Task difficulty rather than reward method modulates the reward boosts in visual working memory

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Both monetary and notional rewards are important to motivate individuals to prioritize specific items in visual working memory (VWM). However, whether the reward method and task difficulty are the key factors that modulate the reward boosts in VWM is unclear. In this study, we designed two experiments to explore this question. Experiment 1 examined whether the reward method modulates reward boosts in VWM by manipulating the item type (high reward, low reward, equal reward) and reward method (monetary and notional). Experiment 2 examined whether task difficulty modulates reward boosts in VWM by manipulating the number of high-reward items (1, 2, 3), reward method, and item type. The results indicated reward boosts for high-reward items compared to low- and equal-reward items. Moreover, the VWM performance was higher in the monetary reward condition than in the notional reward condition; however, there was no interaction between the reward method and item type. Additionally, a significant interaction was found between the reward number and item type: Reward boosts on VWM performance occurred only when one or two higher reward items were present. In conclusion, reward boosts in VWM tasks are modulated by task difficulty but not the reward method.

Introduction

Visual working memory (VWM) is a system that temporarily holds and manipulates visual information (Baddeley, 2012; Baddeley, Hitch, & Allen, 2019). It plays a critical role in many cognitive activities, such as reading, reasoning, and performing arithmetic calculations. However, the resources that can be used in VWM tasks are severely limited (Luck & Vogel, 1997, 2013). To help individuals use their limited VWM resources efficiently to succeed in various cognitive tasks, researchers often use notional (Hitch, Allen, & Baddeley, 2020; Hu, Hitch, Baddeley, Zhang, & Allen, 2014) or monetary rewards (Klyszejko, Rahmati, & Curtis, 2014) to motivate people to focus on the most important items. Notional rewards are usually achieved by assigning different virtual reward points to memory items. For example, participants can be informed that correct recall of a certain item in the array would earn them 4 points, while correct recall of other items would earn them 1 point. The points are notional; participants’ cumulative points are usually not calculated, and no actual rewards are provided (Atkinson, Berry, et al., 2018). In contrast to notional rewards, participants are given more money for higher rewarded items in studies that use monetary rewards.

Studies have shown that both notional and monetary rewards efficiently motivate individuals to prioritize more valuable items in VWM. In these studies, the participants were usually presented with a memory array and told that one or some items were more valuable than others; if they correctly recalled the items at retrieval, they would get more rewards. The results consistently indicated that, compared to equal-reward (or no-reward) items, the participants obtained better VWM performance for high-reward items and worse VWM performance for low-reward items irrespective of whether the rewards were notional (Allen & Ueno, 2018; Atkinson, Baddeley, & Allen, 2018; Atkinson, Berry, et al., 2018; Hitch, Hu, Allen, & Baddeley, 2018; Hu, Allen, Baddeley, & Hitch, 2016; Hu et al., 2014)
or monetary (Infanti, Hickey, Menghi, & Turatto, 2017; Jimura, Locke, & Braver, 2010; Klyszejko et al., 2014; Krawczyk, Gazzaley, & D’Esposito, 2007). This suggests that both notional and monetary rewards help individuals prioritize the most valuable items at the cost of low-reward items. Further, the size of reward boosts is related to the number of high-reward items (Allen & Ueno, 2018; Hitch et al., 2018). Regarding the mechanisms underlying the reward effect, researchers suggest that reward manipulations reflect executive control of the most important information in the VWM, which causes participants to employ different encoding or refreshing strategies for the high- and low-reward items (Hitch et al., 2020). Rewards alter participants’ motivation and engagement in tasks and enhance goal-directed behavior (Atkinson, Waterman, & Allen, 2019).

However, participants are not always motivated to prioritize more valuable items. For example, a study demonstrated that children aged 7 to 10 years cannot prioritize more valuable information when notional rewards are provided before a sequence of three memory items (Berry, Waterman, Baddeley, Hitch, & Allen, 2018). Studies evince that a task with a small monetary reward can impair performance more than one with no reward because the reward is so small that it is considered insulting (Gneezy & Rustichini, 2000); similarly, a large monetary reward can impair performance because it could result in participants “choking under pressure” (Botvinick & Braver, 2015). Botvinick and Braver (2015) proposed three boundary conditions for reward boosts in cognitive tasks to explain why rewards can enhance task performance in some task conditions but not in others. First, rewards can enhance task performance only when the task difficulty and information capacity are accessible to the participants; when the tasks are too difficult, no reward effects will appear. Second, contrary effects can arise when the reward magnitude becomes too large or small. Finally, although rewards enhance participants’ motivation and executive control ability, this reward boost might relate to the extrinsic (e.g., monetary) rewards, thus reducing the intrinsic motivation associated with a task. These boundary conditions imply that the task difficulty, reward magnitude, and reward method can influence how reward manipulations affect VWM performances. Therefore, we propose the following question: Do all three boundary conditions for reward boosts in VWM by manipulating the item types (high-reward, low-reward, and equal reward) and reward methods (notional and monetary).

