The Effect of Distractor Location on (Un) Prioritized Working Memory

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Abstract

This thesis examined the effects of distractors and their locations on reaction time and errors in recalling prioritized versus unprioritized working memory items. Previous research agrees that prioritized items are recognized more quickly and accurately during working memory. However, there is debate about whether these items are protected from or vulnerable to distraction, with some suggesting that distractor location relative to the memory item might have differing effects. In this study, 25 participants completed a working memory recall task involving two gratings and two retro-cues. Distractors appeared either at the location as the target, away from it, on a different side, or not at all. Results showed that reaction time and errors were lower for prioritized items. Distractors at the target location or on a different side significantly impaired performance for prioritized items, but this was not the case for unprioritized items. Thus, prioritized items are more quickly and accurately recalled but are vulnerable to distraction with differing effects based on distractor location from unprioritized items.

Keywords: distraction, prioritization, visual working memory

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Introduction

After letting the guest memorize a set of cards, the magician lets the guest think about one of the cards. In this scene, the guest prioritizes an item (i.e., a card) from your working memory (i.e., the card set). Many studies compared the overall characteristics (e.g., reaction time, accuracy) of prioritized and unprioritized items in working memory. As resistance to distraction is vital for working memory (Lorenc et al., 2021), more and more studies have focused on the influence of distraction on prioritized items in working memory. Some studies even started to change the distractors (e.g., form, location) to see different effects of distraction on prioritized items and understand better the mechanism behind prioritization.

Prioritization and Unprioritization

Different studies have proved that prioritized items are quicker and more precisely activated than unprioritized items in working memory (Myers et al., 2017). Some studies (e.g., Hollingworth & Maxcey-Richard, 2013; Rerko et al., 2014; Schneider et al., 2017) showed that recognizing or recalling prioritized items is overall faster than recognizing or recalling unprioritized items. Schneider et al. proposed that prioritization initiates motor planning processes ahead of the probe stimulus, allowing for a quicker response. More studies (e.g., Gupta & Sridharan, 2023; Hautekiet et al., 2023; Hollingworth & Maxcey-Richard, 2013; Makovski & Pertzov, 2015; Rerko et al., 2014; Schneider et al., 2017; van Moorselaar et al., 2015) had found that participants had overall less error when recognizing or recalling prioritized items than when recognizing or recalling unprioritized items. Makovski and Pertzov (2015) showed that prioritization decreased swap errors (reporting a wrong item in memory) and guessing rates, indicating a more accurate and reliable memory performance.

When is Visual Working Memory Content Vulnerable to Distraction?

Most studies believe prioritization brings protection instead of vulnerability to memorized items when facing distraction. For example, in the van Moorselaar et al. (2015) study, participants made the same number of errors on prioritized items regardless of distractions while making significantly more errors with distractions than without distractions. Other studies (e.g., Makovski & Pertzov, 2015; Schneider et al., 2017) also had similar findings. Makovski and Jiang (2007) indicated that prioritization can filter out irrelevant input and determine what is encoded into visual working memory, so prioritized items are protected from distraction.

Mallett and Lewis-Peacock (2019) used different kinds of items (i.e., faces and scenes) in the memory array to differentiate the fMRI signal of prioritized and unprioritized items, which showed that the more a participant prioritized the cued item, the greater the influence of distraction. They proposed that the distraction task they implemented, which involved a change-detection task for an array of letters, may interfere with the neural decoding of memory representations (Mallett & Lewis-Peacock, 2019). Then, low-priority items were more successfully recovered due to enhanced neural separation between relevant and irrelevant information compared to high-priority items (Mallett & Lewis-Peacock, 2019). However, participants did not respond more accurately to prioritized data than unprioritized data (Mallett & Lewis-Peacock, 2019). Therefore, only neuroimaging and no behavior evidence show the vulnerability of periodized items.

Zhang and Lewis-Peacock (2023) suggested that protecting prioritized items may come from strengthening prefrontal control or prefrontal-sensory interactions during working memory maintenance. They found that prioritization protected working memories and reduced the occurrence of catastrophic loss (fewer "swap errors"), although it increased susceptibility to distortion (more significant attraction towards the distractor) (Zhang & Lewis-Peacock, 2023).

