# The Influence of Reward on Recognition Memory and Source Memory

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## Abstract

Reward motivation is an important factor that influences human learning and memory. In this behavioural study, we explored the influence of reward anticipation on recognition memory and source memory in a dual rewarded memory task. The experiment consisted of a study phase followed by separate recognition memory and source memory test phases. During the study phase, participants saw words following high or low or reward cues. The reward cues indicated the monetary rewards participants would get by the correct memory judgments in the following recognition memory and source memory tests. The words were presented in one of four locations of a computer screen. Participants were instructed to remember the words and memorize the locations of the words. In the recognition memory test, studied (old) words mixed with some new words were presented to the participants one at a time. Participants made an old/new recognition memory judgment to these words. In the subsequent source memory test, all old words were shown again in the middle of a screen. Participants made source memory judgments to indicate the location of the words which were shown during the study phase. Participants were rewarded for the correct judgments in the recognition memory and source memory tests. The results showed that the recognition memory and source memory performances in the high-reward and low-reward conditions were not significantly different. Our findings indicate that rewards cannot enhance item recognition memory and source memory in a dual rewarded memory task. In our study, we both rewarded item recognition memory and source memory with the same amount of monetary rewards. In a dual rewarded memory task, due to the people' s processing resources are limited, rewards might lead to resource competition and influence resource allocation. Because rewards given to the correct item recognition memory and source memory were the same, the resource allocated to memorize the item and location might be nearly equal. This discouraged participants from allocating more resources to one type of memory to enhance either item or source memory performance. Thus, in our dual rewarded memory task, rewards

may have failed to improve memory performance due to nearly equal resource distribution between item and source memory. Our data also suggest that the dopaminergic reward mechanism cannot explain memory performance in our dual rewarded memory task. However, the executive control mechanism might act on our dual rewarded memory task to influence resource allocation. In future work, we want to further test our hypotheses on reward-guided resource allocation and memory, and explore other factors that might influence the effects of reward on human memory.

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# Chapter 1: Introduction

Reward motivation is one of the important factors that influences human cognition and behaviour. In our real life, we can see that reward influences a lot of cognitive processes and boosts people's working and study performances. Thus, exploring the effects of reward on human cognitive processes and the mechanisms behind this phenomenon has important theoretical and practical implications.

One of the interests in the area of reward and cognition is to explore the link between reward and memory. Monetary incentives and point-values are commonly used reward forms in reward and memory studies. In the current study, we used monetary rewards to explore the influence of reward on recognition memory and source memory and the underlying cognitive mechanisms.

In the following parts of this chapter, we first review the previous studies on the effects of reward on memory, including reward and recall, reward and recognition memory and source memory. Then, we introduce two existing hypotheses about the mechanisms of the influence of reward on memory. Finally, we propose the current study.

## 1.1 The Effects of Reward on Human Memory

Reward is an important factor that influences human memory. In the past, a wealth of studies have shown that reward motivation can enhance human memory, and this memory enhancement by reward is associated with dopamine release in the mesolimbic reward system (for a review, see Miendlarzewska, Bavelier, & Schwartz, 2016). Previous studies have demonstrated that reward influences different types of human memory, including recall, recognition memory, source memory, and paired-associative memory (e.g., Adcock, Thangavel, Callan and Schweighofer, 2006; Castel, Benjamin, Craik, & Watkins, 2002; Eysenck & Eysenck, 1982; Hennessee, Castel, & Knowlton, 2017; Castel, & Knowlton, 2014; Cohen, Rissman, Suthana, Soderstrom & McCabe, 2011; Shigemune, Tsukiura, Kambara, and Kawashima, 2014; Weiner, 1966; Weiner & Walker, 1966; Wittmann et al., 2005; Wolosin, Zeithamova, & Preston, 2012).

In the following part of the literature review, we first introduce the previous findings on the effects of reward on recall. We then introduce the previous studies on the effects of reward on recognition memory and source memory which had close relationships to the current study.

### 1.1.1 The Effects of Reward on Recall

The behavioural research on the effects of reward motivation on memory has a long history. In early behavioural studies, researchers used monetary incentives to investigate the effects of reward motivation on short-term recall (Weiner, 1966; Weiner and Walker, 1966). Researchers explored whether the magnitude of incentives, the types of incentives, and the time interval between the stimulus presentation and the recall test influence the short-term recall rate (Weiner, 1966; Weiner and Walker, 1966). In their behavioural study, Weiner and Walker (1966) used four colours to indicate four incentive conditions: get 1 cent for correctly remembered items, get 5 cents, receive a pulse shock of 110 v for incorrect recall, and a control condition. Participants learned the stimuli and performed the recall task in all four conditions. There was an intervening task between a study phase and a short-term recall task, and the task was to read digits before the recall task. There were two time intervals for interpolated activity between a study phase and a short-term recall task: 4.47 sec and 15 sec. The results showed that reward has no effect on the correct recall rate in the short-time interval condition. However, recall rates in the long interval condition were significantly better in the 5 cents and the shock conditions than the 1 cent and the control conditions. The results indicate that the effect of reward on short-term recall was influenced by the magnitude of reward, and the time intervals between the study phase and the short-term recall test. The effects of monetary reward on short-term recall were only found in intervening activity with long time interval condition. The results were consistent with those of

Weiner (1966), who reported the results of 15 experiments which manipulated different variables during study phases to investigate the effects of reward on short-term recall.

Regarding the effects of reward on recall, Atkinson and Wickens (1971) suggested that the greater attention and rehearsal given to high-incentive items is responsible for better memory performance for these items. This view was supported by a study from Eysenck and Eysenck (1980) that investigated the effects of reward on cued recall. Researchers found that high-incentive words were recalled better than low-incentive words, and the monetary reward effects on recall were greater in words with weak retrieval cues than strong retrieval cues. They concluded that different rehearsal for high and low-incentive items leads to the more elaborative or extensive encoding to high-incentive items, leading to the superior memory effects in high-incentive items.

In a subsequent study, Eysenck and Eysenck (1982) also investigated the effects of monetary incentives on cued recall with different concurrent tasks. In their Experiment I, participants saw high-incentive and low-incentive words printed in different colours at the study phase. During the presentation of words, participants also performed three types of concurrent tasks, counting backwards, articulatory suppression, and no concurrent task control. Participants received 10 pence and 2 pence for correctly recalling each word in the high-incentive and low-incentive conditions respectively. Their results showed that high-incentive words were recalled better than low-incentive words in the no concurrent task condition. However, the incentive effects were reduced in the articulatory suppression condition, and the effects were eliminated in the counting backwards condition. The concurrent tasks in these two conditions were designed to minimize rehearsal.

One explanation for the results of Experiment I in the study by Eysenck and Eysenck (1982) was based on the view of monetary incentive effects proposed by Atkinson and Wickens (1971). According to the view of Atkinson and Wickens, the effects of reward on recall were caused by the differential rehearsal to high-incentive and low-incentive items, and any task that eliminates or reduces the rehearsal can eliminate the monetary incentive effects on recall. Thus, monetary incentive effects were only found in the recall task with no concurrent task. A more detailed explanation by the researchers was based on the working memory model proposed by Baddeley and Hitch (1974). The researchers argued that the incentive effects were due to the greater use of the articulatory loop for the high-incentive items than for low-incentive items, due to the fact that in the articulatory suppression condition the incentive effects were reduced. Also, the use of the central executive component of working memory was also related to the incentive effects, because the incentive effects were eliminated in the counting backwards conditions. This suggests that the superior recall performance of high-incentive words over low-incentive words is not only caused by different rehearsal but also by the executive control processes.

A number of other studies have also used point-values to investigate the effect of values on recall and found positive effects of values on recall performance. (Castel et al., 2002; Castel, Murayama, Friedman, McGillivray, & Link, 2013; Cohen, Rissman, Suthana, Castel, & Knowlton, 2014; Cohen, Rissman, Hovhannisyan, Castel, & Knowlton, 2017; Stefanidi, Ellis, & Brewer, 2018). In these studies, researchers used value-directed remembering (VDR) paradigms in which participants learn words paired with different point-values during the encoding and earn point-values for correct recall. The participants' goal is to maximize their score in recall (Watkins & Bloom, 1999; Castel et al., 2002).