### Methods

#### Participants

The required sample size was calculated through a power analysis based on the predicted effect size using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009). We predicted a medium effect size ($f = 0.25$) for Experiments 1 and 2 with 95% power at a significance level of 0.05. For the $2 \times 3$ mixed-experimental design (two groups of participants for six levels of measures) in Experiment 1, the suggested sample size was 28 individuals for two groups. For the $3 \times 3 \times 2$ mixed-experimental design (two groups of participants for 18 levels of measures) in Experiment 2, the suggested sample size was 14 individuals.
To ensure that the sample size is comparable to that of the previous studies using reward paradigms (Allen & Ueno, 2018; Hitch et al., 2018; Hu et al., 2014) and ensure sufficient statistical power, we recruited 56 undergraduate students (mean age: 19.79 ± 1.25 years, among which there were 35 women). Half of the 56 participants (mean age: 19.75 ± 1.38 years; 18 women) were assigned to the monetary reward condition, and the other half (mean age: 19.82 ± 1.12 years; 17 women) were assigned to the notional reward condition. All participants were recruited from Weifang Medical University and provided written informed consent. The study protocols were approved by the Ethics Committee of Weifang Medical University. All participants were native Chinese speakers and had normal or corrected-to-normal vision and no color blindness.

Materials

The experiment was run on an ASUS 15.6-in. screen with a resolution of 1,920 × 1,080 pixels and driven at a 120-Hz refresh rate, using E-prime software (version 2.0). The memory items were four colored shapes (visual angle: 1.5° × 1.5°) presented against a gray (RGB: 128, 128, 128) background. Viewers were positioned approximately 60 cm from the screen. For each trial, the items were chosen randomly, without repetition, from a set of 36 items taken from a pool of six colors (red [RGB: 255, 0, 0], yellow [RGB: 255, 255, 0], green [RGB: 0, 255, 0], blue [RGB: 0, 0, 255], purple [RGB: 128, 0, 128], and black [RGB: 0, 0, 0]) and six shapes (circle, triangle, cross, star, diamond, and arrow). The test cue was either a shape outline or a color blob of one of the memory items with a visual angle of 1.5° × 1.5°.

Experimental design and procedure

We employed a 3 × 2 mixed-experimental design, with item type (high, low, and equal reward) as a within-subject factor and reward method (monetary and notional) as a between-subject factor. For the item type, in the high- and low-reward conditions, a numerical cue (1, 1, 1, 5) was presented at the same location as the four memory items before the memory array (see Figure 1). If the participants correctly recalled the item at the same location as the number “1,” they earned 1 point (low reward). If they recalled the item at the same location as the number “5,” they earned 5 points (high reward). In the equal-reward item condition, a numerical cue (2, 2, 2, 2) was presented at the location of each memory item before the memory array was presented (see Figure 1). If the participants recalled the item at the same location as the number “2,” they would get 2 points. For the reward method, in the notional reward condition, the participants were told that the reward points were notional, that is, they were not related to monetary compensation at the end of the experiment. In the monetary reward condition, the participants were told that the points they collected were related to monetary compensation at the end of the experiment; that is, the more points they collected, the more money they would earn.

The experimental procedure is presented in Figure 1. Each trial began with the presentation of the word “Da.” The participants pressed the space button on a keyboard when they were ready and repeated the word “Da” aloud until they were shown the test cue. Next, a fixation cross appeared at the center of the screen. After 500 ms, four number cues were presented simultaneously for 1,000 ms at the corners of an invisible square (visual angle: 3.8° × 3.8°) at the center of the screen. After an interval of 3,000 ms, the four memory items were simultaneously presented at each of the locations of the numbers for 2,000 ms. Then, after a lag of 1,000 ms, the test cue—either a color blob or a shape outline—appeared at the center of the screen. Participants were asked to recall the other features of the probe verbally. They were encouraged to guess if they were not confident about their answer. The color- and shape-tested trials were randomly distributed across the experiment (50% chance). Participants were not provided with any feedback on task performance. Their responses were recorded by an experimenter who pressed a button on the keyboard to proceed to the next trial.
Experiment 1 aimed to examine whether the reward method modulates the reward effect in VWM. We found that the VWM performance was better in the monetary reward condition than in the notional reward condition. Furthermore, there was a reward boost on high-reward items compared to low-reward or equal-reward items. However, the interaction between the item type and reward method on VWM performance was not significant.

