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Value-driven Attentional Refreshing and Its Mechanism

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Abstract

People can prioritize more valuable information in working memory, possibly because they prioritize the refreshing of this information during the working memory maintenance phase. So, how do people prioritize the refreshing of this information? This study manipulated the value of information through a value-directed memory paradigm, combined with a dot-probe task (Experiment 1 and Experiment 2) and a blank-screen paradigm (Experiment 3) to investigate value-directed attentional refreshing and its mechanism. The results showed that: (1) memory performance for high-value items was better than for low-value items; (2) regardless of whether items were presented simultaneously or sequentially, compared to low-value items, dot-probe reaction times at locations corresponding to high-value items were significantly faster; (3) compared to low-value items, participants' fixation frequency at locations corresponding to high-value items was significantly higher. These results indicate that value can guide attentional refreshing; value-directed attentional refreshing may be achieved by increasing the refreshing frequency of high-value information.

Full Text

Value-Directed Attentional Refreshing and Its Mechanism

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Abstract

People can prioritize more valuable information in working memory, possibly because they preferentially refresh this information during the maintenance phase. But how exactly do people achieve this priority? This study manipulated information value through a value-directed memory paradigm and investigated value-directed attentional refreshing and its underlying mechanism by combining a dot probe task (Experiments 1 and 2) and a blank screen paradigm (Experiment 3). The results showed that: (1) Memory performance for high-value items was better than for low-value items; (2) Regardless of whether items were presented simultaneously or sequentially, dot probe reaction times at locations corresponding to high-value items were significantly faster than those at low-value item locations; and (3) Participants showed significantly higher fixation frequencies at locations corresponding to high-value items compared to low-value items. These findings indicate that value can guide attentional refreshing, and that value-directed attentional refreshing may be achieved by increasing the refresh frequency of high-value information.

Keywords: attentional refreshing, value-directed, working memory, refresh frequency, fixation duration

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1. Introduction

Forgetting and maintenance of information represent a central focus in working memory research. Most theories posit that information in working memory decays over time or through interference from distractors (Barrouillet & Camos, 2012; Ricker et al., 2020), while an attention-dependent maintenance mechanism can resist this forgetting—known as attentional refreshing (Barrouillet & Camos, 2007). Attentional refreshing differs from updating. Updating is a function of the central executive system in working memory that replaces old information with new information during memory processing (Kaur et al., 2020). In contrast, attentional refreshing refers to the process of retrieving information into the focus of attention to promote, prolong, and strengthen the activation of that information (Camos et al., 2018).

Previous research on attentional refreshing has revealed two primary patterns. First, people can refresh designated information in working memory guided by retro-cues (Jafarpour et al., 2017; Lemaire et al., 2018; van Moorselaar et al., 2015). Second, refreshing can be spontaneously influenced by experience, such as reward-related or self-related stimuli (Thomas et al., 2016; Yin et al., 2019; Vergauwe et al., 2014). The former process is passive and conscious, while the latter is spontaneous and unconscious. Recent studies on the value effect in working memory have found that people prioritize more valuable information in working memory (e.g., Allen et al., 2020; Atkinson et al., 2019; Hitch et al., 2018; Hu et al., 2016). This effect may imply the existence of a spontaneous yet conscious attentional refreshing process—value-directed attentional refreshing.

In a recent study, Atkinson et al. (2022) used a probe-value paradigm to investigate whether the probe value effect in working memory is caused by attentional refreshing. In their experiment, participants memorized four colors associated with different values. In the final memory test, participants had to report one of the colors on a color wheel. In some trials, colors had high or low values, with one item valued at 4 and the other three valued at 1; in other trials, all colors had equal values of 1. During the memory maintenance phase, a guided refreshing procedure was inserted, prompting participants to "think of" the color indicated by a cue. In the cued condition, two cues guided participants to think about two colors, and one of these colors was tested in the memory test; in the uncued condition, two cues similarly guided thinking about two colors, but the memory test probed one of the two colors not guided by cues; in the no-cue condition, no cues appeared, and the memory test randomly probed one of the four colors. The results showed that recall accuracy for high-value items was significantly better than for low-value and equal-value items. Cues improved recall accuracy for low-value and equal-value items (i.e., better performance in cued vs. no-cue conditions), but this cueing effect disappeared for high-value items (i.e., no significant difference between cued and no-cue conditions for high-value items). This suggests that even without cues to guide refreshing of high-value items in the no-cue condition, participants may have actively and preferentially refreshed high-value items, rendering the cueing effect ineffective for these items.