In the study of Castel et al. (2002), the researchers used VDR paradigms to investigate the influence of values on recall in younger and older adults. Participants were instructed to remember a series of words paired with different point-values, and they performed a short-term recall task. Their results suggested that value improved recall in both younger and older participants. Although older participants recalled fewer words than the younger participants, their ability to selectively remember high-value words was equal to that of younger participants. Similar results were also found in a self-regulated learning task in which participants could control their study time and the choice to restudy words that were paired with different point values (Castel et al., 2013). These results indicate that ageing does not impair older peoples' ability to selectively remember more important information, which is one of the most important functions of human memory.

In a functional magnetic resonance imaging (fMRI) study on the influence of value on free recall, Cohen and colleagues found that encoding high-value words produced greater brain activation than encoding low-value words in the semantic processing regions in the brain. This indicates that participants might use an elaborative strategy that engages deeper semantic processing for encoding high-value words than low-value words (Cohen et al., 2014). In a further study, Cohen et al. (2017) also found that participants use metacognitive control to apply more effective encoding strategies for high-value items.

In another study, Stefanidi, Ellis, & Brewer (2018) used modified VDR paradigms to investigate the influence of value-directed encoding on free recall and memory organization. In their Experiment 1, participants learned 20 lists of words with 10 in each list in the study phase. For example, participants learned words paired with values such as "Chart 4" and "Kitten 9". In each list, the values 1-10 were randomly paired with different words. There were two experimental conditions in the experiment, and the equal number of participants were randomly assigned to each condition. In the value condition, value indicated the importance of the words and participants needed to remember more high-value words to maximize their points. In the control condition, the value did not indicate the importance of the words. After the presentation of each list, participants performed a 16 s distractor task before immediate recall. After immediate recall for the last list, participants performed a surprise final free recall task. They were asked to recall the words from any list in any order. According to their Experiment 1, value did not remove the typical serial position effect, and the serial position effects appeared in both the value condition and the control condition. In addition, the total free recall rates in the delayed free recall task were not significantly different between the value condition and the control condition. However, the effects of value on delayed free recall rates were only found in the value condition. Compared with the control condition, participants recalled more high-value words and less low-value words in the value condition.

In Experiment 2 of Stefanidi et al. (2018), they changed the order of the words presented in each list. The three conditions in the experiment were random, ascending, and descending. In the ascending condition, values assigned to the words were presented in ascending order from 1 to 10 in each list, while in the descending condition, values assigned to the words were presented in descending order from 10 to 1. In the random condition, values were randomly assigned to the words. In this experiment, they found that the total free recall rates in the delayed recall task were not significantly different among the three conditions. However, value affects final recall in all three conditions and participants always recalled more high-value words than low-value words. Changing the presentation order of values did alter the serial position effects in immediate recall in each list. Overall, the results of Stefanidi et al. (2018) suggest that value influences memory encoding, organization, and search processes in free recall.

Reward-motivated memory enhancement has also been found in studies of paired-associative memory (Soderstrom & McCabe, 2011; Wolosin, et al., 2012). In one of these studies (Soderstrom & McCabe, 2011), participants studied word pairs with high or low values during the study phase. The values were presented before or after the presentation of the words. During the test phase, participants completed a cued recall task. When values were presented before the word pairs, participants performed better on the cued recall task in the high-value condition than in the low-value condition. When values were presented after the word pairs, they had no effect on memory. This indicates that reward values anticipation enhances associative memory encoding. In addition, Wolosin et al. (2012) also found that participants memorized objects pairs better in a high monetary reward condition than in a low monetary reward condition, as indicated by performance on the cued recall task. They proposed that reward enhances associative memory through interactions between the midbrain dopaminergic reward systems and the medial temporal lobe (MTL). These results suggest that reward motivation not only improves free recall performance, but also promotes associative learning processes.

### 1.1.2 The Effects of Reward on Recognition Memory and Source Memory

In this section, we first introduce recognition memory and source memory. Then we review key studies on the influence of reward on recognition memory and source memory. Finally, we indicate the research gaps in previous studies that motivated our reward and memory study.

Recognition memory is the ability to identify previously presented stimuli, such as words, objects, people, or events. In recognition memory tasks, people typically need to discriminate previously presented old stimuli from new stimuli. Recollection and familiarity are considered to be two key components of recognition memory, and sometimes they are also measured by asking participants whether they "remember" an item or just "know" that they have seen it before. Recollection is consciously remembering details surrounding a previous experience or event. Familiarity is recognizing that an item has been previously presented but without recalling any further details about the moment it was previously presented (Medina, 2008). Dual-process models of recognition memory have suggested that recognition memory performance is determined by these two separate processes: familiarity and recollection ( Yonelinas, 2001; for a review, see Yonelinas, 2002). In the typical recognition memory test, participants usually see old stimuli previously presented during the study phase mixed with some new words. They are asked to make simple Old/New recognition memory judgments or Remember/Know/New judgments during the recognition memory tests. Remember/Know recognition memory tests provide an additional measure of subjective awareness at the time of recognition memory judgments. Remembering means conscious recollection of a previous experience or event, including the details of episode. Knowing means recognizing information without conscious recollection, and can be described as a feeling of familiarity. Thus, Remember responses are based on recollection of previous specific events, while Know responses are associated with a general feeling of familiarity for the tested item (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Tulving, 1985).

Signal detection theory (SDT) has been widely used in psychophysical tasks in which participants have to distinguish a signal in a background of noise (for review, see Stanislaw & Todorov, 1999). The theory also has been applied in the measurement of recognition memory. In recognition memory tests, participants need to discriminate old stimuli they saw in the study phase from new stimuli. There are four types of responses in the SDT model of recognition memory. In Hit responses, participants give Yes (Old) responses to old items. In False Alarms, participants give Yes (Old) responses to new items. In Correct Rejections, participants give No (New) responses to new items. In Miss responses, participants give No (New) responses to old items. One advantage of SDT measurement of recognition memory is that it provides separate estimates of recognition sensitivity (based on the relative frequency of hit and false alarm responses) and response bias (based on the relative frequency of old and new responses). Critically scoring memory this way means that measures of recognition sensitivity (the quality of memory) are relatively unaffected by participants' motivations to systematically respond either yes or no (for review, see Banks, 1970).

Source memory is a memory for the context of previously presented information (Johnson, Hashtroudi, & Lindsay, 1993). For example, memory for the location of previously presented stimuli, the colour of the stimuli, the person who provided information, or the precise time at which the information was presented. Compared with the subjective judgments of Remember/Know in recognition memory tests, source memory tests provide a more direct and objective measure of recollection. We thus chose to use separate Old/New recognition memory and source memory tests to investigate the influence of reward on human memory in the current study.

Prior findings on the influence of reward on recognition memory have demonstrated that reward anticipation during the encoding phase enhances recognition memory (e.g., Adcock et al., 2006; Elliott et al., 2020; Hennessee et al., 2017; Spaniol, Schain, & Bowen, 2013). In an fMRI study, Adcock et al. (2006) found that participants showed better memory for high-reward stimuli than low-reward stimuli in a delayed (24 hrs later) recognition memory task. Compared with low-reward stimuli, high-reward stimuli activated the brain regions of the ventral tegmental area (VTA), nucleus accumbens (NAcc), and hippocampus during the encoding of scene stimuli that were later remembered. There was a positive correlation in brain activation in reward-related regions and memory-related regions. The authors suggested that dopamine release in the midbrain regions was associated with the enhancement of memory in hippocampus.

In a subsequent study, Hennessee et al. (2017) used VDR paradigms to investigate the effect of value on recognition memory, recollection, and familiarity. In their Experiment 1, participants learned a series of words that were paired with high or low point-values in the study phase. Participants expected to receive point-values for the correct recognition memory judgments in the recognition memory test and their goal was to maximize their score. During the test phase, participants first made old/new recognition memory judgments and then made Remember/Know judgments to “old” items. The behavioural data indicated that value enhanced recognition memory, with participants recognizing words with high point-values better than words with low point-values. Recognition sensitivity for high-value items was significantly higher than for low-value items. Also, response times for high-value words were faster than those for low-value words. In addition, researchers found that reward value increased remember responses in recognition memory, but had no effects on ‘know’ responses. The proportion of remember responses was greater in the high-value condition than in the low-value condition. However, the proportion of know responses was not significantly different between the high-value and low-value conditions. This results indicate that recognition memory enhancement by reward may be mainly driven by recollection rather than familiarity.

