images in the reward category than the non-reward category presented in the preconditioning phase for all three reward conditions.

> **H1.1a:** In the monetary reward condition, *d'* will be greater for images in the reward category than the images in the non-reward category presented in the preconditioning phase.

H1.1b: In the social reward condition, *d'* will be greater for images in the reward category than the images in the non-reward category presented in the preconditioning phase.

H1.1c: In the intrinsic reward condition, *d'* will be greater for images in performance feedback category than the images that did not receive feedback presented in the preconditioning phase.

Hypothesis 1.2: There will be an effect of reward type on *d'*. Specifically, *d'* will be greatest for images in the monetary reward condition, followed by the social reward condition, and lowest for the intrinsic reward condition.

Aim 2. Role of Rewards in False Memories

Hypothesis 2.1: False alarms will be greater for images in the reward category than the non-reward category for all three reward conditions.

H2.1a: In the monetary reward condition, false alarms will be greater for images in the reward category than the non-reward category.

H2.1b: In the social reward condition, false alarms will be greater for images in the reward category than the non-reward category.

H2.1c: In the intrinsic reward condition, false alarms will be greater for images in the performance feedback category than the images that did not receive feedback.

Hypothesis 2.2: There will be an effect of reward type on false alarms. Specifically, false alarms will be greatest for images in the monetary reward condition, followed by the social reward condition, and lowest for the intrinsic reward condition.

Materials and Methods

Participants

A total of 113 participants were recruited for this study. Undergraduate students were recruited through the University of California, Irvine's (UCI) Human Subjects Pool (SONA). Participants were also recruited from the community through flyers posted around UCI. Five of the 113 recruited participants failed to attend Session 2 (described below). One participant had to be excluded from analysis as they had been recruited despite participating previously, and four more participants were excluded due to experimenter error (incorrect condition administered in Session 1). In the final sample of 103, 75.7% were female, with a mean age of 21.00 years (*SD* = 3.67, range from 18-42). Approximately 32.0% of the participants were East Asian, 20.4% were Hispanic, 17.5% were biracial or multiracial, and 14.6% were White.

Materials

Stimuli

Stimuli used in the study were selected through two stages. The goal was to create a final set of 288 images. Of the 288 images, 144 (72 animal images and 72 tools images) were presented across the preconditioning, conditioning, and postconditioning phases of Session 1. Each phase in Session 1 of the main experiment contained unique sets of 48 images (24 animals and 24 tools), and these sets were consistent across the groups. A further 96 images were introduced during the recall phase in Session 2, and 48 images were used as foils during the conditioning phase. The foil images were from the same category as the target image but were not used in the recognition test in Session 2.

In the first stage toward having a final set of 288 images, I used the 144 images from Hennings et al. (2021). In order to obtain another 144 images, I collected images from publicly available websites and added them to the stimuli set. Furthermore, the data provided by Hennings et al. (2021) on the stimulus set they used revealed that some images had low stimulus typicality. The research team (N = 18) rated 163 images of animals and 164 images of tools for stimulus typicality and image similarity. The instruction for stimulus typicality was “How typical is this image of a tool/animal?” and the instruction for stimulus similarity was “How similar in perceptual features (and not conceptual similarity) was this image to another image presented?”. For each set, images with low stimulus typicality (lower than two standard deviations below the mean) and images with high similarity (higher than two standard deviations above the mean) were removed. As fewer than 288 images were in the stimulus set after removing images with low stimulus typicality and similarity, further images were sourced from publicly available websites. The stimulus set consisted of 186 tools and 186 animals (372 total) for testing in the second stage.

In the second stage, participants were recruited through UCI SONA to rate these 372 images on stimulus typicality and similarity. Of the 64 participants who participated in the image ratings, 44 completed ratings for all the images. From these ratings, images with high similarity were removed, and 144 images with the highest stimulus typicality for the categories of animals and tools each were identified. Thus, 84 images with the lowest ratings were excluded. The remaining images were then sorted by stimulus typicality and sequentially split into six sets of 48 images each so that the average stimulus typicality across the six sets would be similar. Images presented in the preconditioning, conditioning, and postconditioning phases, as well as the foil images in Session 1, were unique sets of 48 images. In comparison, two sets of images for a total of 96 unique images were used as lures to test false alarms in Session 2.

Encoding Paradigm

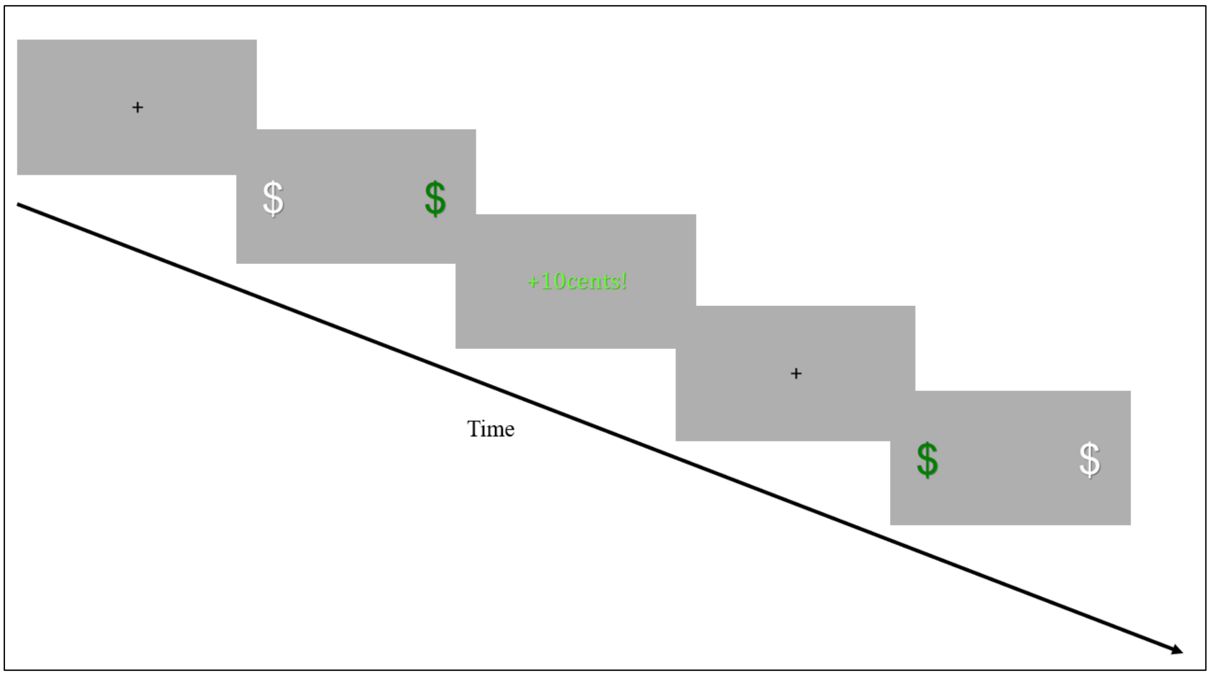
Training. Providing monetary compensation to participants makes the reward tangible, and the associations between cues of monetary rewards and monetary rewards themselves are strong (Matyjek et al., 2020). However, it is difficult to provide social rewards in the lab to participants in an equivalent manner. To make the learned associations of the cues used in the experiment more equivalent across monetary and social reward conditions, participants underwent a training session to learn the association between the reward cues we used and the rewards they represented.

For the monetary reward condition, the goal of the training session was for participants to learn that green “$” represents a higher monetary reward value (see Figure 1). Participants were instructed that their goal was to win as much money as possible, with a possibility of winning a maximum of $5 paid out at the end of the study. The participants were first presented with a black fixation cross in the center of the screen against a gray background. The fixation cross was replaced by a green “$” and a white “$” on either side of the screen for 1000ms. The location of the “$” symbols was pseudo-randomized such that the green “$” appeared on the right side of the screen for half the trials, and the white “$” appeared on the right side for the other half of the trials. By pressing the right “alt” key or the left “alt” key, they could select the image on the right or left of the screen. If they selected the green “$”, the image was replaced with a screen informing them that they had won 10 cents, and if they selected the white “$”, it was replaced with a screen informing them that they had won 1 cent. The feedback on the reward they received for each trial was presented for 1500ms before being replaced by the fixation cross, signaling the start of the next trial. The intertrial interval, including the fixation cross, was 2500ms ± 1000ms. There were ten practice trials followed by two blocks of 25 trials each, with a

1-minute break between blocks. Participants were instructed to sit in their chairs and relax during the short break. The total duration of the training session for the monetary reward condition lasted about 10 minutes.

Figure 1.1

Monetary Reward Training Task



Note: The sequence of images here depicts the participant selecting the green dollar sign. The slide would show "+1 cent" in white instead if they had selected the white dollar sign.

For the social reward condition, the goal of the training session was for participants to learn that the red heart emoticon represents a higher social reward value (see Figure 2). Participants were told that they were to create a social media profile on a "social media platform," which was adapted from the "Social Media Ostracism Paradigm" (Wolf et al., 2015), and their goal was to receive as many social credits from other users as possible. They had 3 minutes to choose an avatar from a list of 84 and write a short description about themselves in less than 400 characters. They were informed that they had 45 social credits and 5 minutes to validate other profiles, just as the other "users" would validate their profile. Participants could validate the other profiles by reading them and awarding a red heart emoticon worth 10 social credits or a thumbs-up emoticon worth 1 social credit. Although participants were informed that these were profiles of other users from the UC schools, every participant viewed the same 14 profiles generated in advance. The validation that participants in the social reward condition training session received was preprogrammed such that each participant received 6 red heart emoticons and 7 thumbs-up emoticons for a total of 67 social credits awarded. The total duration of the training session for the social reward condition lasted about 12 minutes.

For the intrinsic reward condition, there was no training session. Following the training session for the monetary and social reward conditions, participants were given a 1-minute break before moving on to the main experiment. Participants were instructed to sit in their chairs and relax during the short break.

Figure 1.2

Social Reward Training Task

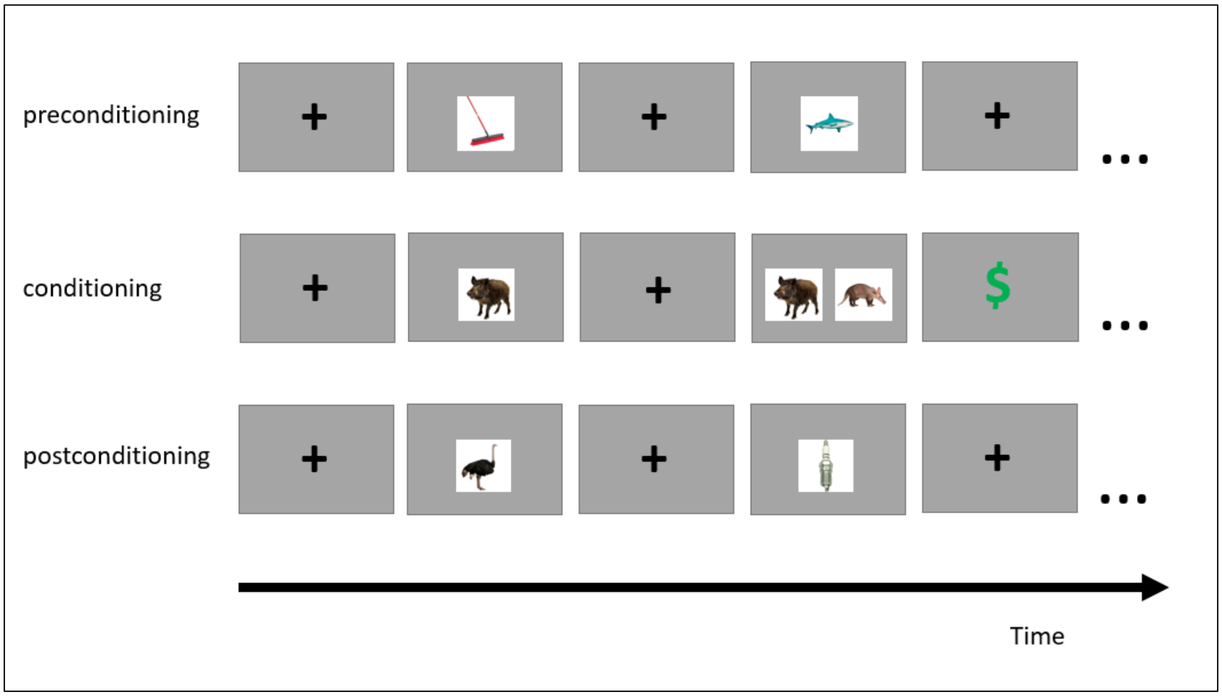
Note: The profile highlighted in red on the top left is the participant's profile.