However, these results only indirectly demonstrate that participants may have prioritized refreshing high-value items during the memory maintenance phase. This is because recall performance is influenced not only by attentional refreshing during maintenance but also by memory encoding. Because items were high-value, participants may have adopted more elaborate encoding strategies for high-value items or spent more time on them during encoding (Castel et al., 2002; Cohen et al., 2017; Hennessee et al., 2019), thereby strengthening the memory traces of high-value items. Thus, the superior recall performance for high-value items in the no-cue condition may not be entirely due to preferential attentional refreshing. Atkinson et al. (2022) also acknowledged that attentional refreshing only partially explains the probe value effect in working memory.

Moreover, although Atkinson et al. (2022) indirectly demonstrated that the value effect in working memory can be partially explained by attentional refreshing, their study could not address how the attentional refreshing advantage for high-value information is obtained. According to the time-based resource-sharing (TBRS) model, memory traces decay over time, and refreshing through attention can restore these decayed traces (Barrouillet & Camos, 2007). This model assumes that people reactivate memory traces by focusing attention on previous memory items, and the attentional focus can only concentrate on a single item at a time. Therefore, attentional refreshing is achieved by rapidly and frequently switching between processing and maintenance during task completion. Furthermore, researchers have suggested that the value effect in working memory may result from a biased attentional refreshing procedure, where during the maintenance phase, people may process more valuable items more frequently or for longer durations (Atkinson et al., 2018, 2021; Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014). However, no evidence currently supports this claim.

Recent studies using dot probe tasks and blank screen paradigms allow experimenters to measure value-directed attentional refreshing and its mechanism more directly. Attentional bias during refreshing can be reflected by inserting a dot probe task during memory maintenance (Yin et al., 2019). The rationale is that when attention is directed toward a location stored in working memory, processing of external stimuli presented at that location is enhanced (Awh et al., 1998). Therefore, participants' reaction times to dot probes inserted during the maintenance phase can reflect their attentional refreshing advantage for information corresponding to that location. Shorter reaction times indicate greater attentional refreshing advantage. If high-value information has an attentional refreshing advantage over low-value information, then dot probe reaction times at locations corresponding to high-value information should be significantly faster than those at locations corresponding to low-value information.

The blank screen paradigm uses eye movement data to describe individuals' internal attentional processes (Káldi & Babarczy, 2021). A common practice in this paradigm is to present a blank screen after visual stimuli and record participants' eye movements during this period. The underlying principle is that participants construct a mental representation of the visual scene during the encoding phase, and task-relevant items in this representation can still receive attention even in the absence of the visual scene. Thus, focal attention is reflected in fixation locations: participants fixate on screen areas previously marked by task-relevant items (Hoover & Richardson, 2008; Spivey & Geng, 2001; Theeuwes et al., 2009). Previous research has shown that attending to the region where an item was located can improve working memory performance for that item after the stimulus disappears (Kuo et al., 2012; Martarelli et al., 2007; Vankov, 2009). Eye movements measured on the blank screen are related to attention shifts to relevant memory items (Scholz et al., 2016). Therefore, attentional refreshing directs attention to the location area of items, causing eye movements toward corresponding spatial positions on the blank screen. If high-value information has an attentional refreshing advantage over low-value information, then eye movement metrics (such as fixation count, fixation duration, etc.) at locations corresponding to high-value information should show an advantage over those at locations corresponding to low-value information.