Zhang and Lewis-Peacock (2023) had two hypotheses for such a result. First, strong distractor signals may increase decoding noise, potentially resulting in swap errors when recalling memories that were not given priority (Zhang & Lewis-Peacock, 2023). However, prioritized memories may only be slightly altered, leading to subtle biases (Zhang & Lewis-Peacock, 2023). Second, Memory biases and swap errors are generated by unique mechanisms (Zhang & Lewis-Peacock, 2023). Biases may arise from degradation in item representation, while swap errors could be attributed to difficulties in binding items to context (Zhang & Lewis-Peacock, 2023). Overall, whether a prioritized item is vulnerable or protected depends on the distractor it faces.

Effect of Distractor Locations

The sensory recruitment theory of working memory proposes that the same neural regions process perceptual stimulus and maintain working memory content, and the similarity between memory items and distractors increases interference (Scimeca et al., 2018). Zhang and Lewis-Peacock (2023) indicated that the similarity between memories and distractors makes unprioritized items more likely to be distorted than prioritized items, which might suggest that prioritized items suffer more from a close distractor than unprioritized items. A study showed that a distractor on the same side as a probed item brought more error in recall than a distractor on the different side (Gupta & Sridharan, 2023). However, the errors in the study were the average of prioritized and unprioritized items' errors, so the difference in the effect of the distractor on prioritized and unprioritized items still lacks evidence.

Current Study

There was only some indirect evidence suggesting prioritized items are more sensitive to the location of distractors than unprioritized items, so this study focused on the difference in the effect of distractors on prioritized and unprioritized items. The current study's design was based on the experiment of Gupta and Sridharan (2023). However, Gupta and Sridharan (2023) only had three conditions for distractors: the same side as the probed item, the different side as the probed item, and no distractor. In this study, there would be four distraction conditions for both prioritized and unprioritized items: same location as the probed item, away from the probed item, different side as the probed item, and no distractor. This setting can help to distinguish whether the performance difference comes from different locations of distractors or merely their sides.

This study will focus on the following two questions. Firstly, do participants recalling prioritized items outperform unprioritized items? If responding to prioritized items is quicker and more accurate than responding to unprioritized items, it would show the overall benefit of prioritization. Secondly, are prioritized items more vulnerable or protected from distraction than unprioritized items? If prioritized items suffer more performance decrement from distraction than unprioritized items, it would show they are more vulnerable than unprioritized items. Lastly, are prioritized items more sensitive to distractors' location than unprioritized items? When facing distractors in different locations, if the performance difference of responding to prioritized items is higher than that of responding to unprioritized items, prioritized items are more sensitive to distractors' location than unprioritized items. According to the sensory recruitment theory of working memory, the similarity between memory items and distractors increases interference because the same neural regions process perceptual stimuli and maintain working memory content. Suppose a distractor closer to a prioritized item brings more distraction than the distractor far away from the prioritized item, and the same rule applies little or none to unprioritized items. In that case, it suggests that prioritized items in working memory are stored closer to the perceptual stimuli than unprioritized items.

Method

Participants

Twenty-five participants (18 females and seven males) with normal or corrected-to-normal vision were recruited to participate in the experiment. The research was conducted in adherence to the approved protocol of the Ethics Committee at the Faculty of Social and Behavioral Sciences of Utrecht University, and it complied with the Code of Ethics outlined by the World Medical Association's Declaration of Helsinki. Participants received remuneration at a rate of 8 euros per hour.