Session 1. The first session of the main experiment included three phases: the preconditioning phase, the conditioning phase, and the postconditioning phase. Each phase included 48 images of animals and tools (24 each) presented against a gray background. In preconditioning, participants had to categorize the images as animals or tools. A black fixation cross was presented on a gray background, which was then replaced by an image presented for 4500 ± 500ms. The participants were instructed to categorize the image as an animal or a tool by pressing the "1" or "2" key on the numpad of the keyboard. This keymapping was counterbalanced across participants. At the end of the image presentation, the fixation cross was displayed on the screen to signal the start of the next trial. The intertrial interval was varied at 6000ms ± 1500ms. The total duration of the preconditioning phase was around 8.5 minutes.

The conditioning phase began after a 1-minute break. During this break, participants were instructed to remain seated in their chairs and relax. In this phase, participants had to identify the image they had seen in the previous trial. Correct responses were reinforced with a reward depending on their assigned group. For example, participants in the monetary reward + tools group were presented with a monetary reward only if they correctly identified images from the tools category, and participants in the social reward + animals group were presented with a social reward only if they correctly identified images from the animals category. Participants were first presented with a black fixation cross on a gray background, which was replaced by an image of a tool or animal, presented for 3000ms. After a 5000ms delay, they were presented with two images on the right and left of the screen for 1000ms. One of the images was the image presented previously (target), and the other was a foil image from the same category of images as the target image. The participants had to indicate which of the two images was the image they had seen previously by pressing the right "ctrl" key for the image on the right and the left "ctrl" key for the image on the left. When the image was correctly identified, a reward was presented for 1500ms. However, only 75% (18/24) of eligible trials were programmed with the reward following a variable ratio reinforcement schedule.

Figure 1.3

Sequence of Trials in Session 1



Note: While the sequence is the same for the social and intrinsic reward conditions as well, the reward cue would be a red heart instead of the green dollar sign for the social reward condition and a purple circle for the intrinsic reward condition.

The cue for monetary reward was a green "$" symbol, the cue for social reward was a red heart "❤", and the cue for intrinsic reward was a purple circle "●". If participants took longer than 600ms to make their response or responded incorrectly, they were instead presented with a blank gray screen for 1500ms before the presentation of the fixation cross again. Correctly identifying images in the non-reward category also resulted in the presentation of the blank grey screen. The intertrial interval included the presentation of the black fixation cross and was varied at 4500ms ± 1000ms. This phase lasted about 7.5 minutes.

The postconditioning phase began after a 1-minute break in which participants were again instructed to remain seated in their chairs and relax. The postconditioning phase was similar to the preconditioning phase, but participants viewed a different set of 48 images and had to categorize them as animals or tools.

Session 2. Participants returned to the lab 24 hours after Session 1 for a recognition test. The recognition test included the original 144 images (24 images from 2 categories over 3 phases) seen during the first session and an additional unseen 96 images (48 images of animals and 48 images of tools) for a total of 240 images. The recognition test did not include the foil images used in the conditioning phase. Participants first rated whether the image was old if they had seen them previously or new if they had not seen them previously. They then indicated their confidence in their choice (0 = Not at all confident – 10 = Extremely confident). Participants also indicated the phase in which they thought they had seen the image (preconditioning, conditioning, and postconditioning) and their confidence in their choice. Correct hits and false alarms were calculated from images rated as old with a confidence greater than 6. The main outcome measure was *d'*, which is the standardized mean difference between the distribution of correct hits and false alarms. *d'*s were calculated separately for the reward and non-reward categories.

Procedure

The study involved two in-lab sessions. Following informed consent, in Session 1, participants were randomly assigned to one of six groups (monetary reward + tools, monetary reward + animals, social reward + tools, social reward + animals, intrinsic reward + tools, intrinsic reward + animals). While the group denoted the pairing of the image category with the reward category, all participants viewed both categories of images (i.e., tools and animals). In

Session 1, participants first engaged in a training session specific to the monetary or social reward conditions. There was no training for the intrinsic reward condition. Following training, participants performed the preconditioning, conditioning, and postconditioning phases of the encoding paradigm. They then returned to the lab 24 hours later for Session 2 to complete an image recognition test. Participants were required to indicate if they expected a recognition test in Session 2 in case they engaged in rehearsal, which might have influenced the results. Upon completion of the study, participants were debriefed and compensated for their time. Participants recruited through SONA were compensated with 2 SONA research credits and $20, while participants recruited from the community were compensated $30 for their participation.

Power Analysis

An *a priori* power analysis was conducted using G*Power (Faul et al., 2009) to calculate the required sample size. While the effect size for monetary reward could be estimated based on previous studies (Braun et al., 2018; Murayama & Kitagami, 2014; Patil et al., 2017) that used monetary reward to elicit retroactive enhancement of memory (f = .27), there were no previous studies that had used social reward to elicit the effect. However, in other studies that compared monetary rewards to social rewards, such as the monetary incentive delay and social incentive delay tasks, the effect size of monetary reward was about 50% bigger than that of social reward. Thus, I estimated that the effect size for the interaction between phase and stimulus type for the social reward condition would be f = .18, or 33% smaller than that of monetary reward. Therefore, with an alpha = .05, power = .80, and an effect size of f = .18, the projected sample size required for three conditions (i.e., monetary, social, and intrinsic) was approximately N = 99. The sample size of 104 in the current study should have ensured adequate power.

Data Retention and Cleaning

Data were assessed for homogeneity of variance and sphericity. The Greenhouse-Geiser correction was used in the event of a violation of the assumption of sphericity. Sensitivity analysis was conducted using a subset of the data consisting of only participants who did not expect the recognition test in Session 2. The sensitivity analysis was to determine if the inclusion of participants who expected the recognition test might have engaged in rehearsal, which might have affected the results (see "Sensitivity Analysis for Recognition Test" in the "Results" section).

Hypotheses and Statistical Analysis

The first aim of Study 1 was to examine the effects of (a) monetary reward, (b) social reward, and (c) intrinsic reward on retroactive enhancement of memory. I hypothesized that there would be a significant main effect of stimulus type and a significant interaction effect such that *d'* for the images in the reward category would be higher in the preconditioning phase than the *d'* for the non-reward category in monetary, social, and intrinsic reward conditions (Hypothesis 1.1). To test this, I conducted a 2x3 repeated measures ANOVA for each reward condition, in which stimulus type (reward/non-reward) and phase (preconditioning/conditioning/postconditioning) were within-subjects factors, and *d'* was the outcome variable. I also hypothesized an effect of reward type such that *d'* in the monetary reward condition would be highest, followed by the social reward condition, and lowest in the intrinsic reward condition (Hypothesis 1.2). To test this, instead of examining the difference in recall between the three reward conditions using only the reward category of images, I collapsed across stimulus type (i.e., collapsing across reward and non-reward images). This collapsing was done as results from analysis for Hypothesis 1.1 indicated no significant difference in stimulus type. Therefore, collapsing across stimulus type was a more appropriate statistical test to examine the difference in recall between the reward conditions. To that end, I ran a mixed model-ANOVA with phase serving as the within-subjects factor, reward type as the between-subjects factor, and *d'* as the outcome variable.

The second aim of the study was to investigate the influence of (a) monetary reward, (b) social reward, and (c) intrinsic reward on false memories. I hypothesized that false alarms in the reward category would be higher than in the non-reward category for monetary, social, and intrinsic reward conditions (Hypothesis 2.1). To test this, I ran dependent means *t*-tests comparing the mean false alarms between reward and non-reward categories for each reward condition. I also hypothesized that false alarms would be highest in the monetary reward condition, followed by social and lowest in the intrinsic reward condition (Hypothesis 2.2). As with Hypothesis 1.2, for Hypothesis 2.2, I ran a one-way ANOVA with reward type serving as the between-subjects factor (collapsing across stimulus type) and false alarms serving as the outcome variable.

Partial Eta squared in ANOVA models less than .01 were interpreted as small, .06 as medium, and greater than .14 as large (Cohen, 2013). As my sample sizes are relatively small Hedges' *g* was the preferred effect size when comparing means between groups. Hedges' *g* smaller than .2 were interpreted as small, .5 as medium, and greater than .8 as large effect sizes (Hedges, 1981).

Results

Aim 1: Retroactive Enhancement of Memory

Contrary to what I had hypothesized, there was no significant main effect of stimulus type for monetary [$F(1, 35) = 1.05$, $p = .31$, $\eta_p^2 = .03$] (see Figure 4), social [$F(1, 37) = .19$, $p =$

.66, $\eta_p^2 = .01$] (see Figure 5), or intrinsic [$F(1, 28) = 3.47$, $p = .073$, $\eta_p^2 = .11$] (see Figure 6) reward conditions, with small to medium effect sizes across all three reward conditions. There was also no significant stimulus type x phase interaction effect for monetary [$F(1.54, 53.90) = .52$, $p = .55$, $\eta_p^2 = .02$, Greenhouse-Geiser corrected], social [$F(1.72, 63.48) = .66$, $p = .50$, $\eta_p^2 = .02$, Greenhouse-Geiser corrected], or intrinsic [$F(2, 56) = 1.30$, $p = .28$, $\eta_p^2 = .04$] reward conditions, with small to medium effect sizes across all three conditions. There was, however, a significant main effect of phase for monetary [$F(2, 70) = 73.58$, $p < .001$, $\eta_p^2 = .68$], social [$F(2, 74) = 76.53$, $p < .001$, $\eta_p^2 = .67$] and intrinsic [$F(2, 56) = 31.42$, $p < .001$, $\eta_p^2 = .53$] reward conditions, with large effect sizes across all three conditions.

Pairwise comparisons revealed that in all three reward conditions, there was significantly higher recall in the preconditioning and conditioning phases compared to the postconditioning phase (*p*s < .001). However, while there was no significant difference in *d'* between the preconditioning and conditioning phases in the monetary ($p = .58$) or social ($p = .29$) reward conditions, there was a significant difference in the intrinsic reward condition ($p = .049$) collapsing across stimulus type. Simple effects analysis revealed that there were no significant differences in *d'* between the reward and non-reward category of images across all three phases (*p*s >.1) for the monetary and social reward conditions. In the intrinsic reward condition, while there were no significant differences in *d'* between the reward and non-reward category of images in the preconditioning and postconditioning phases, it was trending toward significance in the conditioning phase ($p = .057$)

Figure 1.4

Pattern of Recall in Monetary Reward Condition (Study 1)