These findings indicate that both the notional and monetary reward manipulations can efficiently motivate participants to prioritize the most important items—in line with previous findings (i.e., Allen & Ueno, 2018; Atkinson, Berry, et al., 2018; Hitch et al., 2018; Hu et al., 2016; Infanti et al., 2017; Jimura et al., 2010; Klyszejko et al., 2014; Krawczyk et al., 2007). Although the monetary rewards were more efficient in motivating participants to achieve better VWM performance than notional rewards, it must be noted that the improvement in VWM performance on high-reward items was not at the expense of low-reward items. This may be because the low-reward items have the same probability of being detected in the task; thus, although the participants could prioritize the high-reward items, they did not simply discard the low-reward ones. However, we did not observe an interaction between the item type and reward method on VWM performance, indicating that the latter was not a key factor in modulating the reward boosts in VWM in the present study.

Experiment 2 aimed to examine whether task difficulty modulated the reward effect in VWM tasks with different reward methods. The task difficulty was manipulated by changing the number of high-reward items (1, 2, 3). Additionally, we manipulated the item types (high, low, equal) and reward methods (monetary and notional).
Method

Participants

We recruited 40 undergraduate students (mean age: 20.35 ± 0.94 years; 20 women) to participate in the experiment. Half of the 40 participants (mean age: 20.35 ± 1.14 years; 10 women) were assigned to the monetary reward condition, and the other half (mean age: 20.35 ± 0.75 years; 10 women) were assigned to the notional reward condition. All participants were recruited from Weifang Medical University and provided written informed consent. The study protocols were approved by the Ethics Committee of Weifang Medical University. All participants were native Chinese speakers and had normal or corrected-to-normal vision and no color blindness.

Equipment and materials

Experiment 2 used the same equipment and materials as Experiment 1.

Design and procedure

The experiment employed a $3 \times 3 \times 2$ repeated-measures design, with item type (high, low, and equal reward) and reward number (1, 2, and 3) as within-subject factors and reward method (monetary and notional) as a between-subject factor. The experimental manipulations and trial procedure were identical to that of Experiment 1 with this exception: We added a reward number in Experiment 2 as a within-subject factor. The reward number refers to how many high-reward items in a memory array were 1, 2, or 3 high-reward items.

The monetary and notional conditions each had 216 trials: The 1 high-reward item condition had 80 trials (high- and equal-reward items each had 16 trials and low-reward items had 48 trials), the 2 high-reward item condition had 56 trials (high- and low-reward items each had 24 trials and equal-reward items had 8 trials), and 3 high-reward item condition had 80 trials (low- and equal-reward items each had 16 trials and high-reward items had 48 trials). The participants performed all four reward number conditions (1, 2, 3) in the monetary or notional reward conditions; the four reward number conditions were counterbalanced between the participants, and the participants were randomly allocated to the monetary or notional reward conditions.

Results

The mean accuracy for shape-color collapsed data in Experiment 2 is shown in Figure 3. The main effect of item type was significant ($F(2, 76) = 5.00, p = 0.009, \eta_p^2 = 0.12, BF_{10} = 3.88$). Multiple comparisons indicated that the recall accuracy of low-reward items was worse than that of high-reward items ($t(38) = -3.53, p = 0.003, d_z = -0.31, BF_{10} = 36.66$); however, there were no differences between the accuracy of the low- and equal-reward items ($t(38) = -2.08, p = 0.131, d_z = -0.21, BF_{10} = 0.73$) or the high- and equal-reward items ($t(38) = -0.88, p = 1.000, d_z = 0.09, BF_{10} = 0.17$). The main effect of reward number was significant ($F(2, 76) = 10.58, p < 0.001, \eta_p^2 = 0.22, BF_{10} = 1,093.93$). Multiple comparisons indicated that the recall accuracy in the 1 high-reward item condition was worse than that in the 2 ($t(38) = -2.97, p = 0.016, d_z = -0.32, BF_{10} = 7.06$) and 3 high-reward item conditions ($t(38) = -4.40, p < 0.001, d_z = -0.45, BF_{10} = 4,602.13$); however, there were no differences between the accuracy of the 2 and 3 high-reward item conditions ($t(38) = -1.39, p = 0.191$).
The effect of reward number and reward type interaction on participants’ VWM performance also revealed that the participants used different strategies to process the memory items according to task difficulty. When there was only one high-reward item in a trial, the reward cue allowed them to remember as many items as possible to receive more cumulative rewards. When there were two high-reward items in a trial, the participants used their resources to prioritize the two most important items at the expense of the low-reward items. However, when there were three high-reward items (only one low-reward item) in the trial, the participants may not have been able to prioritize one or several memory items; instead, they could adopt the same processing strategy for all memory items to improve their overall memory performance.