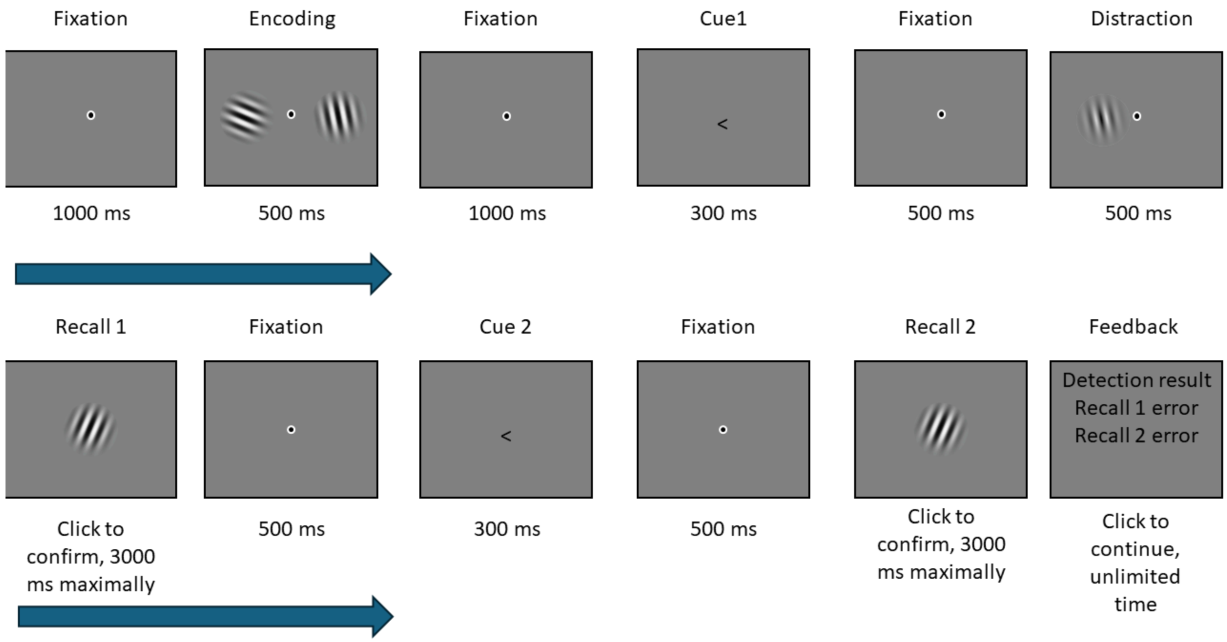
Protocol

Stimuli were displayed on a high-resolution LED monitor (Asus RoG Swift PG278Q, 27-inch, 2560 x 1440 resolution, 120 Hz refresh rate, with response times of 8.6 milliseconds for black-to-white transitions and 6.9 milliseconds for grey-to-grey transitions) using the PsychoPy (Peirce et al., 2019) software platform. Participants were positioned at a standard distance of 60 cm from the screen using a chinrest to minimize unnecessary head movements.

Each trial began with a fixation dot (black, radius = 0.25 dva) at the center of the screen for 1000 ms. The fixation dot was kept on the screen except when cues, recall probes, and feedback were shown. Then, two gratings (black and white, radius = 1.5 dva, spatial frequency = 2 cpdva) presented at left and right to the fixation dot (eccentricity = 6) for 500 ms. The orientations of two gratings were random, and participants needed to memorize the orientations. Then, the fixation dot showed for another 1000 ms. Next, there was the first cue on the center of the screen for 300 ms. "< "instructed participants to recall the left grating later, and">" instructed the participant to recall the right one later. After a 500 ms fixation, it was a 500 ms distraction period. There could be no distraction (33%) or a grating (black and white, radius = 1.5 dva, spatial frequency = 2 cpdva) distractor. The distractor flashed five times (50ms on and 50ms off), and each distractor had a random orientation. In 10% of trials, the first, third, and fifth distractors had 50% contrast, which ensured participants were moderately sensitive to low-contrast distractors and paid more attention to all distractors. In this case, participants were supposed to press the space bar. The distractor sequence could be located at one of the encoded items' positions (33%) or a random location on the orbit around one of the encoded items' positions (33%). The radius of the orbit was 4.5 dva. In the first recall, a grating (black and white, radius = 1.5 dva, spatial frequency = 2 cpdva) probe was on the center of the screen. Participants needed to move the mouse to make the probe's orientation match the cued grating's orientation. They could click the left mouse button to confirm, and this phase lasted maximally 3000ms. After another 500ms fixation, a second cue was shown. It was the same as the first cue but could cue the left or right grating. Then, there was another 500ms fixation and the second recall. The second recall was the same as the first, except that participants needed to recall according to the second cue. Lastly, there was feedback for the low contrast detection during the distraction and two recalls. Participants needed to click the left mouse button to enter the subsequent trial, and they could choose to rest during the feedback session. The procedure of one trial is shown in **Figure 1**. Participants had self-paced practice before the formal trials.