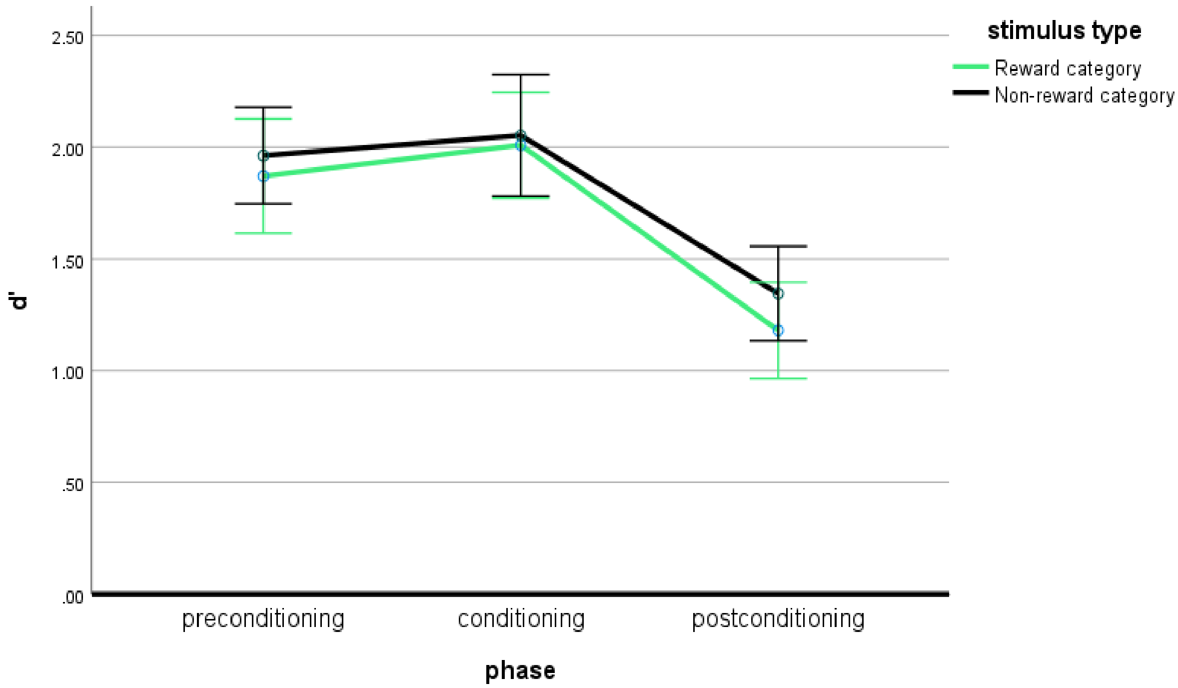


Figure 1.5

Pattern of Recall in Social Reward Condition (Study 1)

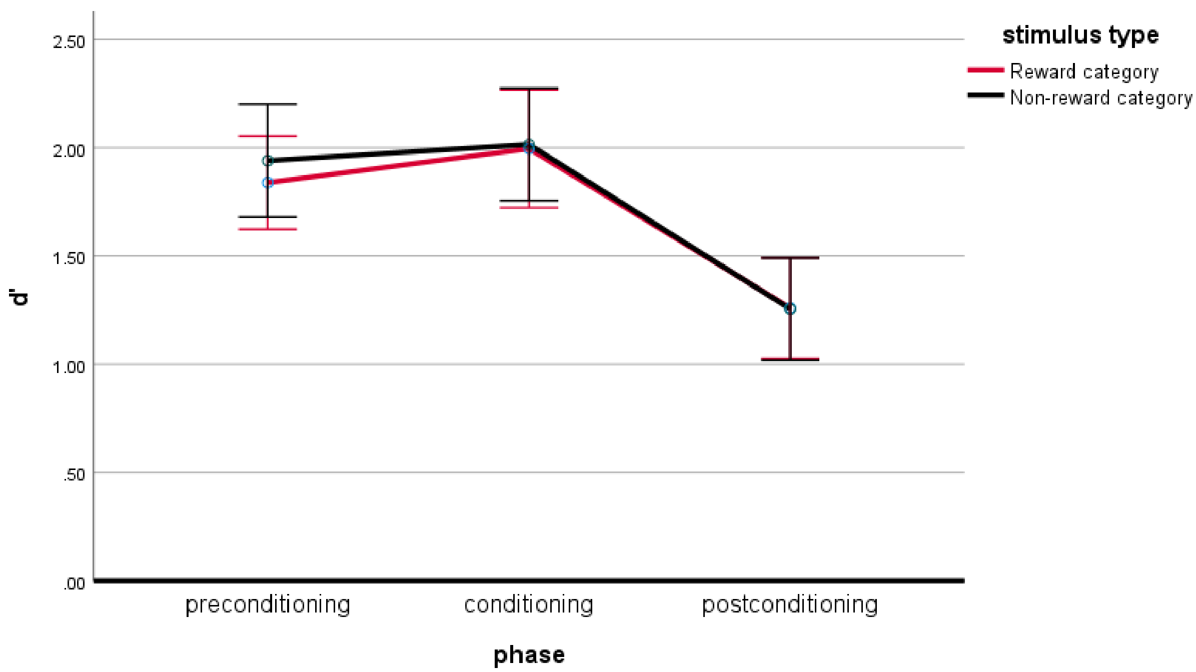
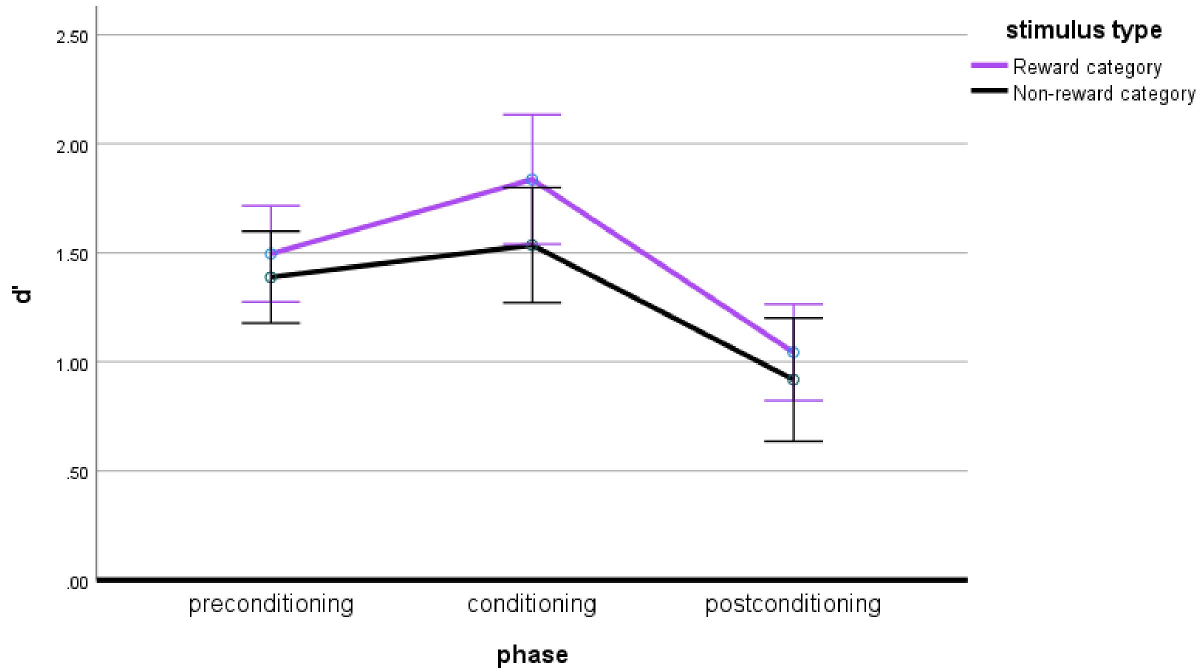


Figure 1.6

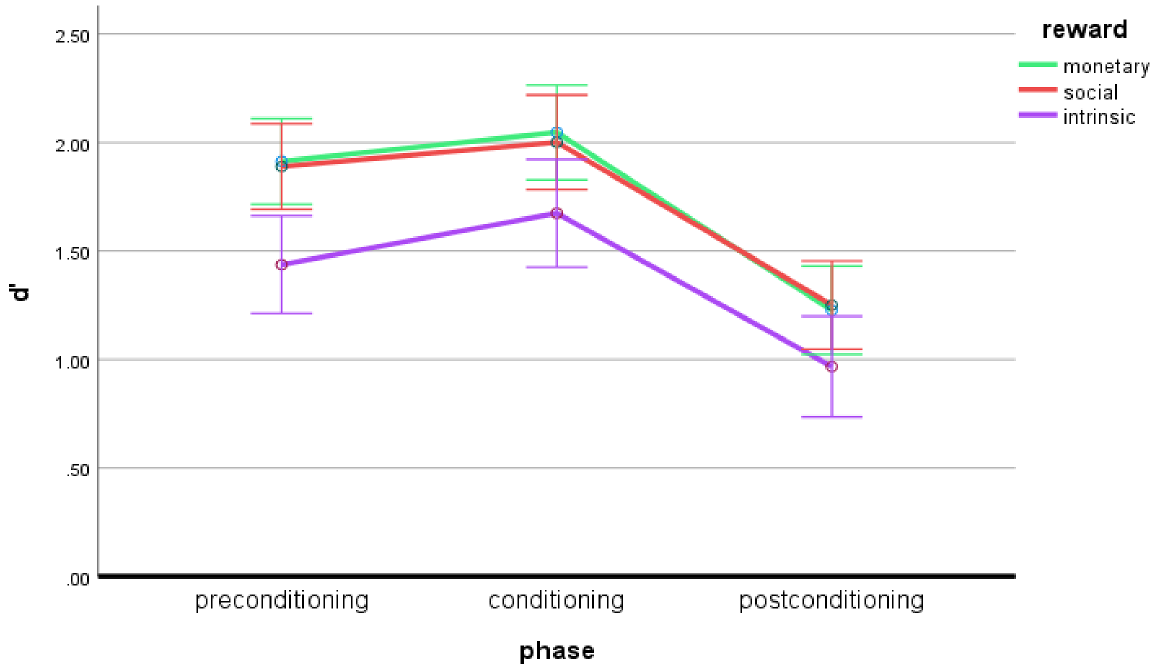
Pattern of Recall in Intrinsic Condition (Study 1)



As there was no significant main effect of stimulus type, I compared the pattern of recall across the three phases for all three reward conditions collapsing across stimulus type (see Figure 7). There was again a significant main effect of phase with a large effect size [F(2, 200) = 169.68, p < .001, η_p^2 = .63] but no phase x condition interaction effect [F(4, 200) = 1.25, p = . 29, η_p^2 = .02] with a small effect size. There was, however, a significant main effect of reward with a medium effect size [F(2, 100) = 4.19, p = .018, η_p^2 = .08]. Simple main effects analysis revealed that while there were no significant differences in *d*' between the three reward conditions in the conditioning and postconditioning phases, *d'* was significantly higher in the monetary and social reward conditions (*p*s < .05) compared to the intrinsic reward condition in the preconditioning phase. There was also no significant difference in *d'* between monetary and social reward conditions for all three phases (*p*s = 1.00). The significant difference in *d'* between extrinsic and intrinsic reward conditions in the preconditioning phase indicates that retroactive enhancement of memory was elicited in at least the monetary and social reward conditions.

Figure 1.7

Pattern of Recall for All Three Reward Conditions Collapsing Across Stimulus Type (Study 1)



Aim 2: False Alarms

Contrary to my hypotheses, there was no significant difference in mean false alarms between reward and non-reward categories for monetary [$t(35) = 1.51$, $p = .14$, $g = .25$], social [$t(37) = .38$, $p = .71$, $g = .06$] and intrinsic [$t(28) = 1.39$, $p = .18$, $g = .25$] reward conditions with small to medium effect sizes across all three reward conditions (see Figure 8). To further explore the pattern of false alarms across the reward types, I ran a mixed-model ANOVA. There was no significant main effect of stimulus [$F(1, 105) = .023$, $p = .88$, $\eta_p^2 = .00$] nor reward type [$F(2, 105) = 1.28$, $p = 2.81$, $\eta_p^2 = .02$] with small effect sizes. The interaction effect between reward type and stimulus type was trending towards significance [$F(2, 105) = 2.93$, $p = .058$, $\eta_p^2 = .053$].

Though non-significant (see Figure 8), the pattern of interaction was such that for the monetary reward condition, false alarms of reward category images were higher than the non-reward category. For the social reward condition, false alarms in the reward and non-reward categories were similar. For the intrinsic reward condition, false alarms in the reward category were lower than in the non-reward category. False alarms for all three reward conditions were similar. However, false alarms of the non-reward category were lowest in monetary, followed by social, and highest in the intrinsic reward condition.

In line with my findings from testing the hypotheses relating to Aim 1 (i.e., the rewards generalized to the entire set), I ran a one-way ANOVA, collapsing across stimulus types to examine if there were differences in false alarms between reward conditions (see Figure 9). There were no significant differences between conditions, and the effect size was small [$F(2, 100) = 1.07$, $p = .35$, $\eta^2 = .02$].