**General discussion**

In the present study, we designed two experiments to examine whether reward method and task difficulty are the key factors that modulate the reward boosts in VWM. In Experiment 1, we manipulated reward method (monetary and notional) and item type (high reward, low reward, and equal reward) to test whether reward method influenced reward boosts in VWM. The results showed significant main effects of reward method and item type in that participants demonstrated better VWM performances on the high-reward items compared to equal-reward items, and this reward boost was higher in the monetary than notional reward condition. However, no interaction was observed between the reward method and item type on VWM performance. In Experiment 2, we further manipulated the number of high-reward items, as well as reward method and item type, to reveal whether task difficulty modulated the reward boosts in VWM for different reward methods. The results showed a significant interaction between item type and reward number, in that participants obtained higher VWM performances on high-reward items than equal-reward items when there were one or two high-reward items in the array; however, the item type did not have an effect when three high-reward items were presented in the array. The
present results suggest that reward boosts in VWM are modulated by task difficulty but not reward method.

Our findings align with many studies that have shown that notional and monetary rewards can effectively direct participants’ attention to high-reward items (Hitch et al., 2018; Hitch et al., 2020; Hu et al., 2014; Hu et al., 2016; Infanti et al., 2017; Jimura et al., 2010; Krawczyk et al., 2007). Regarding the cognitive mechanisms underlying reward boosts, researchers have suggested that reward manipulations can alter participants’ motivation and engagement in tasks, enhancing goal-directed behavior (Atkinson et al., 2019; Botvinick & Braver, 2015); this reflects the attentional refreshing of the most important information in VWM, which relies on the executive control system (Allen & Ueno, 2018; Atkinson, Berry et al., 2018; Hitch et al., 2018; Hitch et al., 2020). Participants are motivated to pay greater attention to refreshing high-reward items more frequently than low-reward items (Hitch et al., 2018; Hitch et al., 2020; Hu et al., 2016). Consequently, high-reward items are better memorized in VWM and are more likely to be retrieved than low-reward items (Hitch et al., 2018; Hitch et al., 2020; Hu et al., 2014). It should be noted that participants’ VWM performance was better motivated by monetary rewards than notional rewards. This is not surprising since monetary rewards are extrinsic, which hold certain social attributes and values. Participants are likely more motivated by monetary rewards compared to notional rewards, since notional rewards are virtual and do not have the same social value.

More important, we found that the reward boosts toward high reward items in VWM tasks were modulated by the task difficulty but not reward methods. In other words, our results did not prove that the extrinsic reward method was the boundary condition for the presence or absence of reward boosts in VWM. This is beyond our anticipation. The lack of sufficient evidence in the present study for Botvinick and Braver’s (2015) reward method boundary condition might be attributable to the fact that the experiments in the present study were too underpowered to detect a two-way interaction in VWM performance. However, we found that task difficulty is a key factor that modulates reward boosts in VWM tasks, as participants could prioritize the more valuable items only when there were one or two high-reward items. Botvinick and Braver (2015) have proposed that rewards can enhance task performance only when the task difficulty and information capacity are accessible to the participants; when the tasks are too difficult, no reward effects will appear. Our second experiment findings support this presumption.

In the present study, we found that when there was only one high-reward item in the memory array, participants could efficiently prioritize the valuable item without impairing the processing of other items. This could have occurred because the remaining resources were sufficient to process the low-reward items. However, when the participants were asked to prioritize two high-reward items, the VWM performances of the lower reward items were significantly impaired compared to high- and equal-reward items. This is because when two items needed to be prioritized, the remaining resources were insufficient to process the low-reward items. We did not find a reward effect when three high-reward items were presented in the memory array. This could be because the participants could not prioritize more than two items, or because most of them (three in four) were high-reward items, thus enabling participants to focus on processing all items instead of only a few to get more rewards. Therefore, the differences in the reward effects concerning different numbers of high-reward items in the present study show that the participants’ processing strategies vary as the task difficulty changes.

**Conclusions**

In conclusion, our findings show that the reward method cannot modulate reward boosts in VWM; however, task difficulty is a key factor in modulating the reward boosts in VWM. Moreover, the modulation of task difficulty on reward boosts in VWM tasks is independent of reward methods.

**Keywords:** visual working memory, attention prioritization, reward method, task difficulty, motivation

**Acknowledgments**

Supported by the PhD Scientific Research Start-Up Fund (No. 02195601) and Student Innovation and Entrepreneurship Training Program (No. X2021590) of Weifang Medical University.

Commercial relationships: none.

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