Figure 1

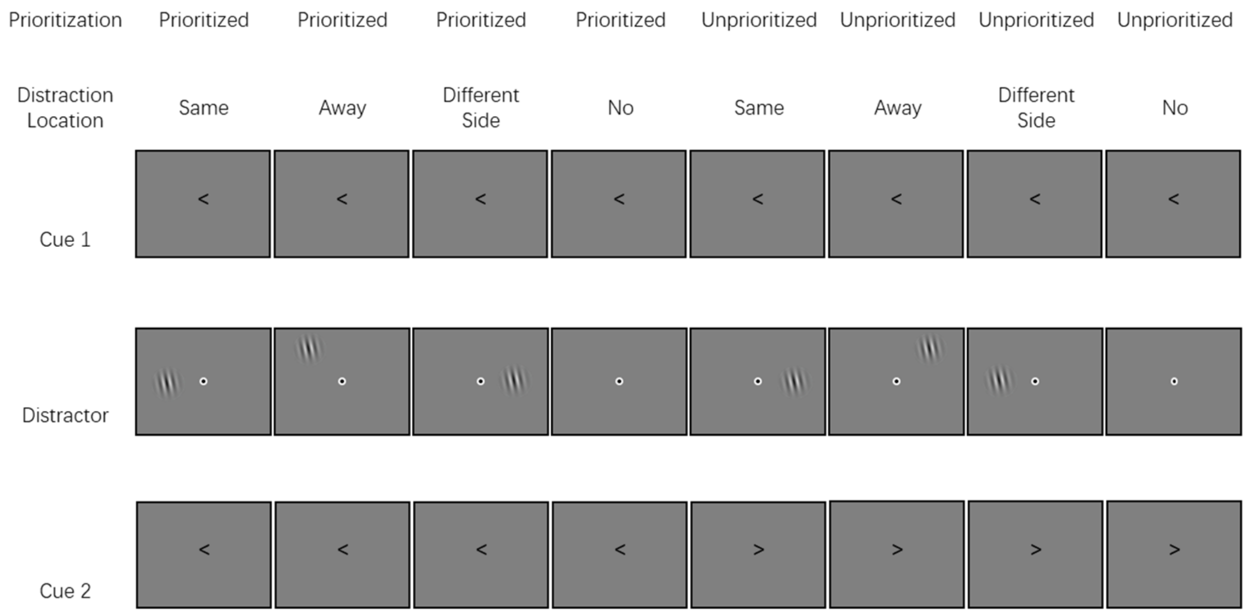
Experiment Paradigm



Each participant needed to accomplish 408 trials (i.e., a trial includes one distraction display and two recalls) in total. Among 408 trials, half of them (204) tested prioritized gratings in the second recall (two cues had the same direction), and another half (204) of them tested unprioritized gratings in the second recall (two cues had a different direction). Among 204 trials, 68 of them had no distractions, 34 of them had a distractor in the same location as the secondly cued grating, 34 of them had a distractor on the orbit around the secondly cued grating, and 68 of them had a distractor on the different side from the secondly cued grating. **Figure 2** illustrates the distraction and cueing of each condition.

Figure 2

Illustration of each condition's distraction and cueing



Results

Four of the 25 participants were excluded from the data set. Two participants were excluded because of their error of more than three conditions outlined. Another two were excluded since they failed to detect any low contrast distractor. The absolute values of the difference between the orientation of the probe and the target were calculated as errors. Every trial with a larger than 45-degree error was excluded. Trials with reaction times lower than 100ms or higher than 2000ms were also excluded.

Figure 3 shows the reaction time of recalling target items in each condition. The first two-way repeated measures ANOVA explored the effects of prioritization and distraction on reaction time. Descriptive statistics revealed that participants' mean response times were slightly faster when recalling prioritized items (mean = 949.79ms) than unprioritized items (mean = 982.28ms).