Sensitivity Analysis for Recognition Test

Of the final sample of 103 participants, 25 had expected the recognition test, making the sample size for the sensitivity analysis 78 (26 in monetary, 29 in social, and 23 in novel). However, the results were primarily the same, with no differences in significance testing. This finding suggests that regardless of expecting a recognition test, when engaged in a task using an operant conditioning paradigm, there are no significant differences in recall nor false alarms.

Figure 1.8

Pattern of False Alarms Between Stimulus Type and Across Reward Type (Study 1)

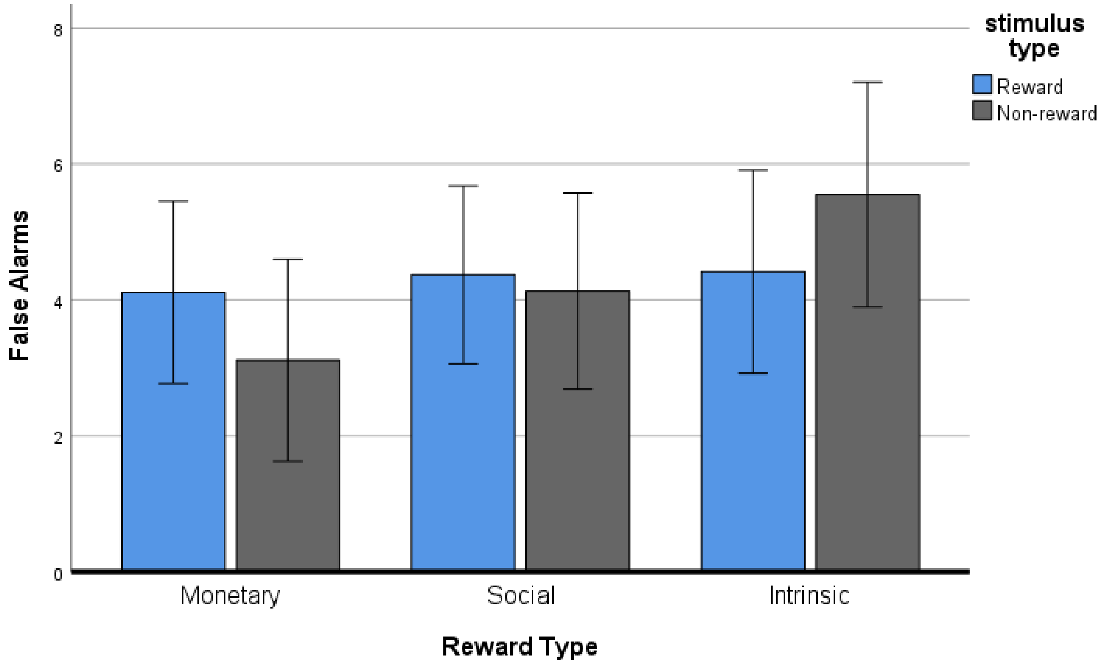


Figure 1.9

Pattern of False Alarms for All Three Reward Conditions Collapsing Across Stimulus Type (Study 1)

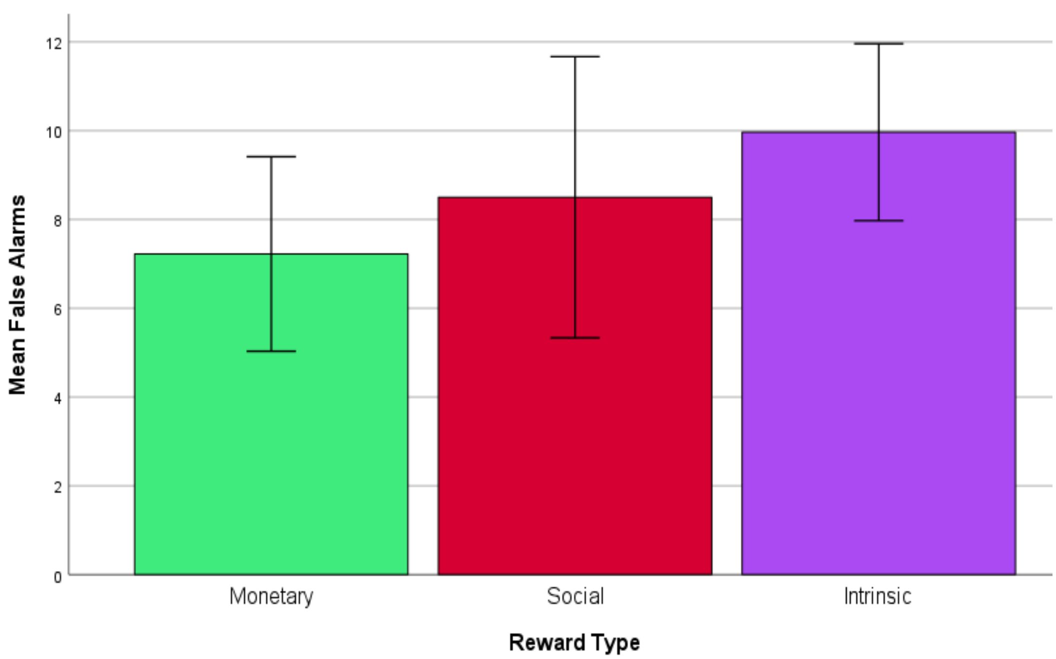


Table 1.1

Memory at 24-hour recognition (Study 1)

		Monetary (*N* = 36)	Social (*N* = 38)	Intrinsic (*N* = 29)
Preconditioning	Raw reward	15.17 (5.27)	15.16 (4.59)	13.00 (5.39)
	Raw non-reward	15.36 (4.83)	15.16 (5.01)	13.03 (4.62)
	Raw total	30.53 (9.45)	30.32 (8.22)	26.03 (9.01)
	d' reward	1.88 (.77)	1.84 (.66)	1.50 (.58)
	d' non-reward	1.97 (.65)	1.94 (.79)	1.39 (.55)
	d' total	1.94 (.66)	1.90 (.69)	1.42 (.49)
Conditioning	Raw reward	16.31 (5.20)	16.11 (5.01)	15.66 (5.88)
	Raw non-reward	15.61 (5.40)	16.18 (3.65)	14.38 (5.23)
	Raw total	31.92 (9.36)	32.29 (7.54)	30.03 (10.03)
	d' reward	2.01 (.72)	2.00 (.833)	1.84 (.78)
	d' non-reward	2.05 (.83)	2.02 (.79)	1.54 (.69)
	d' total	2.02 (.71)	2.01 (.75)	1.66 (.61)
Postconditioning	Raw reward	9.25 (4.44)	10.16 (5.05)	9.38 (5.63)
	Raw non-reward	9.69 (4.49)	9.47 (4.61)	9.17 (5.22)
	Raw total	18.94 (8.28)	19.63 (8.53)	18.55 (10.46)
	d' reward	1.18 (.65)	1.26 (.71)	1.04 (.58)
	d' non-reward	1.34 (.64)	1.26 (.72)	0.92 (.75)
	d' total	1.26 (.60)	1.28 (.69)	0.97 (.61)
False alarms	Reward	4.11 (4.46)	4.37 (4.60)	4.41 (2.46)
	Non-reward	3.11 (3.00)	4.13 (5.72)	5.55 (4.17)
	Total	7.22 (6.48)	8.50 (9.64)	9.97 (5.24)

Note: Mean (standard deviation). *d'* were standardized mean differences between distribution of raw recall and distribution of false alarms.

Discussion

Retroactive enhancement of memory

In this study, I examined the role of monetary, social, and intrinsic rewards on retroactive enhancement of memory in an operant conditioning paradigm with intentional encoding. An operant conditioning paradigm was used in Study 1 to disentangle motivational salience from Pavlovian-to-instrumental transfer that could have occurred in previous studies, leading to mixed findings. Contrary to my hypotheses, results revealed no main effect of stimulus type and no stimulus type x phase interaction effect for all three reward conditions. One reason for my findings of a non-significant interaction, and especially the lack of a significant main effect of stimulus type, is that participants might not have learned that one category of images was paired with a reward, and therefore, category-based learning did not occur. The reward then generalized to the entire set of images instead of specifically the category of images that were paired with the reward. This generalization was especially apparent in the extrinsic reward conditions (i.e., monetary, and social). If the extrinsic rewards were not effective in influencing memory, then there would have been no significant difference in *d'*s between the extrinsic rewards and intrinsic reward conditions. However, I found that *d'*s of monetary and social reward conditions were significantly higher than those of the intrinsic reward condition. The pattern of *d'* for the three reward conditions across the phases supports the proposition that the extrinsic rewards were effective in influencing memory but were generalized across the entire stimulus set instead.

Although the data do not support my *a priori* hypotheses regarding retroactive enhancement of memory, two pieces of evidence from post-hoc analyses suggest that I elicited retroactive enhancement of memory with the extrinsic rewards (and possibly with the intrinsic reward). First, although there was no significant difference in *d'* between the preconditioning and conditioning phases of monetary and social reward conditions, there was a significant difference in the intrinsic reward condition. Specifically, *d'* of the preconditioning phase was significantly lower than the *d'* of the conditioning phase. Second, recall in the preconditioning phase for monetary and social rewards was similar. There was no significant difference between *d'* in the preconditioning phase of monetary and social rewards, but they were significantly higher than that of the intrinsic reward condition.

Taken together, if there had been no retroactive enhancement of memory, recall in the preconditioning phase would have been significantly lower than the conditioning phase for the extrinsic reward conditions. Most importantly, the recall in the preconditioning phase of the extrinsic reward conditions would have been closer to that of the intrinsic reward condition; but they were significantly higher. As such, although the data did not support my *a priori* hypotheses, the post-hoc analyses suggest that I elicited retroactive enhancement of memory in operant conditioning paradigm using monetary and social rewards. Furthermore, the pattern of recall across the three phases of the extrinsic rewards in this study is similar to previous studies that successfully elicited retroactive enhancement of memory such that recall was highest in the conditioning phase, followed by preconditioning, and lowest in postconditioning (Dunsmoor et al., 2015; Hennings et al., 2021; Patil et al., 2017). However, there is a need to examine if a similar pattern of recall can be replicated in classical conditioning paradigms with rewards. Replicating my findings from operant conditioning will allow us to identify if retroactive enhancement of memory can be elicited through associative learning in classical conditioning without motivational salience. Therefore, Study 2 used classical conditioning with incidental encoding.

Monetary vs. Social vs. Intrinsic Reward

I found a significant main effect of reward with a medium to large effect size such that recall was much greater in extrinsic rewards compared to intrinsic rewards. I also found that monetary and social rewards had comparable effects on memory. I had hypothesized a significantly greater effect of monetary reward than social reward on *d'* and false alarms (Hypotheses 1.2 and 2.2), as previous studies that have compared monetary and social rewards found that monetary rewards elicited a greater effect than social rewards. However, contrary to my hypotheses, there were comparable effects of monetary and social rewards on memory. One reason for the difference between my findings and those from previous studies could be that previous studies did not attempt to make the learned associations of the cues used in the experiment more equivalent across monetary and social reward conditions, while I did so using a two-step conditioning process.

Using an effective cue of social rewards in an experimental setting is difficult as social behavior usually takes place within social situations and interactions rather than in isolated contexts like the lab (Fareri & Delgado, 2014). Furthermore, there is currently no consensus on the definition of "social rewards." As such, unlike tangible monetary rewards, providing social rewards in the lab is far more complex. However, to make the reward cues of monetary and social rewards more equivalent, I used a two-step conditioning process by first training participants to distinguish between cues of higher and lower reward values before using cues of higher reward value in reward-based learning. In turn, I found non-significant differences in *d'* between monetary and social rewards across all three phases. This finding indicates that unlike what was found in previous studies that compared monetary and social rewards, when a two-step conditioning process is used, monetary and social rewards have comparable influence on memory. Thus, researchers who are interested in studying differences in the influence of monetary and social rewards on memory and other processes should use a two-step conditioning process to ensure that the values of the cues representing the rewards are made more equivalent. As was done in Study 1, Study 2 also used a two-step conditioning process to make the learned associations of the cues used in the experiment more equivalent across reward conditions.