This paper aims to directly replicate and verify value-directed attentional refreshing and explore its mechanism through three experiments. Experiments 1 and 2 combine a value-directed memory paradigm with a dot probe task to verify whether high-value information can gain an advantage in attentional refreshing. Participants first memorized six letters simultaneously or sequentially, with each letter associated with a number indicating its value. During the memory maintenance phase, a dot probe task was inserted, with the probe stimulus randomly appearing at locations corresponding to high- or low-value items. If participants preferentially refreshed high-value information during attentional refreshing, their dot probe reaction times at locations corresponding to high-value items should be significantly faster than those at locations corresponding to low-value items. Experiment 3 combines a value-directed memory paradigm with a blank screen paradigm and uses eye-tracking technology to further explore the mechanism of value-directed attentional refreshing. Participants simultaneously memorized four shapes, each associated with a number indicating its value, followed by a blank screen. If participants refreshed high-value information more frequently during memory maintenance, their fixation counts at locations corresponding to high-value items should be significantly higher than those at locations corresponding to low-value items. If participants spent more time on high-value information during memory maintenance, their fixation durations at locations corresponding to high-value items should be significantly longer than those at locations corresponding to low-value items.

2. Experiment 1: Value-Directed Attentional Refreshing Under Simultaneous Presentation

2.1 Participants

Referring to previous related studies (Sandry & Ricker, 2020; Yin et al., 2019), we set the effect size to 0.5–0.8. To observe significant differences in dot probe reaction times ($\alpha = 0.05$, one-tailed, power = 0.95), a sample size of 19–45 participants was required. We recruited 25 participants in this experiment. One participant was excluded due to dot probe accuracy below 80%, leaving 24 valid participants (7 males, mean age = 18.92 ± 1.14 years). All participants volunteered for the experiment, were native Chinese speakers, had normal or corrected-to-normal vision, and had no physical or psychiatric disorders. Participants received 20 RMB as compensation after the experiment.

2.2 Materials, Design, and Procedure

The experiment was programmed using E-Prime with a default black background and run on a laptop computer with a 13-inch screen and resolution set to 1600 × 900 pixels. Memory materials consisted of 21 uppercase consonant letters (B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, X, Y, Z) paired with numbers 1 or 9 (connected by a hyphen), presented in white, 22-point Times New Roman font at the six vertices of a virtual regular hexagon centered on the screen (center distance = 495 pixels, visual angle = 7.55°). In each trial, participants memorized six items, with five items paired with value "1" and one item paired with value "9" .

[Figure 1: see original paper] Flowchart of Experiment 1

At the start of each trial, a fixation point appeared for 500 ms, followed by an articulatory suppression task requiring participants to continuously repeat "Fujian Normal University" until the dot probe task was completed. After a 500 ms interval, memory materials were presented, and participants were instructed to memorize all letters within 4000 ms. Each letter was associated with a number indicating its value. Subsequently, only a fixation point appeared for 3000–3700 ms, followed by a 300 ms square around the fixation point to alert participants that a dot probe task was imminent. In the dot probe task, participants had to judge whether two small dots presented on the screen were arranged vertically or horizontally within 1500 ms. They pressed "9" for vertical and "0" for horizontal, with key assignments counterbalanced across participants. The probability of vertical and horizontal dots was 50% each. The dots randomly appeared at one of the previous letter locations, with probe locations balanced across values. After the dot probe task, participants entered the recall phase, where they had to input the letters they remembered in six boxes presented on the screen within 12 s (numbers were not required). After input, participants received feedback on dot probe accuracy and recall score for that trial. At the end of each trial, participants placed their right index and middle fingers on the "9" and "0" keys and pressed the spacebar to proceed to the next trial. Each participant completed three blocks of 48 trials each, totaling 144 trials. Before the formal experiment, participants completed five practice trials with the same procedure to ensure familiarity with the task.

This experiment used a single-factor within-subjects design, with information value (low = 1, high = 9) as the independent variable and free recall accuracy and dot probe reaction time as dependent variables.

2.3 Results

Data were analyzed using JASP 0.16. For reaction time analysis, trials with dot probe errors (5.38% of total trials) and trials where the probed location was recalled incorrectly were first removed, followed by exclusion of outliers beyond three standard deviations (0.58% of total trials). Paired-samples t-tests revealed: (1) Memory performance for high-value items (83.50% $\pm$ 7.47%) was significantly better than for low-value items (54.35% $\pm$ 15.07%), $t(23) = 8.55$, $p < 0.001$, 95% CI = [0.22, 0.36], Cohen's $d = 1.75$, indicating the presence of value-directed memory in working memory; (2) Dot probe reaction times at locations corresponding to high-value items (770 ms $\pm$ 102 ms) were significantly faster than those at locations corresponding to low-value items (789 ms $\pm$ 117 ms), $t(23) = -2.41$, $p = 0.012$, 95% CI = [-34.50, -2.60], Cohen's $d = -0.49$, indicating that under simultaneous presentation conditions, attentional refreshing during the working memory maintenance phase is guided by value information.