Monetary reward was also found to produce recognition memory enhancement in older adults (Spaniol et al., 2013). Participants in this experiment were instructed to encode picture stimuli during the study phase and their recognition memory was tested 24 hours later. Both younger and older people demonstrated better recognition memory performance in the high monetary reward condition than in the low monetary reward condition, which indicates that ageing has not influenced the positive effect of reward on memory.

Although there is consistent evidence that rewards improve memory overall, specific studies on the effect of reward on source memory have shown less consistent results. In an fMRI study Shigemune et al. (2014) investigated the effects of monetary reward and punishment expectations on intentional source memory. There were three conditions in the experiment: Reward, Punishment, and Control. During the study phase, participants first saw a cue that indicated Reward, Punishment or Control conditions. After the presentation of a cue, a fixation appeared. Japanese words were then presented on the left or right side of the screen with three different types of fonts. Participants were instructed to make font type judgments to the words to maintain their attention to the task. They needed to remember the words and the side (left or right) of the words during the encoding phase. During the test phase, participants saw the previously presented words mixed with new words. They were instructed to judge whether the words were presented during the study phase and make source (location) memory judgments to previously presented words. The results showed that reward and punishment anticipation during the encoding phase enhanced intentional source memory. The fMRI data further indicated that the interactions between reward/punishment-related brain regions and memory-related brain regions contribute to the enhancement of source memories by reward and punishment. However, in this study, reward and punishment had no effect on recognition memory. The authors suggested that the font judgment task during the study phase might have divided participants' attention and eliminated the effect of reward on recognition memory.

In Experiment 3 from Hennessee et al. (2017), they investigated the effect of value on recognition memory and incidental context memory. They reported that value increased remember responses in recognition memory, which supports the idea that value improves recognition memory mainly through increased recollection. However, in their study, value had no overall effect on the retrieval of irrelevant context information such as colour. Specifically, for remember responses of recognition memory, high-value words had lower context (colour) memory than low-value words. For familiar responses of recognition memory, high-value words had better context memory than low-value words. The authors argued that value enhances recollection of recognition memory at the expense of irrelevant context information.

We can see that the effects of reward on recognition memory and source memory from the studies of Shigemune et al. (2014) and Hennessee et al. (2017) were not consistent. While the first study showed reward-related enhancements in memory for source without enhancements in item memory, the second one showed reward-related enhancements in item memory without enhancements in memory for source. These different results might be caused by different tasks and procedures during the study and test phases which might influence the attention allocation and memory processes.

Overall, while many previous studies have investigated the effects of reward on recall and recognition memory with the general finding that rewards successfully enhance memory, very few studies have investigated the effects of reward on source memory. Those that have explored both recognition memory for individual items and source memory have provided more mixed patterns of results (Shigemune et al., 2014; Hennessee et al., 2017). The factors that influence the different effects on recognition memory and source memory in previous studies are not yet clear.

Therefore, in the current study, we wanted to investigate the influence of reward anticipation on recognition memory and source memory. Unlike previous studies, we chose to give participants direct reward anticipation for both item and source memory. We chose to test both item recognition memory and source memory as intentional memory. In this case, rewards are less likely to cause participants to allocate more attentional resources to item memory at the cost of irrelevant context information at the encoding stage, as in the study of Hennessee et al. (2017). We wanted to examine whether rewards have different effects on recognition memory and source memory and gain some insights into the cognitive mechanisms underlying the influence of reward on memory.

### 1.2 The Mechanisms of the Influence of Reward on Memory

There are two main hypotheses that have been used to explain the mechanisms of the influence of reward on memory (Elliott, Blais, McClure, & Brewer, 2020). One hypothesis is that the midbrain dopaminergic reward system may be responsible for memory enhancement by reward (e.g., Adcock et al., 2006; Elliott et al., 2020; Shigemune et al., 2014; Wittmann et al., 2005; for a review, see Shohamy & Adcock, 2010). The fMRI study by Adcock et al., (2006) found that reward anticipation during the encoding phase enhanced recognition memory 24 hours later. This memory enhancement appeared to be related to the increased correlation between the reward-related and memory-related regions (Adcock et al., 2006). In the brain imaging study by Shigemune et al. (2014), researchers also reported that reward and punishment expectations during the memory encoding phase enhance source memory. This source memory enhancement appeared to be related to interactions between the brain regions related to reward/punishment processing and memory. In addition, a recent event-related potential (ERP) study on the influence of value on recognition memory revealed that the P300 ERP component that indexes the dopamine-driven attention allocation at the encoding phase is associated with enhanced recollection in recognition memory in the test phase (Elliott et al., 2020). These findings all support the idea that dopamine release in the reward-related regions leads to memory enhancement in hippocampus.

The other hypothesis is that reward value enhances memory via top-down executive control processes (Elliot & Brewer, 2019). The prefrontal executive control processes lead to different encoding strategies for high-value and low-value information. For encoding high-value items in the free recall task, participants might use an elaborative strategy that engages deeper semantic processing（Cohen et al., 2014). In a previous study, Eysenck and Eysenck (1982) investigated the effects of monetary incentives on cued recall. According to their results, the effects of reward on recall were reduced by the concurrent task of articulatory suppression, and the effects were eliminated by the concurrent task of counting backwards. The finding that concurrent tasks that interfere with rehearsal and executive control processes during the memory encoding phase reduce or remove the effects of reward on recall suggests that reward-related enhancements might be primarily the results of top-down executive control process. Also, a recent behavioural study using different divided attention tasks to investigate the effects of value on recognition memory supports this idea, finding that executive resources are needed at the memory encoding phase for value-enhanced recognition memory to emerge (Elliot, & Brewer, 2019). These studies indicate that top-down executive control is another mechanism that may be responsible for the effects of reward on memory.

In the current behavioural study, we want to test these two hypotheses on the mechanisms of the influence of reward on memory, and explore which mechanisms might be applied to our experiment.

### 1.3 The Current Study

In this section, we first propose the aim and research questions of the current study, and introduce the dual rewarded memory task which was used in this study. After that, we introduce how our experiment was designed to answer our research questions. Finally, we propose our hypotheses and expected results for our study.

The current study aimed to investigate the influence of reward anticipation on recognition memory and source memory. We wanted to know whether rewards could simultaneously enhance recognition memory and source memory or whether they would have different effects on recognition memory and source memory. We also want to test previous hypotheses on reward and memory, and explore the cognitive mechanisms underlying the influence of reward on memory.

In our study, we used a dual rewarded memory task. Here, we defined the dual rewarded memory task to indicate the memory task that simultaneously rewards two types of memory. For example, in our study, we both rewarded item recognition memory and source memory. In our experiment, participants made high or low reward anticipation for both item recognition memory and source memory during the study phase. During the test phase, they were rewarded for each correct memory judgment of recognition and source memory. We contrast this with what we term single rewarded memory task that just rewards one type of memory test and which have been used in most previous studies (e.g., Adcock et al., 2006; Castel et al., 2002; Cohen et al., 2014; Elliott et al., 2020; Hennessee et al., 2017).

Therefore, the current study was designed to examine the influence of reward on recognition memory and source memory in a single experiment using a dual rewarded memory task. In our study, there were two reward conditions: high-reward and low-reward conditions. We chose "10 P" and "1 P" as two distinct reward levels based on previous studies on reward and memory (Eysenck & Eysenck, 1982; Hennessee et al., 2017). The reward cues "10 P" and "1 P" were presented at the beginning of each trial to distinguish the high-reward and low-reward trials. Participants thus had reward anticipation for both item memory and source memory at the encoding stage. In the high-reward and low-reward conditions, participants expected to receive 10 pence or 1 penny for each correct judgment of recognition memory and source memory in the following memory tests.