In addition to monetary and social rewards, I examined the influence of intrinsic rewards in eliciting retroactive enhancement of memory. The results indicate that recall in the intrinsic reward condition was significantly lower than in the extrinsic reward conditions. There was a non-significant effect of stimulus type in the intrinsic reward condition with a medium to large effect size, such that the pattern of difference between stimulus types was in line with what I had hypothesized. In contrast, the differences in mean recall of stimulus type in extrinsic reward conditions were smaller, as reflected by the small effect sizes. One possible reason for this finding is that with intrinsic rewards, there was a larger proportion of participants who learned, whether consciously or unconsciously, the rule for category-based learning. Another possibility is that intrinsic rewards were not as salient as extrinsic rewards to elicit retroactive enhancement of memory.

Further research on the role intrinsic rewards play on memory – especially retroactive enhancement of memory – is needed to clarify which of the abovementioned reasons account for the difference in finding between extrinsic and intrinsic rewards. However, including predictions in the instructions to promote rule-based category learning is not an option when studying intrinsic rewards, as intrinsic motivation can only be examined using an operant conditioning paradigm. Instead, a future direction for research in intrinsic reward could involve asking participants to indicate if they knew what the rule was after the encoding paradigm. Reports of knowledge of the rule can be used as a moderator to examine if learning the rule for category-based learning moderates the effect of intrinsic reward on recall between categories. In turn, we can examine the influence of intrinsic rewards on retroactive enhancement of memory. Understanding the role extrinsic and intrinsic rewards play on (retroactive enhancement of) memory can have a profound influence on our understanding of learning.

False alarms

The second aim of this study was to investigate the influence of monetary, social, and intrinsic rewards on false memories. I hypothesized that false alarms in the reward category of images would have been higher than in the non-reward category of images. However, the result from examining recall suggests that reward-learning likely generalized to the entire stimulus set instead of the specific categories. This generalization was also reflected in the analysis of false alarms, with no significant difference in false alarms between reward and non-reward categories of images across all three reward conditions. Although non-significant, the pattern suggests that false alarms remain similar for the reward category of images but were numerically lowest in monetary reward, followed by social reward, and highest in intrinsic reward in the non-reward category of images.

There are two possible reasons for my non-significant finding on the influence of rewards on false alarms. One reason could be that rewards exert a non-significant influence on false alarms. Another possibility is that motivational salience moderates the influence of rewards on false alarms. Therefore, while the data showed no significant effect of reward on false alarms in an operant conditioning paradigm, there might be a significant effect in classical conditioning paradigms where there is no motivational salience. However, as none of the previous studies that had examined the role of rewards on retroactive enhancement of memory reported analysis of false alarms, there needs to be further research to understand the role of rewards (and motivational salience) on false alarms.

To address the possible moderation of motivational salience on the effect of rewards on false alarms, Study 2 used a classical conditioning paradigm. Moreover, future research focused on the effect of rewards on false alarms could include the prediction of rewards to promote rule-based category learning. The rule-based learning would further clarify the role rewards play in recall and false alarms. To that end, learning from the findings of Study 1, Study 2 required participants to predict if a reward would be co-presented with a category of images to promote rule-based learning. I had identified Pavlovian-to-instrumental transfer as a potential confound and attempted to use operant conditioning with intentional encoding in Study 1 to disentangle motivational salience from Pavlovian-to-instrumental transfer. While I found some success in eliciting retroactive enhancement of memory using operant conditioning, the results of Study 1 suggest that reinforcement learning occurred for the entire set of stimuli instead of rule-based category learning (for a review, see Mitchell et al., 2009). These results also imply that prediction of the reward association might be essential to category learning. Indeed, a previous study (Dunsmoor et al., 2015) using classical conditioning found that when participants had to predict if a shock would follow the presentation of an image, CS^+ images (paired with the reward) that had been presented in the preconditioning phase of the same category of images were encoded stronger than the CS^- images (not paired with the reward). As such, Study 2 required participants to predict if a reward would follow the presentation of an image.

Study 2

The Effect of Monetary and Social Reward on Retroactive Enhancement of Memory in Classical Conditioning Paradigm

Pavlovian or *classical conditioning* is the process of learning associations between a neutral stimulus and an unconditioned response (UR) to an unconditioned stimulus (US), such as an appetitive reward or an aversive stimulus. The previously neutral stimulus then becomes the conditioned stimulus (CS), eliciting a conditioned response (CR). According to models of classical conditioning, as the learned predicted value of the CS relative to the receipt of the US increases, the CS gains significance and gets stronger (Pavlov, 1927; Schultz, 2007). However, unlike operant or instrumental conditioning, the presentation of both the neutral and the unconditioned stimuli is not contingent on the subject's behavior. Upon successful conditioning, the subject learns that cues such as the CS predict the delivery of the US (Pavlov, 1927). Over trials, the anticipation for the appetitive reward (US) dissipates and instead coincides with the anticipation of the CS in classical conditioning (Hollerman & Schultz, 1998; Sutton & Barto, 1981)

The conflation between classical conditioning and incidental encoding could be one reason for the mixed findings in previous studies examining retroactive enhancement of memory. The mixed findings from previous studies make it difficult to ascertain the conditions under which retroactive enhancement of memory can be elicited. Not accounting for Pavlovian-to-instrumental transfer that could occur from lack of distinction in the paradigms used makes it difficult to determine if motivational salience plays a role in eliciting the effect. As such, Study 1 used intentional encoding with operant conditioning for monetary (and social rewards) to elicit retroactive enhancement of memory to disentangle motivational salience from Pavlovian-to-instrumental transfer. Study 2 then used a classical conditioning paradigm to clarify if motivational salience is a necessary condition in eliciting retroactive enhancement of memory. Moreover, as the anticipation for the reward dissipates and instead coincides with the anticipation of the cue in classical conditioning paradigms, understanding the role rewards play in eliciting retroactive enhancement of memory can improve our understanding of the anticipation and consummation of rewards.

Social Reward

The role of social rewards in memory processes – especially in retroactive enhancement of memory – using classical conditioning is not well understood. Anticipation and consummation of social rewards are implicated in social learning and social behavior. As social behavior takes place within large, complex social networks, it is virtually impossible to acquire firsthand knowledge of all relations from observation alone. Consequently, individuals must crucially make informed inferences about relationships based on indirect social clues (Brands, 2013). Associative learning aids one in acquiring knowledge about individuals and the relations between individuals within a network through social learning from observing social interactions (FeldmanHall et al., 2017, 2018). Therefore, evaluating associative learning of social rewards through classical conditioning will improve our understanding of social learning and the navigation of social networks. Examining retroactive enhancement of memory in the presence of social rewards might also shed light on the mechanism through which individuals encode previously seemingly irrelevant information at a later time point through social learning. In turn, we might be better able to identify factors leading to social dysfunction.

False Alarms

While there has been research conducted on the relation between false alarms and pain or fear, there has been little research on associative learning of rewards through classical conditioning and their relation to false alarms, especially in paradigms eliciting retroactive enhancement of memory. Accuracy of memories and confidence in memories has been found to be impacted in those with psychopathology. For example, increased memory confidence despite significant memory errors has been found in those with schizophrenia, while confidence in accurate memories has been slightly poorer compared to healthy controls (Bhatt et al., 2010; Gawęda et al., 2012; Moritz & Woodward, 2006; Moritz et al., 2004; Moritz et al., 2006; Moritz et al., 2008; Peters et al., 2013). It has also been argued that this bias for overconfidence in false memories might play a role in the development and maintenance of positive symptoms in schizophrenia. These issues with accuracy and confidence in memories might be especially exacerbated in retroactive enhancement of memory. Therefore, understanding the role rewards play in the distortion of memories and the generation of false memories in associative learning through classical conditioning, especially with retroactive enhancement of memory, might shed light on the mechanisms that lead to aberrant learning and recall of memories.

Current Study

Study 1 used operant conditioning with intentional encoding to elicit retroactive enhancement of memory. To disentangle the role of motivational salience and to identify if motivational salience is a necessary condition to elicit retroactive enhancement of memory, Study 2 used a classical conditioning paradigm with incidental encoding. Furthermore, in Study 1, the data suggest that the rewards generalized to the entire stimulus set instead of a specific category. Thus, in Study 2, participants were instructed to predict reward expectation to encourage rule-based category learning. As intrinsic motivation can only be examined using an operant conditioning paradigm, unlike Study 1, Study 2 did not have an intrinsic reward condition. Therefore, Study 2 aimed to (1) examine the effects of (a) monetary reward and (b) social reward on retroactive enhancement of memory and (2) investigate the influence of (a) monetary reward and (b) social reward on false memories of images using a classical conditioning paradigm.

Hypotheses

Aim 1. Role of Rewards in Eliciting Retroactive Enhancement of Memory.

Hypothesis 1.1: *d'* (standardized mean difference between the distribution of correct hits and false alarms) will be greater for CS^+ (conditioned) images than CS^- (non-conditioned) images presented in the preconditioning phase for both reward conditions.

> **H1.1a:** In the monetary reward condition, *d'* will be greater for CS^+ images than CS^- images presented in the preconditioning phase.

> **H1.1b:** In the social reward condition, *d'* will be greater for CS^+ images than CS^- images presented in the preconditioning phase.

Hypothesis 1.2: There will be an effect of reward type on *d'*. Specifically, *d'* will be higher in the monetary reward condition than the social reward condition.

Aim 2. Role of Rewards in False Memories

Hypothesis 2.1: False alarms of images will be greater for CS^+ images than CS^- images for both reward conditions.

> **H2.1a:** In the monetary reward condition, false alarms will be higher for CS^+ images than CS^- images.

H2.1b: In the social reward condition, false alarms will be higher for CS^+ images than CS^- images.

Hypothesis 2.2: There will be an effect of reward type on false alarms. Specifically, false alarms will be higher in the monetary reward condition than in the social reward condition.

Materials and Methods

Participants

A total of 93 participants were recruited for this study. Recruitment was identical to Study 1 in that undergraduate students were recruited through the UCI SONA and from the community through flyers posted around UCI. Eight of the 93 recruited participants failed to attend Session 2. Although we intended that participants would not participate in both studies, two participants signed up for both Study 1 and Study 2 and were thus excluded. In the final sample of 83, 75.9% were female, with a mean age of 20.96 years (SD = 3.65, range from 18-41). Approximately 27.7% of the participants were East Asian, 19.2% were White, 16.9% were Hispanic, and 13.3% were biracial or multiracial.

Materials

Stimuli

The stimuli used in Study 2 were the same as those used in Study 1.

Encoding Paradigm

The protocol for Study 2 is largely similar to Study 1 with the following modifications:

Training. The training protocol for monetary and social reward conditions was identical to that used in Study 1. I did not include an intrinsic reward motivation in Study 2, as participants could not receive feedback on their performance in a classical conditioning paradigm.

Session 1. In the conditioning phase, the reward was paired with a category of images based on their assigned group (i.e., monetary reward paired with tools, monetary reward paired with animals, social reward paired with tools, and social reward paired with animals). While participants viewed images from both categories, the images in the category paired with the reward formed the conditioned stimuli (CS^+), and the images in the category not paired with the reward formed the non-conditioned stimuli (CS^-). The images in this phase were presented for 6000 ± 500ms, and the intertrial interval varied at 8000ms ± 1500ms. Those in the monetary reward groups were presented with a green "$" symbol, and those in the social reward groups were presented with a red heart "❤️". These rewards were presented right above the image such that the participants were able to attend to it without moving their heads or their eyes. The reward appeared 2500ms after the presentation of the image on 18 out of the 24 trials, co-terminating with the image presentation. Participants were instructed to make a reward expectancy (up arrow key for reward expectation or down arrow key for no reward expectation) within the first 600ms of the stimulus presentation. They were also informed that their key pressing would not influence the occurrence of the reward. The images were presented in the conditioning phase for longer than the preconditioning phase to allow for 1) adequate response time for participants to indicate if they expected a reward in that trial and 2) to account for the additional attention load of the reward cue plus the image appearing on screen. The duration of this phase was about 11.5 minutes.