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3. Experiment 2: Value-Directed Attentional Refreshing Under Sequential Presentation

3.1 Introduction

Experiment 1 confirmed the existence of value-directed attentional refreshing under simultaneous presentation conditions. However, because memory items were presented simultaneously in Experiment 1, several alternative explanations remain possible. First, during encoding, participants may have fixated longer on the locations of high-value items, creating a reactive attentional bias. Thus, the attentional advantage during maintenance might be location-driven rather than value-driven. Second, because memory items were presented simultaneously, participants might have adopted a strategy of starting encoding with high-value items and then sequentially encoding other items to maximize scores. Similarly, during free recall, participants might have prioritized recalling high-value items, leading to better memory performance for high-value items. To rule out these possibilities, Experiment 2 changed the presentation method so that items were presented one at a time, with each letter appearing for the same duration and randomly assigned to one of six locations.

3.2 Participants

Experiment 2 recruited 25 participants. Two participants were excluded due to dot probe accuracy below 80%, leaving 23 valid participants (7 males, mean age = 19.83 ± 1.80 years). All participants volunteered for the experiment, were native Chinese speakers, had normal or corrected-to-normal vision, and had no physical or psychiatric disorders. Participants received 20 RMB as compensation after the experiment.

3.3 Materials, Design, and Procedure

Except for the random, sequential presentation of memory items, the equipment, materials, and procedure were identical to Experiment 1. Each memory item was presented for 1000 ms, with a 250 ms interval between items. Additionally, to test whether smaller value differences could still produce value-directed attentional refreshing, the high and low values were set to "5" and "1", respectively. This experiment used a single-factor within-subjects design, with information value (low = 1, high = 5) as the independent variable and free recall accuracy and dot probe reaction time as dependent variables.

3.4 Results

Reaction time analysis excluded trials with dot probe errors (2.29% of total trials), trials where the probed location was recalled incorrectly, and outliers beyond three standard deviations (0.52% of total trials). Paired-samples t-tests revealed: (1) Memory performance for high-value items (79.41% ± 13.91%) was significantly better than for low-value items (48.71% ± 11.59%), $t(22) = 8.07$, $p < 0.001$, 95% CI = [0.23, 0.39], Cohen' s $d = 1.68$, indicating the presence of value-directed memory in working memory; (2) Dot probe reaction times at locations corresponding to high-value items (735 ms ± 110 ms) were significantly faster than those at locations corresponding to low-value items (751 ms ± 130 ms), $t(22) = -1.79$, $p = 0.044$, 95% CI = [-34.96, -2.58], Cohen' s $d = -0.37$, indicating that under sequential presentation conditions, attentional refreshing during the working memory maintenance phase is guided by value information.

4. Experiment 3: Mechanism of Value-Directed Attentional Refreshing

4.1 Introduction

Experiments 1 and 2 demonstrated that value-directed attentional refreshing occurs regardless of whether information is presented simultaneously or sequentially. Moreover, Experiment 2 proved that even when encoding time for high- and low-value information was identical, high-value information still received preferential refreshing during maintenance. How is this attentional refreshing advantage for high-value information achieved? According to the biased attentional refreshing procedure (Atkinson et al., 2018, 2021; Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014), value-directed attentional refreshing may be implemented in two ways: either by more frequently attending to the location of high-value information for refreshing, or by allocating more time to the location of high-value information for refreshing. Therefore, Experiment 3 used the blank screen paradigm combined with eye-tracking technology to explore this mechanism. When memory items disappear, attentional refreshing during maintenance reactivates location markers corresponding to the items, causing eye movements toward corresponding spatial positions on the blank screen. Thus, fixation counts within interest areas corresponding to different value information during the blank screen period can measure refresh frequency, and fixation duration per fixation can measure refresh time.