The ANOVA revealed that this difference was moderately significant (F (1,20) = 4.25, p = .052, η_p^2 = .175). Distraction had no significant main effect on participants' reaction time (F (2.583,51.653) = 1.247, p = .302, η_p^2 = .059). Participants performed similarly when distracted by the distractor on the same (mean = 965.39ms), away (mean = 979.25ms), different side (mean = 950.55ms) location, or no distractor (mean = 968.94ms). There was no significant interaction between prioritization and distraction (F (2.158,43.152) = .772, p = .478, η_p^2 = .037). Therefore, different distractions did not affect participants' reaction time differently when recalling prioritized and unprioritized items.

Figure 3

The reaction time of each condition

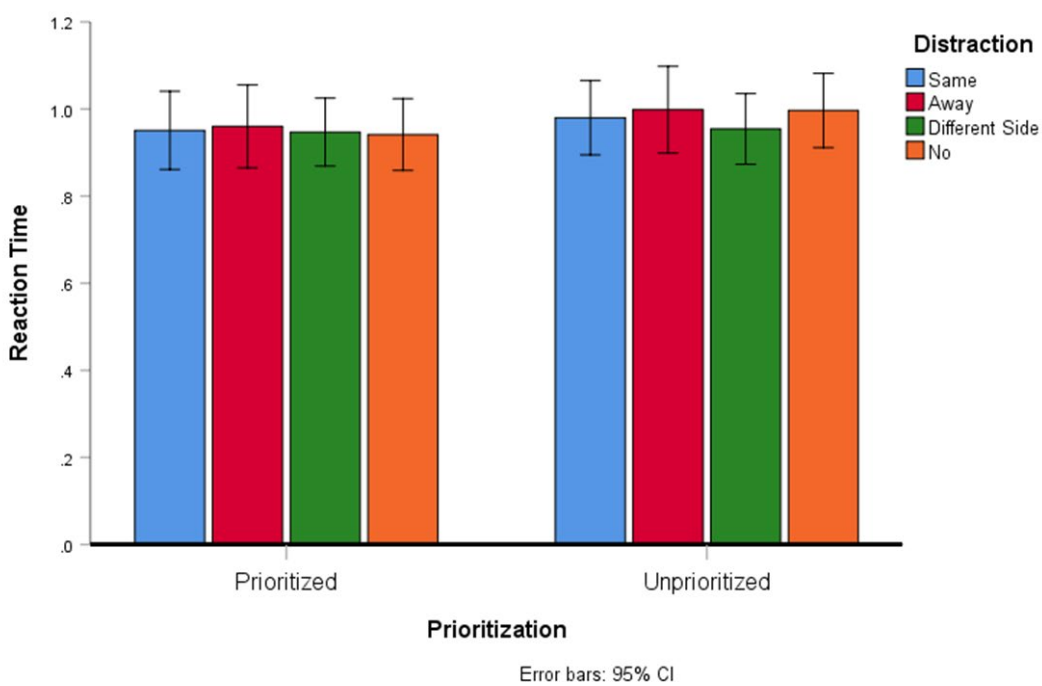
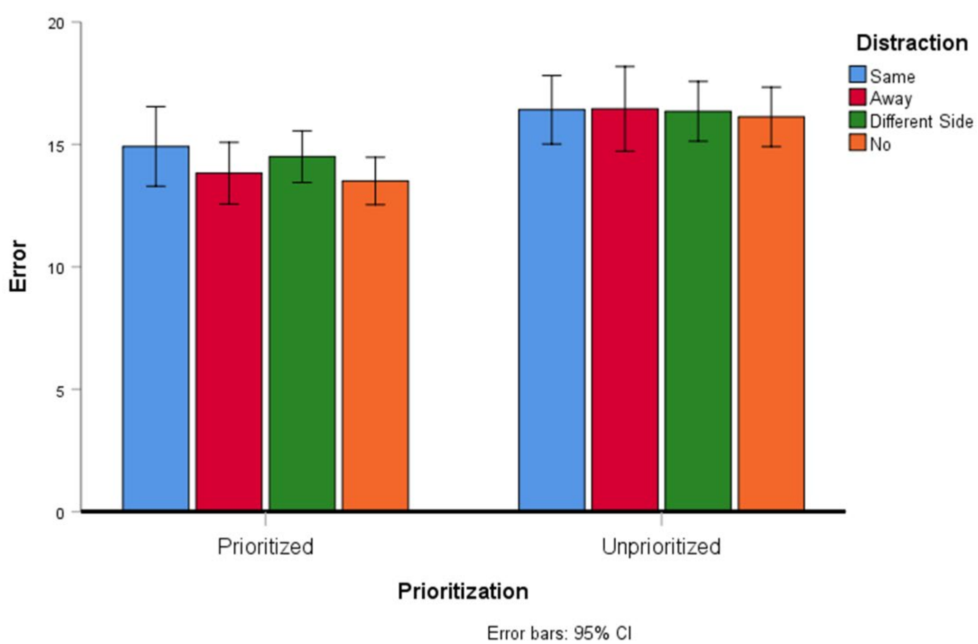