Procedure

The procedure for Study 2 was similar to that of Study 1 with the following difference: following informed consent in Session 1, participants were randomly assigned to one of four groups (monetary reward + tools, monetary reward + animals, social reward + tools, social reward + animals) instead of six.

Power Analysis

The power analysis for Study 2 is similar to the power analysis for Study 1 but includes two conditions (i.e., monetary and social) instead of three. Therefore, the projected sample size required for two conditions was approximately $N = 88$. The current sample size of 83 suggests that Study 2 might be slightly underpowered, and the results should be interpreted with that caveat.

Data Retention and Cleaning

Data were assessed for homogeneity of variance and sphericity. The Greenhouse-Geiser correction was used in the event of a violation of the assumption of sphericity. Just as with Study 1, sensitivity analysis was conducted using a subset of the data consisting of only participants who did not expect the recognition test in Session 2 (see "Sensitivity Analysis for Recognition Test" in the "Results" section).

Hypotheses and Statistical Analysis

The statistical analyses were similar to that of Study 1 for each hypothesis. The first aim of Study 2 was to examine the effects of (a) monetary reward and (b) social reward on retroactive enhancement of memory. I hypothesized that there would be a significant main effect of stimulus type and a significant interaction effect such that *d'* for CS^+ images would be higher in the preconditioning phase than the *d'* for CS^- images in monetary and social reward conditions (Hypothesis 1.1). To test this, I conducted a 2x3 repeated measures ANOVA for each reward condition, in which stimulus type (CS^+/CS^-) and phase (preconditioning/conditioning/postconditioning) were within-subjects factors, and *d'* was the outcome variable. I also hypothesized an effect of reward type such that *d'* in the monetary reward condition would be higher than the social reward condition (Hypothesis 1.2). To test this, instead of examining the difference in recall between the two reward conditions using only the reward category of images, I collapsed across stimulus type (i.e., collapsing across CS^+ and CS^- images). This collapsing was done as results from analysis for Hypothesis 1.1 indicated no significant difference in stimulus type in the social reward condition. Therefore, collapsing across stimulus type was a more appropriate statistical test to examine the difference in recall between the reward conditions. To that end, I ran a mixed model-ANOVA with phase serving as the within-subjects factor, reward type serving as the between-subjects factor, and *d'* serving as the outcome variable.

The second aim of the study was to investigate the influence of (a) monetary reward and (b) social reward on false memories. I hypothesized that false alarms of CS^+ images would be higher than the false alarms of CS^- images for monetary and social reward conditions (Hypothesis 2.1). To test this, I ran dependent means *t*-tests comparing the mean false alarms between CS^+ and CS^- images for each reward condition. I also hypothesized that false alarms in the monetary reward condition would be higher than in the social reward condition (Hypothesis 2.2). To test this, I conducted an independent means *t*-test with reward type serving as the independent variable (collapsing across stimulus type as with Hypothesis 1.2), and false alarms serving as the dependent variable.

Partial Eta squared in my ANOVA models smaller than .01 were interpreted as small, .06 as medium, and greater than .14 as large (Cohen, 1988). As my sample sizes are relatively small, Hedges' *g* was the preferred effect size when comparing means between groups. Hedges' *g* smaller than .2 were interpreted as small, .5 as medium, and greater than .8 as large effect sizes (Hedges, 1981).

Results

Aim 1: Retroactive Enhancement of Memory

As hypothesized, for the monetary reward condition, there was a significant main effect of stimulus type [$F(1, 40) = 5.32$, $p = .026$, $\eta_p^2 = .12$] with a medium to large effect size (see Figure 10). However, contrary to what I had hypothesized, for the social reward condition, there was no significant main effect of stimulus type [$F(1, 41) = .85$, $p = 362$, $\eta_p^2 = .020$] with a small effect size (see Figure 11). There was a significant main effect of phase for both the monetary [$F(2, 80) = 38.24$, $p < .001$, $\eta_p^2 = .49$] and social [$F(2, 82) = 89.98$, $p < .001$, $\eta_p^2 = .69$] reward conditions with large effect sizes. However, while there was no significant stimulus type x phase interaction for the monetary reward condition [$F(2, 80) = 2.44$, $p = .094$, $\eta_p^2 = .06$] with a medium effect size, it was significant for the social reward condition [$F(2, 82) = 7.25$, $p = .001$, $\eta_p^2 = .15$] with a large effect size.

Pairwise comparisons for stimulus type of the monetary reward condition revealed that *d'* was significantly higher for CS^+ images compared to CS^- images collapsing across phases ($p = .026$). Pairwise comparisons for phase in the monetary reward condition indicated that recall was highest in preconditioning (vs. conditioning, $p = .037$; vs. postconditioning, $p < .001$) followed by conditioning phase (vs. postconditioning, $p < .001$) and lowest in postconditioning phase collapsing across stimulus type. In contrast, in the social reward condition, recall was highest in the conditioning phase, followed by preconditioning, and lowest in the postconditioning phase (*p*s < .001), collapsing across stimulus type. Simple effects analysis for both monetary and social reward conditions revealed that contrary to my hypothesis, there was no significant difference in *d'* between CS^+ and CS^- images in the preconditioning phase nor the postconditioning phase (*p*s > .05). In the conditioning phase, however, *d'* of CS^+ images was significantly higher than that of CS^- images (*p*s < .05).

Figure 2.1

Pattern of Recall in Monetary Reward Condition (Study 2)

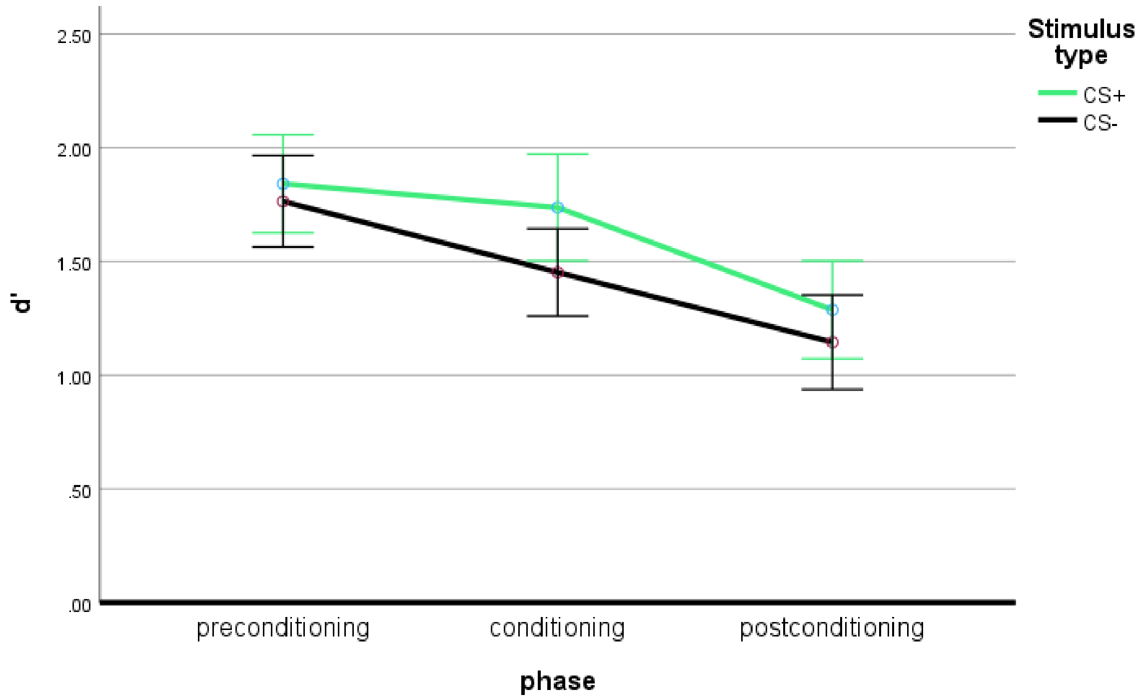
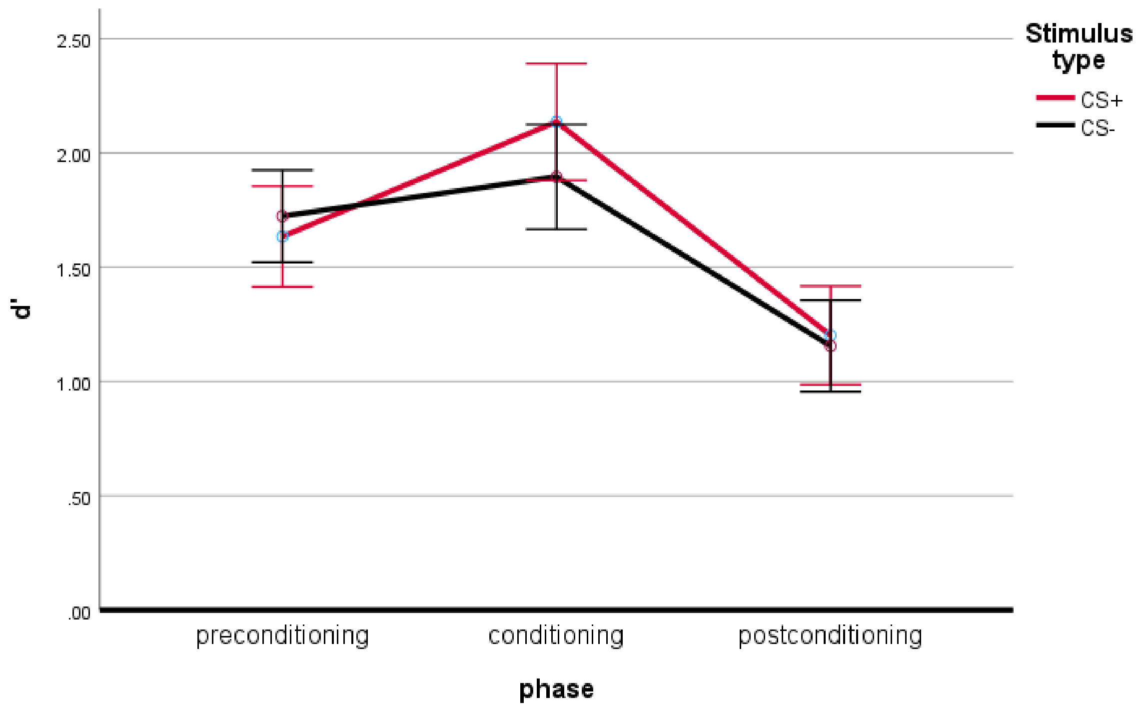


Figure 2.2

Pattern of Recall in Social Reward Condition (Study 2)