4.2 Participants

Experiment 3 recruited 25 participants. One participant was excluded due to missing eye-tracking data, leaving 24 valid participants (10 males, mean age = 21.00 ± 2.38 years). All participants volunteered for the experiment, were native Chinese speakers, had normal or corrected-to-normal vision, and had no physical or psychiatric disorders. Participants received 20 RMB as compensation after the experiment.

4.3 Materials, Design, and Procedure

The experiment was conducted on a 14-inch laptop with a screen resolution of 1600×900 pixels. Eye movements were recorded using an EyeLink Portable DUO eye tracker with a sampling rate of 500 Hz. Eye-tracking data were analyzed using Data Viewer 4.1.1 software. The distance between participants' eyes and the screen was approximately 70 cm.

Considering the operational requirements of the eye-tracking equipment and recall difficulty, Experiment 3 used shapes as memory materials and numbers as value indicators. Number materials consisted of black "1" and "6" in 80-point Times New Roman font, with three "1" s and one "6" randomly appearing at the four vertices of a virtual regular quadrilateral centered on the screen. Shape materials consisted of gray (R118, G113, B113) regular geometric shapes (equilateral triangle, isosceles trapezoid, parallelogram, square, regular pentagon) sized 122 × 122 pixels (visual angle = 1.96°), with four shapes randomly presented at the four vertices of a virtual regular quadrilateral (center distance = 311 pixels, visual angle = 4.98°). The recall cue material was a hollow circle. The recall test presented five shapes identical to the memory shapes, arranged horizontally on a white screen with 30-pixel intervals (visual angle = 0.48°).

[Figure 2: see original paper] Flowchart of Experiment 3

At the start of each trial, a fixation point appeared for 500 ms, followed by an articulatory suppression task requiring participants to repeat "Fujian Normal University" until the recall test. Then, four numbers appeared on the screen for 1000 ms, indicating the value scores of the shapes at those positions. After the numbers disappeared for 500 ms, an interface containing four shapes was presented. Participants had to memorize these shapes within 1500 ms. Subsequently, a blank screen appeared for 3000 ms, followed by a cue material for 1000 ms indicating which position' s shape needed to be recalled. Finally, five shape materials appeared on the screen, and participants had to select the shape matching the one at the cued position within 4000 ms. Each participant completed two blocks of 30 trials each, totaling 60 trials. Before the formal experiment, participants completed five practice trials to ensure familiarity with the procedure.

This experiment used a single-factor within-subjects design, with information value (low = 1, high = 6) as the independent variable and memory test accuracy, fixation count within interest areas, and fixation duration per fixation (total fixation time divided by fixation count) as dependent variables.

4.4 Results

Data were analyzed using JASP 0.16. The interest area for each shape was 170 × 170 pixels (visual angle = 2.73°). Trials with recall errors and fixations shorter than 100 ms (5.17% of total trials) were excluded. Paired-samples t-tests revealed: (1) Memory accuracy for high-value items (85.34% ± 12.52%) was significantly higher than for low-value items (73.33% ± 17.23%), $t(23) = 3.82$, $p < 0.001$, 95% CI = [0.06, 0.19], Cohen' s $d = 0.78$, indicating value-directed memory in working memory; (2) Fixation counts at locations corresponding to high-value items (0.32 ± 0.10 per trial) during the blank screen period were significantly higher than those at locations corresponding to low-value items (0.27 ± 0.08 per trial), $t(23) = 2.63$, $p = 0.007$, 95% CI = [0.01, 0.08], Cohen' s $d = 0.54$; (3) There was no significant difference in fixation duration per fixation between high-value (313 ms ± 102 ms) and low-value (332 ms ± 125 ms) item locations during the blank screen period, $t(23) = -1.55$, $p = 0.135$, 95% CI = [-44.04, 6.33], Cohen' s $d = -0.32$. Since $p > 0.05$ in null hypothesis significance testing does not support the null hypothesis, we conducted a Bayesian test on fixation duration to examine whether it supported the null hypothesis. The results showed $BF_{10} = 0.61$, which does not support the null hypothesis. These results suggest that value-directed attentional refreshing may be achieved by increasing the refresh frequency of high-value information.