In our experiment, we wanted to examine whether high-reward anticipation would enhance item recognition memory and source memory compared with low-reward anticipation. In our study, what was different from most previous studies was that participants made reward anticipation on item memory and source memory simultaneously in a dual rewarded memory task, and both recognition memory and source memory were measured in a rewarded memory test.

The experiment consisted of a study phase and two test phases. During the study phase, participants would see high monetary reward cues: “10 P” (10 pence) or low monetary reward cues: “1 P” (1 penny) presented in the centre of the computer screen. Then, English words would appear in one of four locations of the computer screen (Top, Bottom, Left, or Right). The participants were asked to memorize the word and its location during the study phase, and then indicate the location of the word presented. During the following test phase, we measured the participants’ recognition memory and source memory. First, participants would make old/new judgments to test their recognition memory. After the recognition test, participants would perform source memory judgments, in which they would be asked to judge the location of the words presented during the study phase. Participants would get expected monetary rewards for correct judgments of recognition memory and source memory after the experiment.

In the previous section, we discussed two existing hypotheses relating to the mechanisms of reward on memory in previous studies. If the dopaminergic reward mechanism acts on our reward and memory task, we would expect superior memory performance in recognition memory and source memory. Alternatively, there is also a possibility that executive control processes might influence our reward and memory task. In the current study, we used a dual reward memory task in which we both rewarded item recognition memory and source memory simultaneously, and participants needed to remember both the item and the location of the item. Thus, there is also a possibility that executive control mechanisms might act on our dual rewarded memory task to influence resource allocation between item and source memory.

# Chapter 2: Research Methods

## 2.1 Participants

Forty participants were recruited from the University of Nottingham (19 males and 21females; mean age: 21 years; range: 18-34 years) and each participant received an inconvenience allowance of £6 for their time participating in the experiment. All participants' first language was English, and they had normal or corrected-to-normal vision. To estimate the sample size, we performed power analysis with G*Power analysis software (Faul, Erdfelder, Lang, A, & Buchner, 2007). The sample size $N \geq 34$ was calculated with the power = 0.80, $p < .05$ and a medium effect size ($d = 0.5$), guided by the data in Hennessee et al. (2017). The data from three participants were excluded from final analyses. Two participants were excluded due to low recognition memory performance. In one case, their hit rate in the low-reward condition was lower than minus three standard deviations from the group mean. In the other case, their hit rate in the low-reward condition was lower than their false alarm rate. Another participant was excluded because of remarkably slow response times (RTs) and the participant's RTs in the recognition and source memory test was over three standard deviations above the group mean. We concluded that this participant had not followed the task instructions "You should respond as accurately and as quickly as possible." Thus, the final data analyses included 37 participants (17 males and 20 females; mean age: 21 years, range: 18-34 years). The study was approved by the ethics committee of the School of Psychology, University of Nottingham. Due to the Covid-19 secure measures, the consent forms were delivered to participants through email and all participants provided written informed consent via email before the experiment.

## 2.2 Materials and Design

We used the Toronto Noun Pool (Friendly, Franklin, Hoffman, & Rubin, 1982) to select words for our study. Words that might influence the effects of reward on memory were excluded from the original Toronto Noun Pool. We manually excluded Money-related words such as “money’’, “penny’’, and “dollar’’. We also used the affective norms for English lemmas (Warriner, Kuperman, & Brysbaert, 2013) to exclude negative and positive valence words such as “disease’’, “attack’’, and “laughter’’, and high arousal words such as “spider’’ from the original Toronto Noun Pool. In addition, zero frequency words and words with a frequency of higher than 200 were also removed from the original Toronto Noun Pool. Then, we randomly selected 256 words for our study from the remaining words in the Toronto Noun Pool. We used 240 of these words as stimuli for our main experiment. The word lengths were no more than eight letters and the syllables were no more than two. Two hundred and forty nouns used in the experiment had an average Kucera-Francis frequency of 48.98 (min=1, max=200), an average rating of imageability of 5.05 (min=1.6, max=6.7), and an average rating of concreteness of 5.39 (min=2.1, max=7). The remaining 16 words were used for practice phases (8 used for the practice study list, all 16 for the test list).

One hundred and twenty of these words were presented during the study phase. Half of the words were assigned to the high-reward condition and half of the words were assigned to the low-reward condition. The words were randomly assigned to one of the two reward conditions (high-reward vs. low-reward) and to one of the four locations of the computer screen (Top, Bottom, Left, or Right). The assignments of words to the high-reward word sets and the low-reward word sets were counterbalanced across participants. In the high-reward condition, participants saw a high-reward cue “10 P” prior to the presentation of words, while in the low-reward condition, they saw a low-reward cue “1 P”. The high-reward cue or low-reward cue indicated that participants would earn 10 pence or 1 penny for a correct recognition memory judgment or a correct source memory judgment. During the recognition memory test, 120 words used in the study phase were mixed with 120 new words to present to test participants’ recognition memory. The assignments of words to the old word sets and the new word sets were counterbalanced across the participants. During the source memory test, the 120 words used in the study phase were presented again to test participants’ source memory.

All the stimuli were presented in white on a black background on the computer screen and participants gave responses with the keyboard on the computer. We used the PsychoPy software package (Peirce et al., 2019) to present all stimuli and record data.

### 2.3 Procedure

Participants were tested individually. The experiment consisted of a study phase and two test phases: a recognition memory test and a source memory test. The instructions for the experiment were presented to participants on the computer before starting the experiment. The main content of the instructions was also repeated before the relevant parts of the experiment in the PsychoPy on the computer screen. In the instructions, we told the participants that they would view a series of English words following the high or low monetary reward cues. Their task was to learn the words and memorize the location of the words, and then indicate the location of the words presented before. This location task was designed to maintain participants' attention to the memory task at the study phase. The participants were told that the reward cue presented at the beginning of each trial during the study phase indicated that the monetary reward they would earn for the correct memory judgment for each item in the following recognition memory test and the source memory test. Before the real experiment, participants were given a chance to practice first. In the practice phase, 8 words were used in the study phase, 16 words (8 old words and 8 new words) were used in the recognition memory test, and 8 old words were used in the source memory test.

During the study phase, participants learned 120 English words following high or low reward cues. The stimuli were presented in randomized order. The participants' task was to learn the words and memorize the locations of the words. The reward cue: "10 P" or "1 P" at the beginning of each trial indicated that they would earn 10 pence or 1 penny for the correct memory judgment of each word in the following recognition memory test and the source memory test. **Figure 1** displays the experimental procedure for the study phase.

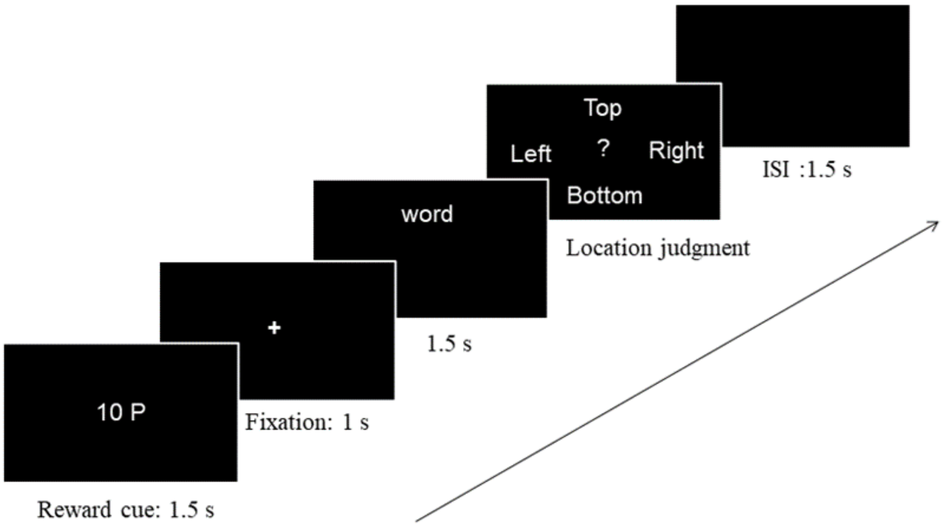


**Figure 1. Experimental procedure for the study phase**

In the study phase, each trial started with a high or low reward cue “10 P” or “1 P” at the centre of the computer screen for 1.5 s, followed by a fixation cross “+” at the centre of the screen for 1 s. Then, participants viewed a word for 1.5 s presented in one of four locations of the computer screen: Top, Bottom, Left, or Right. After that, the words which indicated four locations of the screen: “Top”, “Bottom”, “Left”, and “Right” appeared in the corresponding four locations, with a question mark “?” at the centre of the computer screen. Participants needed to indicate which of four locations the word has been presented before. They used four arrow keys on the keyboard to make location judgments. Press the “up” arrow key for the “Top” location; press the “down” arrow key for the “Bottom” location; press the “left” arrow key for the “Left” location; and press the “right” arrow key for the “Right” location. The screen persisted until the participant made a response. They were instructed to respond as accurately and as quickly as possible. After the participant made a location judgment, a blank screen appeared for 1.5 s. Then, they moved to the next trial.