Figure 4 shows the error of recalling target items in each condition. Another two-way repeated measures ANOVA is about the effects of prioritization and distraction on error. There was a significant main effect of prioritization on participants' accuracy (F (1,20) = 39.765, $p < .001$, $\eta_p^2 = .665$). Participants recalled prioritized items (mean = 14.19 degrees) significantly more accurately than unprioritized items (mean = 16.34 degrees). The distraction had no significant main effect on participants' accuracy (F (3,60) = 1.559, $p = .209$, $\eta_p^2 = .072$) with distractor on the same (mean = 15.67 degrees), away (mean = 15.14 degree), different side (mean = 15.43 degree) location or no distractor (mean = 14.82 degrees) producing a similar amount of error. There was no significant interaction between prioritization and distraction (F (2.615,52.303) = .959, $p = .410$, $\eta_p^2 = .046$). This result suggests that different distractions affect prioritized and unprioritized items similarly.

Figure 4

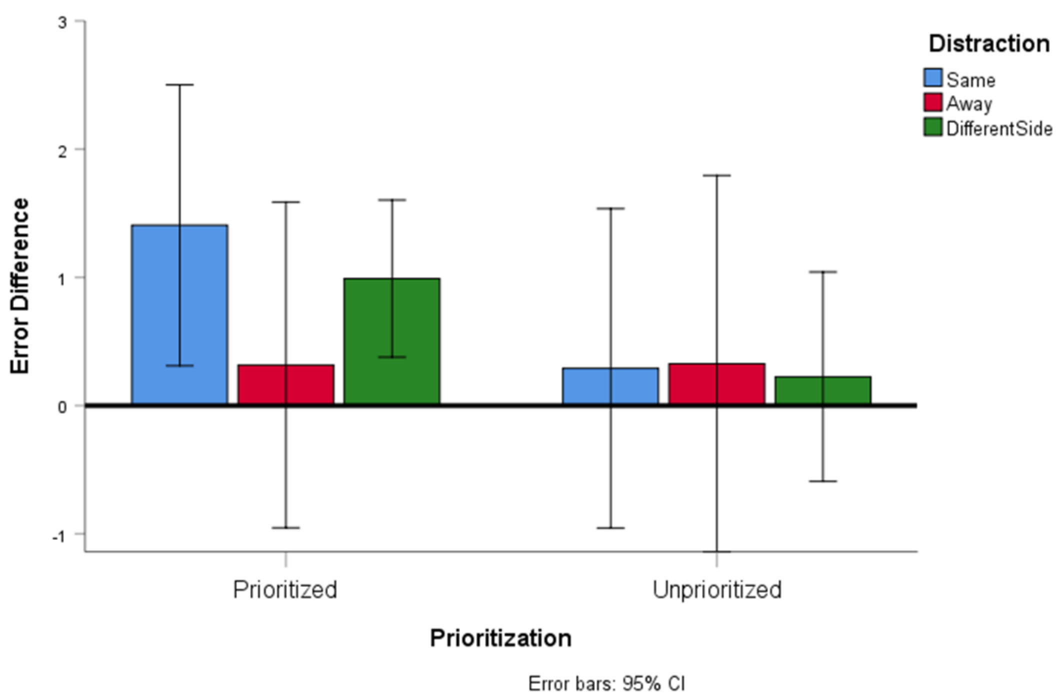
The error of each condition



The error difference is the error of a condition with distractors minus the error without distractors, shown in **Figure 5**. There were one-sample t-tests against 0 for each condition to check the distraction of each condition. For prioritized items, distractors in the same location (t (20) = 2.678, p = .014) and different sides (t (20) = 3.376, p = .003) brought significantly larger than 0 error difference, distractors in the away locations (t (20) = .52, p = .609) did not bring larger than 0 error difference. For unprioritized items, distractors in the same location (t (20) = .487, p = .631), distractors in the away locations (t (20) = .465, p = .647), and different side (t (20) = .576, p = .571). Hence, only distractors on the same or different side locations can distract prioritized items. Other conditions did not produce valid distractions.

Figure 5

The error difference of each condition



Discussion

Some may argue that this study had two retro cues and two recalls in the experiment, which differs from previous studies about prioritization in working memory. Every experiment comparing prioritized and unprioritized items in working memory needs two cues because there must be a second cue to instruct participants to recall the previously unprioritized items. However, two cues in the same experiment can have different forms, which makes the second cue unobvious. For example, in Zhang & Lewis-Peacock (2023), the first cue indicated the target's position and the second cue indicated the target's color. On the contrary, in this study and van Moorselaar et al. (2015), two cues had the same form. The experiment in this study had one more recall than other studies. The additional recall in this study is located between two cues, making sure participants prioritize the first target. After the first recall, participants did the same thing in this study as in other studies. That is, they stayed or changed their prioritization. In addition, only the second recall was considered in the result, and the first recall would not affect the result in this study. The biggest difference between one and two recall designs is that two recall designs increase the first cue's validity.