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5. Discussion and Conclusion

This study manipulated information value through a value-directed memory paradigm and used dot probe tasks and the blank screen paradigm to directly verify value-directed attentional refreshing and explore its mechanism. Experiments 1 and 2 found that regardless of whether information was presented simultaneously or sequentially, participants' dot probe reaction times at locations corresponding to high-value items were significantly faster than those at locations corresponding to low-value items, indicating that high-value information received preferential refreshing during the working memory maintenance phase. Experiment 3 used eye-tracking technology under the blank screen paradigm to record participants' eye movements during the memory maintenance phase, finding that participants had higher refresh frequencies at locations corresponding to high-value items compared to low-value items, suggesting that value-directed attentional refreshing is primarily achieved by increasing the refresh frequency of high-value information.

5.1 Value-Directed Attentional Refreshing

Previous research has shown that people can prioritize more valuable information in working memory (e.g., Allen et al., 2020; Atkinson et al., 2019; Hitch et al., 2018; Hu et al., 2016). In a groundbreaking study, Atkinson et al. (2022) first demonstrated that attentional refreshing partially explains the value effect in working memory. Their experiment found that cues could improve recall accuracy for low-value or equal-value information but could not improve recall accuracy for high-value information. This may be because even without cues to guide refreshing, participants still spontaneously prioritized high-value information, rendering the cueing effect ineffective. This result indirectly proved that high-value information has an advantage in attentional refreshing.

Through three experiments combining reaction time and eye movement measures, this study more directly confirmed this value-directed attentional refreshing. Our results showed that participants responded faster when dot probe tasks appeared at locations corresponding to high-value information compared to low-value information, and fixation frequencies at high-value information locations were significantly higher than at low-value locations. In Atkinson et al.' s (2022) study, the conclusion that participants prioritized high-value items was based solely on the observation that high-value items had higher recall accuracy in the no-cue condition. However, higher recall accuracy for high-value items could also be partially due to participants allocating more attentional resources to high-value items during encoding. Therefore, they acknowledged that attentional refreshing could only partially explain their results. In contrast, our experiments explicitly probed the locations of high- and low-value items and found that high-value items had advantages in both response speed and refresh counts at corresponding locations, providing direct evidence for value-directed attentional refreshing.

Previous attentional refreshing research has focused on two aspects: first, the general pattern of attentional refreshing, where individuals prioritize weakly activated information when items are equivalent (Jafarpour et al., 2017; Lemaire et al., 2018; van Moorselaar et al., 2015); and second, the experience-priority pattern, where experience-related (reward or self) information has an advantage in attentional refreshing (Thomas et al., 2016; Yin et al., 2019). Prioritizing weakly activated items and prioritizing high-value items are not contradictory; both are efficient memory maintenance strategies that function under different circumstances. When memory items have minimal value differences, the optimal strategy for achieving the highest score is to remember as many items as possible. Since lower activation leads to forgetting, prioritizing weakly activated items is undoubtedly the optimal method for improving memory quantity. When memory items have clear value differences, the optimal strategy is to ensure remembering high-value items. Therefore, prioritizing weakly activated items and prioritizing high-value items complement each other, ensuring that people' s memory systems can maximize information storage.

Meanwhile, prioritizing high-value items is fundamentally different from prioritizing experience-related stimuli. Prioritizing high-value items is a goal-directed attentional refreshing strategy that is typically spontaneous and controllable, whereas prioritizing experience-related stimuli is an experience-driven attentional refreshing strategy that is mandatory and uncontrollable (Addleman & Jiang, 2019; Theeuwes, 2019). The combined effect of these two on memory may depend on whether the objects of attentional refreshing are consistent. On one hand, value-directed and experience-driven processes may work simultaneously during attentional refreshing, thereby enhancing memory effects. For example, personally relevant information is often assigned higher value by individuals and thus has a refreshing advantage. On the other hand, the two may compete during attentional refreshing, thereby weakening memory effects. For instance, when people are trying to control attention toward high-value stimuli, experience-related stimuli also compete for attentional resources through mandatory means, while low-value items lacking experience information ultimately become the sacrifice.

5.2 Mechanism of Value-Directed Attentional Refreshing

Although Atkinson et al. (2022) first indirectly confirmed value-directed attentional refreshing, their study could not explain how value-directed attentional refreshing is implemented: whether by more frequently refreshing more valuable items or by "thinking about" more valuable items for longer periods (Atkinson et al., 2018, 2021; Hitch et al., 2018; Hu et al., 2016; Sandry et al., 2014).