After the study phase, participants were instructed to do 60 basic mathematical calculation tasks. For example, 30+16=？ 16×6=?. The calculation task needed to take roughly 5 minutes to complete, and the maximum time-limit for each calculation problem was 20 s. This distractor task was designed to reduce additional rehearsal on the studied items.

During the test phase, participants first performed the recognition memory task. Participants saw 120 old words presented during the study phase mixed with 120 new words. The words were presented in randomized order in the centre of the screen one by one. Participants made old/new recognition memory judgments to indicate whether the words were previously presented during the study phase or not. If participants correctly judged a previously presented word as "old", they would get an anticipated reward: "10 P" or "1 P''. If participants incorrectly judged a "new" word as "old", they would be punished "-6 P". This punishment of "-6 P" for false alarms was set to avoid participants adopting a strategy of pressing "old" to all test words to maximize rewards. The punishment level was chosen at the approximate mid-point between the high and low reward levels, which was a relative balance in penalizing false alarms and could avoid too conservative or lenient responses. Participants were instructed to respond as accurately and as quickly as possible in the recognition memory test. **Figure 2** displays the experimental procedure for the recognition memory test.

In the recognition memory test, in each trial, a word appeared at the centre of the computer screen. Participants were asked to judge whether the word had been previously presented ("old") or not presented before ("new"). The participants used the keys "F" and "J" on the computer keyboard to indicate "old" or "new" judgments, and the responses were self-paced. The assignments of keys to "old" responses and "new" responses were counterbalanced across participants. The word persisted in the screen until the participant made a response. For the Hit responses, in which participants made an “old” response to the previously presented “old” word, they received the “Correct!” feedback at the bottom of the screen and the expected reward “10 P” or “1 P” appeared in the centre of the screen for 1 s. For the Miss responses, in which participants made a “new” response to the previously presented “old” word, they receive the “Incorrect!” feedback at the bottom of the screen and the “0 P” appeared in the centre of the screen for 1 s. For the Correct Rejections, in which participants made a “new” response to the “new” word, they received the “Correct!” feedback at the bottom of the screen and the “0 P” appeared in the centre of the screen for 1 s. For the False Alarms, in which participants made an “old” response to the “new” word, they received the “Incorrect!” feedback at the bottom of the screen and the punishment “-6 P” appeared in the centre of the screen for 1 s. The time interval between the trials in the recognition memory test was 1.5 s with a blank screen.

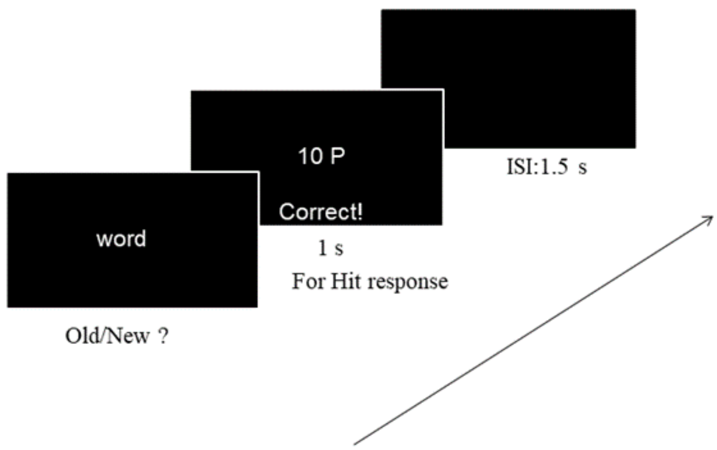


**Figure 2. Experimental procedure for the recognition memory test**

After the recognition memory test, participants performed the source memory test. Participants viewed 120 words previously presented during the study phase in the centre of the screen one by one. The words were presented in randomized order. Participants were asked to judge which of four locations each word was presented during the study phase. Participants would get anticipated monetary rewards “10 P” or “1 P” if they correctly judged the locations of the words presented during the study phase. They would not get any reward for incorrect location judgment. Participants were instructed to respond as accurately and as quickly as possible. **Figure 3** displays the experimental procedure for the source memory test.

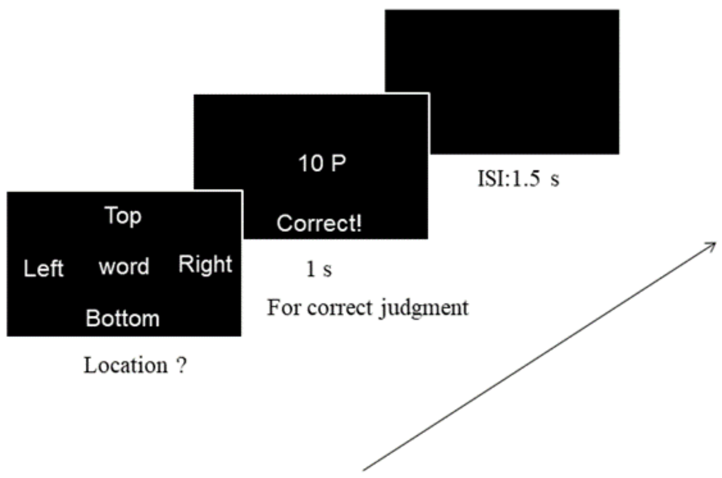


**Figure 3. Experimental procedure for the source memory test**

In the source memory test, in each trial, participants saw a word in the centre of the screen, with the words which indicated four locations of the screen: “Top”, “Bottom”, “Left”, and “Right” in the corresponding four locations. Participants were asked to make a self-paced location judgment to indicate which of the four locations the words appeared on the screen during the study phase. Participants used four arrow keys on the keyboard to make their responses. If the word was presented in the “Top” place in the study phase, they pressed the “up” arrow key. If the word was presented in the “Bottom” place in the study phase, they pressed the “down” arrow key. If the word was presented in the “Left” place in the study phase, they pressed the “left” arrow key. If the word was presented in the “Right” place in the study phase, they pressed the “right” arrow key. The screen persisted until participants made a response. For the correct source memory judgments, the participants received the “Correct!” feedback at the bottom of the screen and the predicted reward “10 P” or “1 P” was presented in the centre of the screen for 1 s; while for the incorrect source memory judgments, the participants received the “Incorrect!” feedback at the bottom of the screen and the “0 P” was presented in the centre of the screen for 1 s. The time interval between the trials in the source memory test was 1.5 s with a blank screen.

After the experiment, participants received the monetary rewards they earned in the recognition memory test and the source memory test, as well as an inconvenience allowance. The actual amount of money they received was rounded up to the nearest £0.10.

### 2.4 Data Analyses

#### 2.4.1 Data Analyses on Recognition Memory

To examine the effects of reward on recognition memory, we performed paired samples t-tests. We compared hit rate, recognition sensitivity, and response bias in the high-reward and low-reward conditions. We also compared the Response times (RTs) in the high-reward and low-reward conditions in the recognition memory task.