Since participants recalled prioritized items faster and more accurately than unprioritized items, this study shows the benefit of reaction time and accuracy brought by prioritization again. This result aligns with most of the previous studies. In addition, the results showed no interaction effect between prioritization and distractions on reaction time and error. Hence, the benefits of prioritization do not change as the distractor location changes or whether there is a distractor.

There is no interaction effect between distraction and prioritization on recall error. The t-tests showed that only distractors on the same or different side distract unprioritized items. Studies with retro cues seldom showed the vulnerability of prioritized items in working memory before. This difference may come from different forms of distractor. Zhang and Lewis-Peacock (2023) proposed that prioritized items are vulnerable to distortions while protected from swap errors. Low engagement distraction tasks (i.e., they require few actions) bring few swap errors but some distortions (Zhang & Lewis-Peacock, 2023). Studies (e.g., Makovski & Jiang, 2007; Schneider et al., 2017; van Moorselaar et al., 2015) showed the protection effect of prioritization, and they just displayed their distractors, which requires low engagement. The participants in this study also engaged in distraction low, but they needed to be more attentive to the distractor (i.e., detecting the contrast of the distractor). Therefore, participants' attention level on distractors may differ from the current results from the results of studies, which may be a new direction for future research.

The interaction effect between distraction and prioritization was not seen. However, prioritized items only had larger than 0 performance decrement when the distractors were in the same location or on different sides, while all kinds of distractors brought no larger than 0 performance decrement to unprioritized items. This may imply that the distractor's location played different roles in prioritized and unprioritized items. Besides, participants made more errors with same side distractors than with different side distractors in Gupta & Sridharan (2023), but this study did not have the same result. In this study, only distractors in the same location and different sides distract unprioritized items, and distractors in the away locations were closer to the targets than those on the different sides. Maybe participants inhibited the distractors close to the target but remained distractor located at the target's position and far away from the target activated. Future studies should have distractors in the same visual hemisphere with different distances to the target to validate this hypothesis.

In summary, participants performed better on recalling prioritized items than unprioritized items. Prioritized items were more vulnerable to distraction than unprioritized items. There are some different effects of distractor location on prioritized and unprioritized items.

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