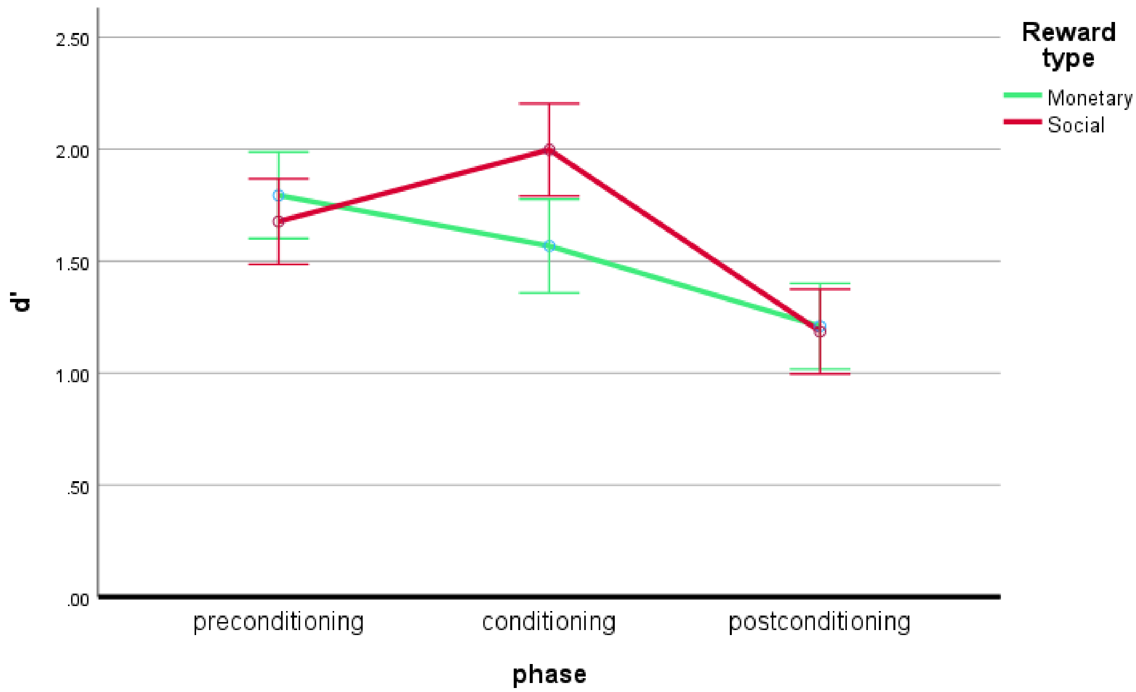


To compare the pattern of recall across the two reward conditions, I collapsed across stimulus type as there was a significant main effect of stimulus type in the monetary reward condition but not in the social reward condition. There was again a significant main effect of phase [$F(2, 162) = 100.20$, $p < .001$, $\eta_p^2 = .55$] (see Figure 12), and a significant phase x condition interaction effect [$F(2, 162) = 20.27$, $p < .001$, $\eta_p^2 = .20$] with a large effect sizes. However, there was no significant effect of reward [$F(1, 81) = .56$, $p = .49$, $\eta_p^2 = .01$] with a small effect size. Simple effect analysis revealed that there were no significant differences in *d'* between monetary and social reward conditions in the preconditioning ($p = .40$) and postconditioning phases ($p = .86$). However, contrary to my hypothesis, *d'* was significantly higher in the social reward condition compared to the monetary reward condition in the conditioning phase ($p = .005$).

To further explore the pattern of difference in *d*' between the monetary and social reward condition in the conditioning phase, I ran an independent means *t*-test examining mean differences in self-reported rating of pleasantness of the monetary and social reward cues. The social reward cue (M = 8.19) was rated as significantly more pleasant than the monetary reward cue (M = 6.78) [$t(70.42) = 2.40$, $p = .02$, $g = .52$) with a medium effect size.

Figure 2.3

Pattern of Recall for Both Reward Conditions Collapsing Across Stimulus Type (Study 2)

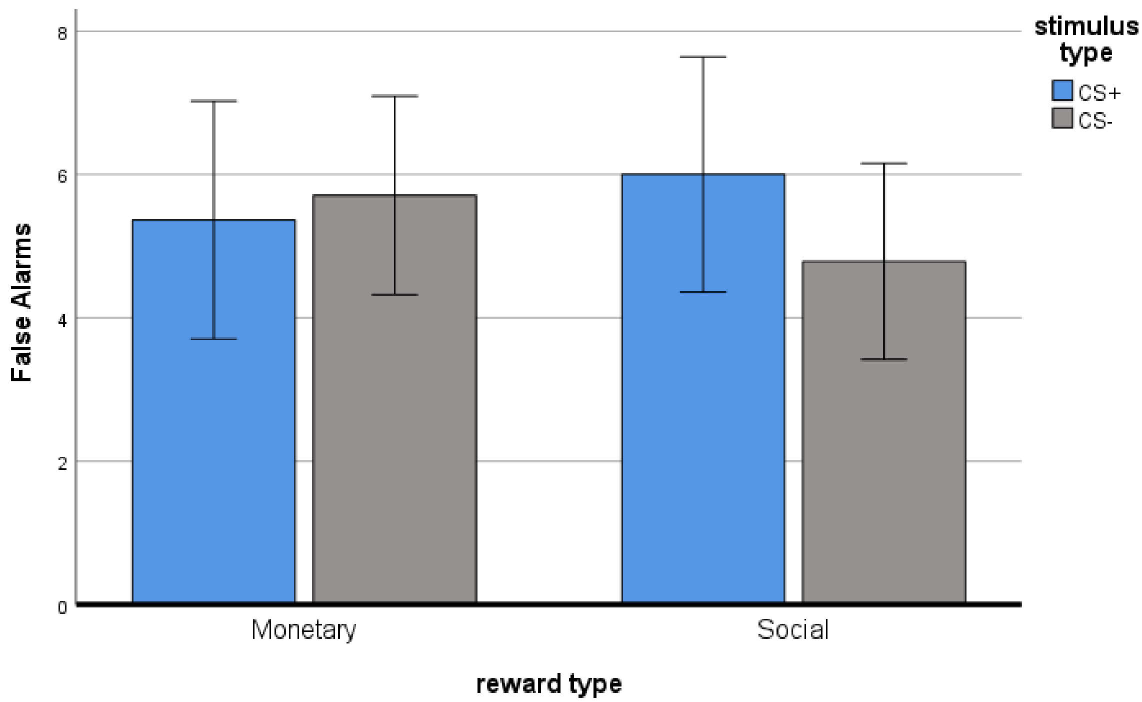


Aim 2: False Alarms

Contrary to my hypotheses, there was no significant difference in mean false alarms between CS$^+$ and CS$^-$ images for monetary [$t(40) = .56$, $p = .58$, $g = .08$] and social [$t(41) = 1.53$, $p = .14$, $g = .23$] reward conditions with small effect sizes across both tests (see Figure 13). To further explore the pattern of false alarms across the reward types, I ran a mixed-model ANOVA with stimulus type serving as the within-subjects factor, reward type serving as the between-subjects factor, and false alarms serving as the outcome variable. There was no significant main effect of stimulus [$F(1, 81) = .75$, $p = .39$, $\eta_p^2 = .01$], reward type [$F(1, 81) = .02$, $p = .89$, $\eta_p^2 = .00$], nor stimulus type x reward interaction effect [$F(1, 81) = 2.39$, $p = .13$, $\eta_p^2 = .03$] with small effect sizes for all three tests. Simple effects analysis revealed that there were no significant differences in false alarms of CS^+ images between monetary and social reward conditions (ps > .1). There were also no significant differences in false alarms of CS^- images between monetary and social reward conditions (ps > .1).

Figure 2.4

Pattern of False Alarms Between Stimulus Type and Across Reward Type (Study 2)



Sensitivity Analysis for Recognition Test

Of the final sample of 83 participants, 20 had expected the recognition test, making the sample size for the sensitivity analysis 63 (32 in monetary, 31 in social). However, the results were primarily the same, with no differences in significance testing, except for false alarms in the social reward condition. For participants who did not expect the recognition test, mean false alarms were higher in CS^+ images compared to CS^- images [$t(30) = 2.06$, $p = .048$, $g = .36$] with a medium effect size. This finding suggests that when using classical conditioning and predicting the category of images paired with the reward, the possibility of engaging in rehearsal from expecting the recognition test did not lead to significant differences in recall but influenced false alarms only in the social reward condition.

Figure 2.5

Sensitivity Analysis of False Alarms in Social Reward Condition (Study 2)

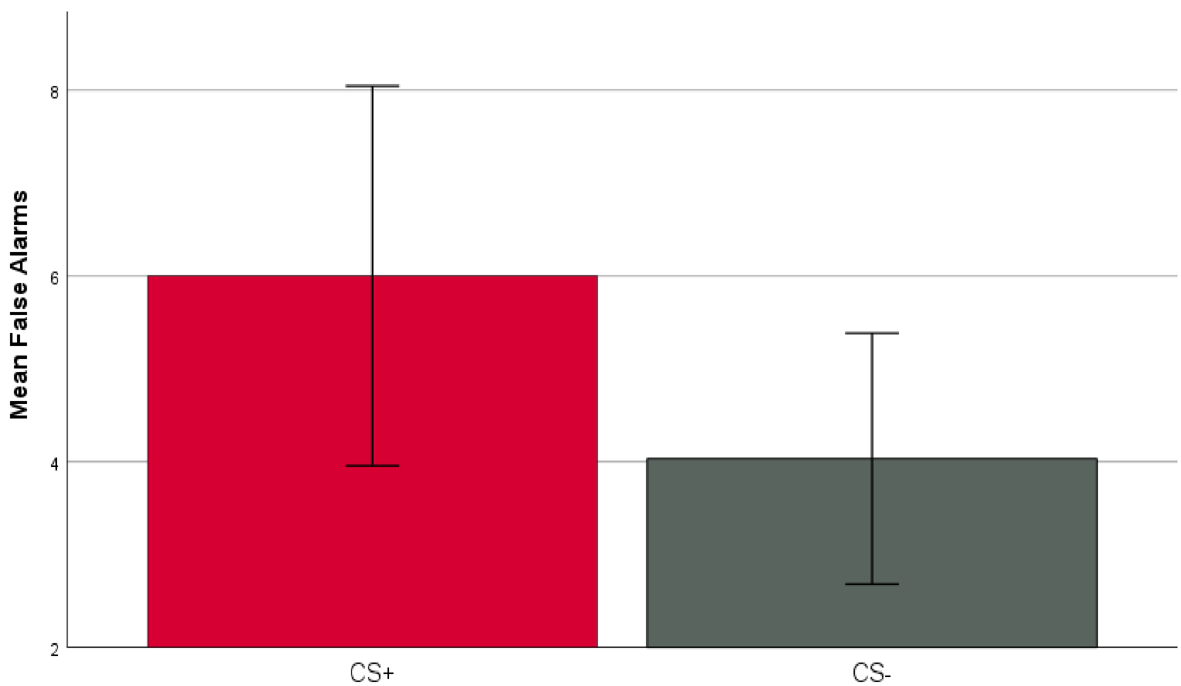


Table 2.1

Memory at 24-hour recognition (Study 2)

		Monetary (N = 41)	Social (N = 42)
Preconditioning	Raw reward	16.20 (5.11)	15.05 (4.53)
	Raw non-reward	16.15 (4.77)	15.02 (4.73)
	Raw total	32.34 (8.81)	30.07 (7.84)
	d' reward	1.84 (.68)	1.63 (.71)
	d' non-reward	1.76 (.64)	1.72 (.65)
	d' total	1.79 (.58)	1.68 (.66)
Conditioning	Raw reward	15.00 (5.62)	18.69 (4.23)
	Raw non-reward	13.59 (5.09)	16.45 (4.55)
	Raw total	28.59 (9.46)	35.14 (7.40)
	d' reward	1.74 (.74)	2.14 (.82)
	d' non-reward	1.45 (.61)	1.90 (.74)
	d' total	1.57 (.60)	2.00 (.74)
Postconditioning	Raw reward	11.44 (4.99)	11.36 (4.55)
	Raw non-reward	10.93 (4.90)	10.17 (4.70)
	Raw total	22.37 (8.96)	21.52 (8.24)
	d' reward	1.29 (.68)	1.20 (.69)
	d' non-reward	1.14 (.66)	1.16 (.64)
	d' total	1.21 (.60)	1.19 (.763)
False alarms	Reward	5.37 (5.17)	6.00 (5.50)
	Non-reward	5.71 (4.91)	4.79 (3.97)
	Total	11.07 (9.29)	10.79 (8.10)

Note: Mean (standard deviation). *d'* were standardized mean differences between distribution of raw recall and distribution of false alarms.

Discussion

Retroactive enhancement of memory

In this study, I examined the role of monetary and social rewards on retroactive enhancement of memory in a classical conditioning paradigm with incidental encoding. This use of classical conditioning contrasts with the operant conditioning paradigm with intentional encoding used in Study 1 to disentangle the role of motivational salience in eliciting retroactive enhancement of memory. I hypothesized that by getting participants to predict the category of images paired with the reward, they would engage in rule-based learning, leading to within-subjects differences reflected in a significant main effect of stimulus type. Although there was a significant main effect of stimulus type in the monetary reward condition, it was non-significant in the social reward condition. While there was a significant difference in *d*' between CS^+ and CS^- images in the conditioning phase of monetary and social reward conditions, there was no significant difference in the preconditioning phase nor postconditioning phases of both reward conditions. Contrary to my prediction, asking participants to predict the category of images paired with the reward did not lead to rule-based learning. Moreover, the pattern of results indicates that I did not find evidence of retroactive enhancement of memory (nor prospective memory) with monetary or social reward using a classical conditioning paradigm. This finding is consistent with a previous study (Oyarzun et al., 2016) that did not find evidence for retroactive enhancement of memory using an incidental encoding paradigm.