Signal detection theory (SDT) measures of recognition sensitivity and response bias were used to compare recognition memory performance. Recognition sensitivity is the ability to discriminate old items from new items in the recognition memory test. Response bias is the general tendency to respond to an item as old (yes) or new (no) in the recognition memory test. There are two commonly used methods to calculate the recognition sensitivity and the response bias. One is the traditional parametric method of calculating d' and c. The other is the non-parametric method of calculating A' and $B_D$'' (for review, see Stanislaw & Todorov, 1999). The traditional way of calculating recognition sensitivity d' and response bias c should meet two assumptions. One is that old and new distributions are normal, and the other is that old and new distributions have equal standard deviations. If our data met these two assumptions, we would use the traditional parametric method to calculate the recognition sensitivity d' and the response bias c. For recognition sensitivity d', larger values indicate a better ability to distinguish old items from new items. For response bias c, negative values indicate a response bias to judge an item as old (yes), whereas positive values indicate a response bias to judge an item as new (no). If our data violated the above two assumptions, we would use the non-parametric method to calculate the recognition sensitivity A' and the response bias $B_D$'', which do not need to meet the above assumptions. For non-parametric measurement of recognition sensitivity A', the values range from 0.5 to 1. The value of 0.5 indicates that participants cannot distinguish signal from noise, and the value of 1 indicates perfect performance. For non-parametric response bias $B_D$'', the values range from -1(extreme bias to respond old) to 1(extreme bias to respond new), and the value of 0 indicates no response bias.

### 2.4.2 Data Analyses on Source Memory

To examine the effects of reward on source memory, we performed paired samples t-tests. We compared the source memory accuracy in the high-reward and low-reward conditions. We also compared the Response times (RTs) in the high-reward and low-reward conditions in the source memory task.

# Chapter 3: Experimental Results

## 3.1 Recognition Memory Performance

**Table 1** displays hit rate, recognition sensitivity A', response bias $B''_D$, and recognition memory response times (RTs) in the high-reward condition and the low-reward condition. A paired samples t-test indicated that hit rates for high-reward words (M = 0.64, SD = 0.13) and low-reward words (M = 0.64, SD = 0.15) were not significantly different, $t(36) = 0.21$, $p = 0.838$. We further ran one-sample t-tests to see whether hit rates in the high-reward and low-reward conditions were above the chance level of 0.5. For high-reward words, $t(36) = 6.77$, $p < 0.001$. For low-reward words, $t(36) = 5.86$, $p < 0.001$. The results showed that in both high-reward and low-reward conditions, hit rates were significantly above the chance level of 0.5.

For the calculation of SDT measures of recognition sensitivity and response bias, we checked whether our data met the traditional SDT assumptions. We ran normality tests to check the data distribution. The Shapiro-Wilk test showed that the data of the false alarm rate was not normally distributed ($p < .05$). Because our data violated the traditional SDT assumptions, we employed a non-parametric method to calculate recognition sensitivity A' and response bias $B''_D$. For recognition sensitivity A', there was no significant difference between high-reward words (M = 0.81, SD = 0.07) and low-reward words (M = 0.81, SD = 0.09), $t(36) = 0.60$, $p = 0.554$. Likewise, for response bias $B''_D$, there was no significant difference between high-reward words (M = 0.38, SD = 0.40) and low-reward words (M = 0.37, SD = 0. 41), $t(36) = 0.44$, $p = 0.666$. In addition, recognition memory RTs for high-reward words and low-reward word were 1100 ms (SD = 217 ms) and 1102 ms (SD = 197 ms). There was no significant difference between RTs for high-reward words and low-reward words, $t(36) = -0.16$, $p = 0.873$.

To summarise, the recognition memory performance: hit rate, recognition sensitivity A', response bias $B''_D$, and recognition memory RTs were not significantly different between the high-reward and low-reward conditions. The hit rates in high-reward and low-reward conditions were nonetheless clearly above the chance level.

**Table 1**

Recognition memory performance in the high-reward and low-reward conditions.

All values are Mean and standard deviations (in parentheses).

| Recognition Memory Performance | High-Reward | Low-Reward |
|---|---|---|
| Hit Rate | 0.64 (0.13) | 0.64 (0.15) |
| Recognition Sensitivity A' | 0.81 (0.07) | 0.81 (0.09) |
| Response Bias $B''_D$ | 0.38 (0.40) | 0.37 (0.41) |
| Recognition Memory RTs (ms) | 1100 (217) | 1102 (197) |

### 3.2 Source Memory Performance

**Table 2** displays source memory accuracy and source memory RTs in the high-reward and low-reward conditions. Source memory accuracy for high-reward words and low-reward words were 0.47 (SD = 0.15) and 0.48 (SD = 0.16). A paired samples t-test indicated that there was no significant difference in source memory accuracy between high-reward words and low-reward words, $t(36) = -0.49$, $p = 0.628$. We further ran one-sample t-tests to see whether source memory accuracy in the high-reward and low-reward conditions were above the chance level of 0.25. For high-reward words, $t(36) = 8.97$, $p < 0.001$. For low-reward words, $t(36) = 8.58$, $p < 0.001$. The results showed that in both high-reward and low-reward conditions, source memory accuracy were still significantly above the chance level of 0.25.

Additionally, source memory RTs for high-reward and low-reward words were 1348 ms (SD = 347 ms) and 1359 ms (SD = 321 ms). A paired samples t-test indicated that source memory RTs were not significantly different between high-reward words and low-reward words, $t(36) = -0.59$, $p = 0.557$.

To summarise, the source memory performance: source memory accuracy and source memory RTs were not significantly different between the high-reward and low-reward conditions. The source memory accuracy in the high-reward and low-reward conditions were nonetheless clearly above the chance level.

**Table 2**

Source memory performance in the high-reward and low-reward conditions.

All values are Mean and standard deviations (in parentheses).

| Source Memory Performance | High-Reward | Low-Reward |
|---|---|---|
| Source Memory Accuracy | 0.47 (0.15) | 0.48 (0.16) |
| Source Memory RTs (ms) | 1348 (347) | 1359 (321) |

### 3.3 Correlation Analysis Results

Given the surprising absence of reward-related differences in memory, we chose to conduct some additional analyses to look for evidence of strategic differences between participants. We chose to explore relationships between recognition memory and source memory, and memory performance and response times in the high-reward and low-reward conditions separately using a correlation analysis. Pearson's correlation coefficients were calculated across the 37 participants, for recognition sensitivity and source memory accuracy, and recognition and source memory response times in the high-reward and low-reward conditions. These correlations are presented in **Table 3**. The logic behind this analysis was that if some participants were selectively focusing on either source memory or item memory then there might be a negative correlation between these measures that might appear specifically in the high-reward trials.

**Table 3**

Correlation matrix for recognition memory and source memory

Pearson's correlations between recognition sensitivity and source memory accuracy, and recognition and source memory response times in the high-reward and low-reward conditions across the 37 participants.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. Recognition Sensitivity (H) | - | | | | | | | |
| 2. Recognition Sensitivity (L) | .896** | - | | | | | | |
| 3. Source Accuracy (H) | .849** | .889** | - | | | | | |
| 4. Source Accuracy (L) | .843** | .872** | .856** | - | | | | |
| 5. Recognition RT(H) | 0.023 | -0.116 | -0.069 | 0.033 | - | | | |
| 6. Recognition RT (L) | 0.077 | -0.030 | -0.044 | 0.047 | .876** | - | | |
| 7. Source RT (H) | 0.140 | 0.195 | 0.127 | 0.242 | .569** | .593** | - | |
| 8. Source RT (L) | 0.215 | 0.217 | 0.152 | 0.270 | .617** | .600** | .946** | - |

H: high-reward words; L: low-reward words

**. Correlation is significant at the 0.01 level (2-tailed).

In the correlation analysis results between recognition memory and source memory, there were high and significant positive correlations between recognition memory sensitivity and source memory accuracy in both high-reward ($r$ = 0.849, n = 37, $p$ < 0.01) and low reward conditions ($r$ = 0.872, n =37, $p$ < 0.01). Recognition and Source memory response times in the high-reward ($r$ = 0.569, n=37, $p$ < 0.01) and low-reward conditions ($r$ = 0.600, n = 37, $p$ < 0.01) were also positively correlated with each other. However, no significant correlations existed between memory performance and response times in any condition.