Our results showed that during the blank screen period in the memory maintenance phase, participants more frequently fixated on locations corresponding to high-value memory items rather than allocating more time per fixation. This indicates that value-directed attentional refreshing is achieved by more frequently attending to locations corresponding to high-value information. This mechanism aligns with computational models developed for TBRS that predict the relationship between information activation level and time. As is well known, memory retrieval depends on item activation level. Lower activation leads to greater forgetting, while higher activation increases the likelihood of priority selection and recall. Oberauer and Lewandowsky' s (2011) computational model found that information activation level changes logarithmically over time; that is, the higher the activation level, the faster its decay. Therefore, to maintain high activation levels of high-value items, individuals must frequently refresh high-value items to ensure their recall advantage.

Additionally, our results showed no significant difference in fixation duration per fixation between high- and low-value item locations, possibly indicating that value-directed attentional refreshing is not achieved by allocating more time to high-value information. We must interpret this result cautiously. Previous research suggests that attentional refreshing has two forms (Camos et al., 2018). One involves placing the attentional focus on an item to be refreshed and then "rapidly" shifting attention to other items. The other involves placing the attentional focus on an item to be refreshed and briefly dwelling on it. However, existing research and experimental paradigms cannot effectively separate these two forms. If participants adopt the first method more frequently, refresh frequency may be a good indicator of attentional refreshing; if they adopt the second method more frequently, fixation duration may be a better indicator. In Experiment 3, where participants were instructed to maximize value scores, they may have adopted a frequent attentional focus shifting strategy and performed more refreshing on high-value items.

5.3 Contributions, Limitations, and Future Directions

This study further enriches and expands attentional refreshing research and provides new evidence for how people prioritize information in daily life. As an internal mental process, prioritizing weakly activated items, experience-related information, and high-value information are all effective ways for individuals to maintain working memory, with no absolute superiority among them. Moreover, this study reveals the mechanism of value-directed attentional refreshing, which to some extent develops the TBRS model and helps people understand more deeply how processing time and attentional resources are shared to maintain memory representations during working memory processes. Understanding this mechanism also helps researchers develop new computational models to simulate people' s attentional refreshing processes.

This study has several limitations. First, although our results support that value-directed attentional refreshing may be achieved by increasing the refresh frequency of high-value information, we cannot completely rule out the mechanism of allocating more time to high-value information. This may be because our experiment tended to encourage participants to adopt a constant attentional focus shifting strategy, or because the time available for attentional refreshing was too short to detect this mechanism. Therefore, future research could manipulate experimental demands (e.g., maximizing total value vs. remembering as many high-value items as possible) to change participants' attentional refreshing strategies, or extend the time available for attentional refreshing, to further investigate whether value-directed attentional refreshing can be achieved through both increased refresh frequency and extended dwell time.

Second, the refresh frequency advantage for high-value over low-value items needs to be replicated across different experimental contexts. Although we found that high-value information had higher refresh frequency than low-value information, both high- and low-value information had relatively low refresh frequencies in Experiment 3. The main reason was that there were four memory items, but the interest area size was relatively small (visual angle = 2.73°), and the blank screen duration was short. Since shapes were not presented on the blank screen, participants had to refresh four items within 3 s, and their fixations could not precisely land in the item regions. Additionally, saccades between items consumed time, resulting in fewer fixations within interest areas. Another possibility is that participants may have refreshed the locations of value information implicitly without making eye movements (Scholz et al., 2018). Future research could use more complex shapes, expand interest areas, increase the visual angle between stimuli, and extend blank screen duration to allow participants' fixations to land more easily within picture interest areas, thereby further investigating attentional refresh frequency.

5.4 Conclusion

This study reached the following conclusions: (1) Regardless of whether information is presented simultaneously or sequentially, dot probe reaction times at locations corresponding to high-value items are faster than those at locations corresponding to low-value items, indicating that value information can guide attentional refreshing; (2) Participants have higher refresh frequencies at locations corresponding to high-value items than low-value items, indicating that value-directed attentional refreshing is primarily achieved by increasing the refresh frequency of high-value information.

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