Monetary vs. Social Reward

I found no significant effect of reward with a small effect size, suggesting comparable effects of monetary and social rewards on memory. Simple effects analysis, however, revealed that while recall was comparable in the preconditioning and postconditioning phases, recall was significantly lower in the conditioning phase of the monetary reward condition compared to the social reward condition. This pattern of recall in the conditioning phase was in the opposite direction of what I had hypothesized. Furthermore, *d*' in the conditioning phase of the monetary reward condition was significantly lower than that of the preconditioning phase, contrary to the pattern of recall in previous results that found recall in the conditioning phase to be either higher than or not statistically different from the preconditioning phase. Comparing the mean pleasantness rating of monetary and social reward cues indicated that the social reward cue was rated significantly more pleasant than the monetary reward cue. This finding also contradicts previous studies that report monetary rewards as more salient or exert a greater influence than social rewards. Notably, significant differences in *d*' between CS^+ and CS^- indicate that both rewards were salient enough to influence memory, albeit only in the conditioning phase when the cues were presented. There are two possible explanations for the difference in recall as well as the pleasantness rating between the monetary and social reward conditions.

One reason is that in my sample, there might have been participants in the social reward condition who engage much more with social media, leading them to find the social reward cue more pleasant. Another possible explanation is that in using a classical conditioning paradigm, the monetary reward cue served as a distractor. In using social media, participants might have become used to viewing content with "like" counters akin to the red heart I used as my social reward cue. As such, participants in the social reward condition might have had an easier time attending to the social reward cue while still attending to the stimuli presented. In contrast, participants in the monetary reward condition might have struggled to divide their attention between the monetary reward cue and the stimuli presented, despite the stimuli being on screen for some time before the cue was presented. This conflict of attention might have led to a poorer encoding and a negative mood state that participants attributed to the monetary reward cue and, in turn, rated the cue as less pleasant. Future research could introduce the cues of rewards in a manner that does not distract the participant from the encoding paradigm. Another potential future direction would be to include a control condition in which there are no cues of rewards that might take up additional attention load to establish a “baseline” pattern of recall.

False Alarms

As part of the second aim of this study, I examined the influence of monetary and social rewards on rates of false alarms. I hypothesized that false alarms of CS^+ images would have been higher than that of CS^- images. Contrary to my hypotheses, there was no significant difference in mean false alarms between CS^+ and CS^- images for monetary and social reward conditions with small effect sizes across conditions. I also hypothesized that false alarms would be greater in the monetary reward condition than in the social reward condition. However, I found no significant effect of reward type nor a stimulus type x reward interaction effect. In my sensitivity analysis, using data from only participants who did not expect the recognition test, I found a significant difference in false alarms between CS+ and CS- images for the social reward condition. This difference in false alarms suggests that reward-generalization might occur when a reward is salient enough, leading to more false alarms in the category of images associated with the reward. A future direction would be to manipulate perceptual features of stimuli and different reward values to model reward-generalization.

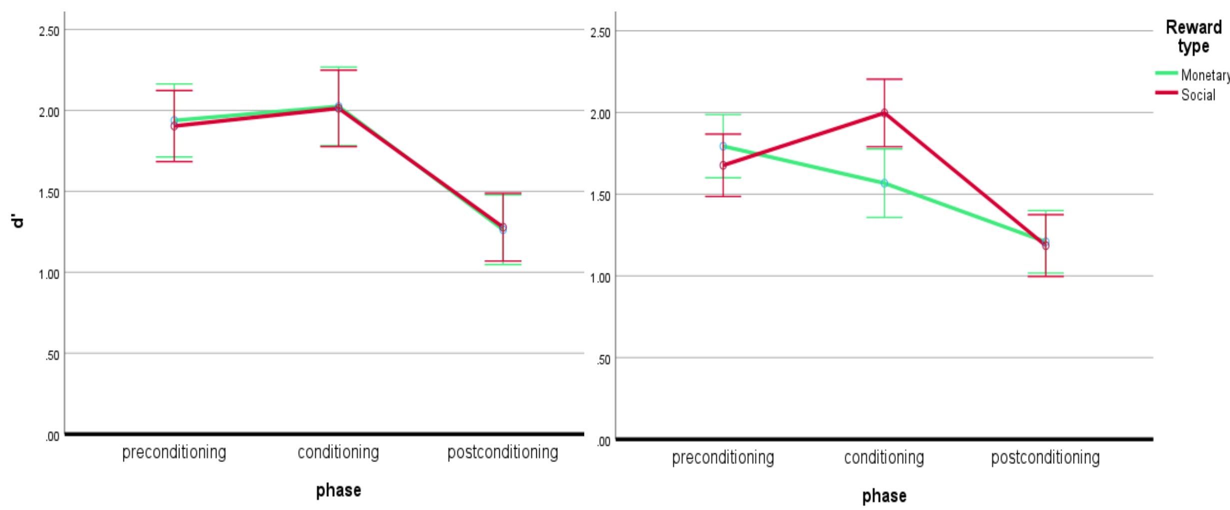
General Discussion

While there has been substantial research on memories enhanced prospectively, there has been a recent advent of research on retroactive enhancement of memories. However, in the few studies that have examined retroactive enhancement of memory thus far, the findings have been mixed. I posited that in using "incidental encoding" and "intentional encoding" paradigms, researchers did not account for Pavlovian-to-instrumental transfer and the role motivational salience might play in eliciting the retroactive enhancement of memory. To that end, Study 1 used an operant conditioning paradigm with intentional encoding, and Study 2 used a classical conditioning paradigm with incidental encoding. Furthermore, as there has been a lack of research on the role of social rewards on memory processes, I used monetary and social rewards in attempts to elicit retroactive enhancement of memory and to compare patterns of recall. While previous studies have found monetary rewards to be more salient or exert a greater influence than social rewards, it is arguably more difficult to provide social rewards in the lab to participants in an equivalent manner. Therefore, I used a two-step conditioning process to make the learned associations of the cues used in the experiments more equivalent across monetary and social reward conditions. Finally, studies that examined retroactive enhancement of memory have not examined the role rewards and reward-generalization play in false alarms. To address that gap in the literature, I examined rates of false alarms in both Study 1 and Study 2, using operant and classical conditioning, respectively.

The main goal of this dissertation was to clarify the conditions under which retroactive enhancement of memory can be elicited. The data in Study 1 provided evidence in support of retroactive enhancement of memory in an operant conditioning paradigm using monetary and social rewards. However, the data in Study 2 did not provide evidence in support of retroactive enhancement of memory in neither monetary nor social reward using classical conditioning paradigms. This difference in findings might suggest that motivational salience is a necessary condition for enhancing memory retroactively, at least when rewards are used. The overall findings across Studies 1 and 2 add to the extant literature by complementing previous studies that found greater success in eliciting retroactive enhancement of memory using rewards and/or paradigms in which motivational salience was induced (by either using operant conditioning or introducing Pavlovian-to-instrumental transfer).

Figure 3.1

Pattern of recall for monetary and social rewards collapsing across stimulus type



Note: From left to right, a) Study 1 using operant conditioning, and b) Study 2 using classical conditioning.

One contribution of this dissertation is the finding that monetary rewards do not always elicit a greater effect. As there is no consensus on the definition of social rewards, partially because providing social rewards in the lab is far more complex than monetary rewards, previous studies have used various cues to represent social rewards. These previous studies have found evidence in support of monetary rewards being more salient or eliciting a greater effect.

However, I found in Study 1 that monetary and social rewards can exert comparable influence on memory when a two-step conditioning process is used (see Figure 15). Furthermore, in Study 2, social reward exerted a greater influence than monetary reward on memory, such that recall in the conditioning phase of the social reward condition was significantly higher than that of the monetary reward. A future direction would be for researchers to use a two-step conditioning process. By making the cues of the rewards more equivalent, a better comparison can be made between monetary and social rewards on the influence they exert on processes such as memory.

Another aim of this dissertation was to examine the influence of rewards and reward-generalization through category-based learning on false alarms and, by extension, false memories. There was a non-significant trend of false alarms in the non-reward category of images in Study 1, such that it was numerically highest in the monetary reward condition, followed by social reward, and lowest in the intrinsic reward condition. In contrast, in Study 2, sensitivity analysis using only data from participants who did not expect the recognition test revealed that false alarms in CS^+ images were higher than that of CS^- images in the social reward condition. This difference in the pattern of false alarms suggests that when motivational salience is involved, rewards might support the integrity of memories. However, when motivational salience is not involved, rewards might lead to greater inaccuracies. A future direction is to further explore the role of motivation salience in false alarms and self-reported confidence in recognition by modeling them using Receiver Operating Characteristics (ROC). Doing so would allow researchers to integrate false alarms rates and confidence in the recognition ratings in analysis.

Limitations

The studies in this dissertation were built on the methods used by previous researchers in examining retroactive enhancement of memory. Previous researchers used images of animals and tools while promoting category-based learning by pairing a category of images with rewards or punishments. The rationale for doing so was to allow for the category of images not paired with rewards to serve as a within-subjects "control" and to increase power. While I was able to determine that retroactive enhancement of memory occurred in the monetary and social reward conditions in Study 1 using the intrinsic condition as a control, the lack of a control condition in Study 2 did not allow for such comparisons. This finding suggests that even in previous studies that did not find evidence for retroactive enhancement of memory using a within-subjects design, retroactive enhancement of memory might have been elicited. However, the lack of a control condition prevented the researchers from drawing inferences based on comparisons between conditions. A future direction would be for researchers to not only rely on within-subjects controls from promoting category-based learning but to also include a between subjects control condition to examine retroactive enhancement of memory. Moreover, across Studies 1 and 2, promoting category-based learning proved difficult despite improving the stimulus typicality of the images used. Even when participants in Study 2 were instructed to predict the category of images paired with the reward, I found no evidence of rule-based learning.

One limitation leading to this difficulty in promoting category-based learning is the stimuli chosen for this study. In using images of animals and tools, semantic encoding – knowing the names of the stimuli (i.e., knowing more names of animals than the names of tools) – could have led to differential encoding. Participants could have encoded images they knew the name of at a greater rate than the images for which they did not know the name. There could also have been a ‘face superiority effect” making images of animals more memorable as they have faces. Greater semantic encoding and “face superiority effect” with animals might have led to higher accuracy in the recall of images of animals regardless of whether they were paired with the reward. This discrepancy would have confounded the results, occluding within-subjects differences. Moving forward, researchers might choose a different set of images, such as manufactured vs. naturally occurring items that are validated for stimulus typicality and semantic knowledge. A further example of an alternative would be using hues of colors vs (different angles of) lines. Another methodological solution to overcome difficulty eliciting within-subjects differences would be to include a control condition.

One other limitation is that participants who enjoy engaging in social media might have found the cue representing social rewards from the training more rewarding than participants who do not enjoy using social media. Moreover, having recruited from SONA and the community, the age range of our participants was 18 to 45 years. The older participants in our sample might not have engaged with the training task as much as younger participants. Future researchers should include a questionnaire on social media use to include social media usage as a covariate if they adopt a similar training task in the future. Another consideration is using a task that might be appropriate for a wider range of ages.

Conclusion

In summary, the findings of this dissertation across Study 1 and 2 identified that motivational salience might be a necessary condition in eliciting retroactive enhancement of memory using rewards. Contrary to previous studies, the data also provided evidence that social rewards are as salient or more salient than monetary rewards when using a two-step conditioning process. The pattern of false alarms across Studies 1 and 2 also suggests that motivational salience when using rewards might moderate the accuracy of memories, such that rewards might lead to greater accuracy of memories when motivational salience is involved and greater rates of false alarms when motivational salience is not involved. The findings of this dissertation not only add to the extant literature but also provide clarity regarding mixed findings in previous studies. In doing so, this dissertation provides us with a better understanding of memory and cognitive processes, especially in the presence of rewards.

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