For correlation analysis between the high-reward and low-reward conditions, there was a high and positive correlation in recognition memory sensitivity between the high-reward and low-reward conditions ($r = 0.896$, n = 37, $p < 0.01$). For source memory accuracy, it also showed a high and positive correlation between the high-reward and low-reward conditions ($r = 0.856$, n = 37, $p < 0.01$). In addition, there was a high and positive correlation in recognition response times between the high-reward and low-reward conditions ($r = 0.876$, n = 37, $p < 0.01$). Likewise, source memory response times also showed a high and positive correlation between the high-reward and low-reward conditions ($r = 0.946$, n = 37, $p < 0.01$).

# Chapter 4: Discussion

In the current behavioural study, we investigated the influence of reward anticipation on recognition memory and source memory in a dual rewarded memory task. The results showed that neither item recognition memory nor source memory performance differed between the high-reward and low-reward conditions. Our findings provide an example of reward not enhancing item recognition memory and source memory in a dual rewarded memory task. In the following section, we would discuss our main findings and give possible explanations for our results.

## 4.1 Reward, Executive Control, and Resource Allocation

Our possible explanation for the failure of reward to enhance item recognition memory and source memory in a dual rewarded memory task is that rewards might lead to resource competition and influence resource allocation between item and source memory. The executive control processes might act on a dual rewarded memory task to influence resource allocation.

In a previous paper, Norman and Bobrow (1975 ) proposed that human processing resources are limited. If several processes use the same resource, the resource must be allocated among them. In our study, we both rewarded item recognition memory and source memory with the same amount of monetary reward. Participants made reward anticipation on both item recognition memory and source memory during the study phase with the same reward cue, and they needed to memorize both the item and the location of the item presented. Thus, in our dual rewarded memory task, memorizing the item and its location might use the same resource, and resource might be allocated between them. Rewards might lead to resource competition between memorizing the item and the location of the item, and influence resource allocation. The executive control processes might be recruited to coordinate and influence resource allocation between memorizing the item and location (source) in a dual rewarded memory task.

Because the amount of reward given to the correct item recognition memory and source memory task were equal, the resource finally allocated to memorize the item and location might be nearly equal. Due to the limited human processing resources and resource competition in a dual rewarded memory task, rewards cannot allocate more resources to either item or source memory to enhance memory performance.

The correlations presented in Table 3 may also provide some insight into whether different participants did use different strategies. If some participants prioritized item recognition, while others prioritized source memory, we might have found negative correlations between source and item memory. In fact, the high positive correlations between recognition memory and source memory in both high-reward and low-reward conditions imply that those participants who were good at item memory were also good at source memory. Additionally, the high and positive correlations between the high-reward and low-reward conditions in both recognition memory and source memory additionally suggest that participants may have used similar attentional strategies in both reward conditions. While these results do not directly support a resource allocation account, it is easy to see how they might be consistent with such an account given that participants had no reason to prioritize one aspect of encoding over the other.

In contrast, if the dopaminergic reward mechanism was active in our dual rewarded memory task, we would predict enhancements of memory for high-reward trials. We would have expected it to find differences in item recognition memory and source between the high-reward and low-reward words. In this case, we would have potentially found much lower correlations in memory performance between high-reward and low-reward items since the high-reward trials might have been exclusively enhanced by such a mechanism. The high positive correlations in memory performances between high and low reward trials are much more consistent with the idea that similar mechanisms are being used in both cases. Therefore, our results indicate that in a dual rewarded memory task, the dopaminergic reward system did not directly act on the memory system to enhance item recognition memory and source memory for high-reward items.

Although our study appears very similar to Experiment 3 in Hennessee et al. (2017), the critical difference may be the awareness that the participants had at the time of encoding of the precise type of memory test they would subsequently receive. In Hennessee et al. (2017) context memory was measured in an incidental memory task, thus, the memory encoding task used in that study was a single rewarded memory task that just rewarded item recognition memory, and source memory was not directly encouraged at the time of encoding. Their results suggested that value improves item recognition memory but that value has no overall effect on the retrieval of value-irrelevant context information such as colour. For remembered responses of recognition memory, context retrieval of high-value items was lower than low-value items. For familiar responses of recognition memory, context retrieval of high-value words was higher than low-value words. The authors argued that value enhances recollection at the expense of irrelevant context information. In their experiment, participants were expected to get high or low point-values just for the correct recognition memory, and source memory (colour) was tested as an incidental memory. They argued that value enhances recognition memory through recollection, and this is mainly driven by the allocation of more attention resources to high-value items, which leads to the deeper semantic encoding of item memory. However, this value-driven enhancement effect on recollection is achieved at the cost of irrelevant incidental memory.

Comparing the study of Hennessee et al. (2017) and our study, we suggest that since our study both rewarded item recognition memory and source memory, reward ended up enhancing neither recognition memory nor source memory. Because in a dual rewarded memory task, the attention resources are nearly equally allocated to the item memory and source memory, rewards cannot encourage participants to allocate more resources to the item or source memory and inhibit unrewarded irrelevant information to enhance rewarded memory.

As we mentioned in the introduction, there have been two hypotheses about the mechanisms of the influence of reward on memory (Elliott et al., 2020). One hypothesis is that dopamine releases in the midbrain reward processing regions lead to the enhancement of memory (e.g., Adcock et al., 2006; Shigemune et al., 2014; Elliott et al., 2020; Wittmann et al., 2005). The other hypothesis is that prefrontal executive control processes lead to different encoding strategies for the high-value and low-value information (Cohen et al., 2014; Elliot, & Brewer, 2019). In our experimental results, reward failed to enhance either item recognition memory or source memory. Thus, the dopaminergic reward mechanism does not provide explanations for our results. In a dual rewarded memory task in our study that both rewarded item recognition memory and source memory, participants needed to remember both item and location of the item in the memory encoding task during the study phase. However, the processing resources of the human cognitive system are limited (Norman & Bobrow, 1975). In a dual rewarded memory task, both memorizing the item and the source might lead to resource competition. Thus, the executive control processes might act on a dual rewarded memory task to influence and coordinate resource allocation between memorizing the item and the source. Because the expected rewards for the correct item and source memory are the same, the resource allocation between the item memory and source memory might be nearly equal. Thus, rewards cannot enhance both item recognition memory and source memory. Therefore, about the mechanisms of the role of reward in a dual reward task in the present study, rewards lead to resource competition in a dual rewarded memory task and the executive control processes might be recruited to affect resource allocation.

### 4.2 Other Factors Might Influence the Effect of Reward on Memory

In this section, we discuss some of other factors that might influence the effects of reward on memory: task, feedback, and time delay, and consider whether these may explain the results from our experiment.

One factor that might influence the effect of reward on memory is the task during the study phase. In the fMRI study of Shigemune et al. (2014) the researchers found that both reward and punishment expectations during the encoding phase can enhance intentional source memory. However, in that study, reward and punishment had no effect on item recognition memory. At the encoding phase of their study, participants needed to encode both words and the location (right or left) of the words by performing the font judgment task. The authors thought that the font judgment task during the study phase might have divided attention and removed the effect of reward on recognition memory. This does support the idea that the task at the encoding phase might influence attention allocation and explain different effects of reward on recognition memory and source memory. The study also supports the idea that reward cannot simultaneously enhance both item recognition memory and source memory. The font judgment task at the encoding phase may indeed have influenced the effects of reward on recognition and source memory, and more attentional resources may have been allocated to source memory. Consequently, reward just enhanced source memory, but did not enhance recognition memory.

In a previous study that investigated the effects of monetary incentives on recall, Eysenck and Eysenck (1982) found that the effects of reward on recall were reduced by the concurrent task of articulatory suppression, and the effects were eliminated by the concurrent task of counting backwards. These results indicate that a concurrent task that interferes with executive control processes during memory encoding reduces or removes the effects of reward on recall. In a following behavioural study, researchers used different divided attention tasks to investigate the effects of value on recognition memory. According to their results, only the divided attention task that consumes more executive resources eliminates the effect of value on recognition memory. Thus, the results indicate that executive resources are needed in the effect of value on recollection, and the memory task that interferes executive control process eliminates the effect of value on recognition memory (Elliott & Brew, 2019). From previous studies, we can see that different tasks used in the study phase might influence the attention allocation and executive control processes, which influences the effect of reward on memory

In our study, the memory encoding task during the study phase was that participants viewed each word and memorized the word and location of the word following high or low reward cues. Then, participants performed the location task to indicate the location of the words presented before. Whether the null effect in our study was caused by the task, we thought this explanation was not applicable to our experiment. Because participants saw each word and memorized the word and its location first, this did not interrupt executive control processes. On the contrary, the executive control processes might be act on to affect resource allocation. Because people's processing resources are limited (Norman & Bobrow, 1975), the resources allocated to the item and source memory are nearly equal in the dual rewarded memory task in the present study. Thus, rewards cannot enhance both item recognition memory and source memory. In addition, not only recognition memory, but also source memory was also not influenced by reward. The location task that was performed after encoding words and their locations also did not enhance source memory. Thus, the null effect of recognition memory and source memory also should not be eliminated by the following location task. Therefore, we concluded that the null effect of reward on memory was less likely caused by the specific task at the study phase, but caused by resource competition and nearly equal resource distribution in a dual rewarded memory task. This needs further confirmation in future studies without the location task at the study phase.

Another confounding factor that we need to consider in reward and memory studies is the feedback during the memory test. Some previous studies did not provide reward feedback during the memory test phase (e.g., Adcock, 2006; Hennessee, 2017), while other studies provided reward feedback during the memory test phase (e.g., Shigemune et al., 2014). However, there was no evidence that the effect of reward on memory depends on the feedback during the memory test in these studies. Thus, we think whether providing feedback or not may not be the key factor influencing the effect of reward on memory. In the fMRI study cited earlier on the effect of reward on recognition memory, participants made high or low reward anticipation during the study phase (Adcock et al., 2006). During the recognition memory test, participants first made an old/new response, and then they rated the memory quality on a 4-point scale with remember, know, pretty sure, and guessing responses. During the recognition memory test, no actual correct/incorrect and reward feedback was provided during the test. However, participants received the money they earned during the experiment after the experiment. Also, in a previous behavioural study, which investigated the effect of value on recognition memory (Hennessee, 2017), participants did not receive value feedback during the recognition memory test. However, they reserved the right to know their score after the experiment. In these two studies (Adcock, 2006; Hennessee, 2017), participants had not received any reward feedback during the memory test.

Nevertheless, in the fMRI study investigating the effect of reward and punishment expectations on source memory, participants received reward or punishment feedback during the memory test, and participants demonstrated enhanced source memory in both reward and punishment conditions (Shigemune et al., 2014). In the present study, we provided correct/incorrect feedback and reward feedback during the memory tests. According to previous studies mentioned above (Adcock, 2006; Hennessee, 2017; Shigemune et al., 2014), whether providing reward feedback or not during the memory test has not affected the influence of reward on memory. We thus think it unlikely that the nature of the feedback was critical in explaining the pattern of results observed in our experiment. This needs further confirmation in future studies without receiving feedback in the memory test phase.

In addition, whether there is a time delay between the study and test phases may also influence the effect of reward on memory. In the study of Adcock et al. (2006), they reported that reward improved recognition memory in a 24-hour delayed recognition memory test. Spaniol et al. (2013) also found the positive effect of reward on memory in a 24-hour delayed recognition memory test; however, they found no effect in an immediate recognition memory test. In these two studies, they used pictures as stimuli.

In a reward and memory study with a short-time delay (5 minutes), researchers also found that high-value words showed better recognition memory than low-value words, and this was achieved by increased recollection (Hennessee, 2017). In the present study, there was also a short-time (5 minutes) delay between the study and test phases, and we used words as stimuli. Because we both measured recognition memory and source memory, and people's source memory was usually very poor, we did not set a long-time delay in our study. The fMRI study by Shigemune et al. (2014) found that monetary reward and punishment expectations enhanced intentional source memory, and there was no time delay between the encoding and test phases.

Clearly it would have been interesting to have had memory tests after a longer delay in the current study, however, there is a danger that if we had done so, any effects of reward might have been hidden by floor effects. Studies that have used longer time delays have typically used pictures as stimuli and it is likely that the higher overall levels of performance in these studies render them more appropriate to use at longer delays. There does seem to be sufficient evidence that with word stimuli we should have been able to obtain reward effects at short delays, so it is unlikely that the short delay is the only reason behind our results.

The clearest distinction between our study and the others that have been described is that we used dual rewarded memory task in the present study while others have used a single rewarded memory task. Thus, our preferred explanation for our results is that rewards might lead to resource competition and influence resource allocation in a dual rewarded memory task that rewarded both item recognition memory and source memory. The item and source memory might use the same resources, and resources might be allocated between them. The executive control mechanism might be recruited to coordinate and influence resource allocation. Due to the same amount of reward given to the item and source memory, the resources allocated to memorize the item and source are nearly equal. Thus, rewards cannot enhance item recognition memory and source memory in the present study. Although this is our preferred explanation, we do not have any data that directly supports this interpretation, so an important goal for future research is to produce designs that test this interpretation directly.

### 4.3 Future Work

In our future work, we want to further test our hypotheses on reward-guided resource allocation and memory. In the present study, we have discussed the relationships between reward, resource allocation, and memory in a dual rewarded memory task. In our future study, we want to further explore the relationships between reward, resource allocation, and memory in studies which reward influences resource allocation directly. One of our hypotheses is that reward might enhance memory through allocation of more resources to the rewarded memory. Using the ERP technique, we will investigate the influence of reward on recognition memory and source memory and test our hypotheses. In one study, we could reward recognition memory but test source memory in an unrewarded memory test. In the other study, we could reward source memory to investigate the effect of reward on intentional source memory, and recognition memory could also be tested in an unrewarded memory test. Through these two experiments, we could investigate directly whether different effects on recognition memory and source memory might be influenced by reward-guided resource allocation. The ERP technique has advantages to dissociate relevant cognitive processes, and we also want to explore specific neurocognitive mechanisms underlying the influence of reward on memory.

In addition, we also want to explore the factors that might influence the effects of reward on human memory in future work. We previously discussed three factors that might influence the effect of reward on human memory. Whether these factors influence the effects of reward on memory needs further clarification in future studies. One important factor that might influence the effect of reward on memory is the task at the time of encoding. We have considered the way that specific aspects of the encoding task might be rewarded; however, unrewarded aspects of the task at encoding are likely to be important too. We can see that previous research has been able to eliminate reward effects by the addition of secondary tasks. This may be a useful way of further exploring reward effects once we have a paradigm that reliably demonstrates clear reward-dependent differences.

Another factor that might influence the effect of reward on memory is the feedback during the memory test phase. Previous studies indicate that whether receiving feedback or not in the memory test phase has not influenced the effects of reward on memory. Reward-enhanced memory effects were found in both studies providing feedback (Adcock, 2006; Hennessee, 2017) and not providing feedback (Shigemune et al., 2014) in the test phase. In the present study, we provided correct/incorrect and reward feedback in the test phase. So far, we have focused almost entirely on factors that act at the time of encoding, but that does not mean that factors at the time of retrieval might not also be important. In a future study, it would be interesting to remove feedback at the test phase to see whether feedback at the time of retrieval does influence the effect of reward on memory.

The time delay between the study and test phases might also have an important influence on the effect of reward on memory. As we mentioned above, a time-dependent effect of reward on recognition memory was found in the study of Spaniol et al. (2013), in which they used pictures as stimuli. Thus, whether the length of time delay influences the effect of memory, and whether the time-dependent effect of reward on memory is also influenced by the types of stimuli needs further clarification in future work.

### 4.4 Conclusion

The main finding of our behavioural study was that reward did not enhance item recognition memory and source memory. We suggest that in a dual rewarded memory task, due to limited human processing resources (Norman & Bobrow, 1975), rewards might lead to resource competition and influence resource allocation between item and source memory. In addition, the dopaminergic reward mechanism cannot provide an explanation for our data. However, executive control processes might act on our dual rewarded memory task to influence resource allocation. In future work, we want to further test our hypotheses on reward-guided resource allocation and memory, and explore other factors that might influence the effect of reward on memory.

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