Processing of Target-Matching Distractors in Visual Working Memory: Attentional Capture and Storage Benefit*

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Abstract

The capacity limitations of Visual Working Memory (VWM) require the cognitive system to possess efficient selection mechanisms. The traditional view holds that once distractors enter VWM storage, they inevitably lead to resource competition and impair target memory performance. However, whether this assumption holds when distractors carry target memory features (i.e., target-matching distractors) remains unclear. Using a lateralized VWM filtering paradigm, the present study examined the processing of target-matching distractors and their effects on behavioral performance through two EEG experiments. Experiment 1 found that when distractors were presented laterally, both the matching and partially matching conditions elicited significant N2pc (reflecting attentional capture) and CDA (reflecting VWM storage). Experiment 2 controlled presentation probability and did not support the possibility that this effect was driven by strategic processing, thereby verifying the robustness of the above effects: although matching distractors occupied storage resources (eliciting CDA), memory accuracy was not impaired and was instead significantly higher than in the mismatching condition. Taken together, the results indicate that target-matching distractors exhibit a distinctive processing pattern in VWM: they can capture attention and occupy storage resources, but they do not lead to a decline in target memory performance; rather, they provide a "gain" for target storage, facilitating target memory performance.

Full Text

Processing of Target-Matching Distractors in Visual Working Memory: Attentional Capture and Storage Benefit*

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Abstract Visual working memory (Visual Working Memory, VWM) is capacity-limited, requiring the cognitive system to possess efficient selection mechanisms. The traditional view holds that once distractors enter VWM storage, they inevitably lead to competition for resources and impair target memory performance. However, when distractors carry target memory features—that is, when they are target-matching distractors—whether this assumption holds remains unclear. In the present study, a lateralized VWM filtering paradigm was used to examine, through two EEG experiments, the processing of target-matching distractors and their influence on behavioral performance. Experiment 1 found that when distractors were presented laterally, both the matching and partially matching conditions elicited significant N2pc (reflecting attentional capture) and CDA (reflecting VWM storage). Experiment 2, by controlling presentation

probability, did not support the idea that this effect was driven by strategic processing, thereby verifying the robustness of the effects described above. Although matching distractors occupied storage resources (eliciting CDA), memory accuracy was not impaired; instead, it was significantly higher than in the non-matching condition. Taken together, the results indicate that target-matching distractors exhibit a distinctive processing pattern in VWM: they can capture attention and occupy storage resources, yet they do not reduce target memory performance; rather, they provide a "benefit" for target storage and promote memory performance for the target.

Keywords attention, visual working memory, selection mechanism

1 Introduction

Visual working memory (Visual Working Memory, VWM) is an important foundation of higher-level human cognitive processing (Baddeley, 2003). Because its capacity is extremely limited—approximately 3–4 chunks (Cowan, 2001; Luck & Vogel, 1997)—the cognitive system must possess efficient information-selection mechanisms to ensure that limited processing resources are not occupied by irrelevant information. However, in complex visual scenes, distractors often divert attention away from the target, causing distractors to be erroneously encoded into VWM and thereby impairing target performance (Lavie, 2005; Schmidt et al., 2002).

In classical theoretical models of VWM, distractors are typically regarded as factors that hinder target processing. Once distractors pass through selection mechanisms and enter VWM storage, they compete with target representations for limited cognitive resources, inevitably leading to mem-

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a decline in memory performance (Awh et al., 2006; Desimone & Duncan, 1995). Behavioral evidence indicates that the presentation of distractors during encoding significantly reduces memory performance, and that this interference effect increases as the number of distractors increases (McNab & Dolan, 2014). Using contralateral delay activity (CDA)—an ERP index reflecting VWM storage load (Vogel & Machizawa, 2004)—Vogel et al. (2005) found that low-capacity individuals elicited larger CDA amplitudes in the presence of distractors, indicating that they failed to filter out distractors effectively, causing distractors to be erroneously encoded into VWM (Vogel et al., 2005). The occupation of target storage resources by distractors is considered the direct cause of impaired memory performance (Fukuda & Vogel, 2009). Therefore, existing research holds

that, to achieve efficient processing of targets, the cognitive system must suppress distractors through a selective filtering mechanism, preventing them from occupying valuable cognitive resources (McNab & Klingberg, 2008).

However, the above conclusions regarding the "interference effect" are mainly based on target-mismatching distractors—that is, distractor items whose features are completely different from those of the targets. At present, few studies have examined the role of target-matching distractors—that is, distractor items consistent with the memorized target features—in VWM. Although research in the visual-search domain suggests that target-matching distractors have stronger attentional capture than mismatching distractors (Zhong et al., 2024), visual-search tasks emphasize target search at the perceptual level, which differs fundamentally in processing mechanisms from VWM, where the maintenance of internal representations is emphasized (Allen et al., 2017; Lavie, 2010). Therefore, conclusions from visual-search tasks cannot be directly generalized to VWM, and how target-matching distractors participate in and influence VWM processing remains to be empirically tested. Notably, although the study by Allen et al. (2017) included target-matching distractors in the stimulus materials, it did not independently analyze their role in the VWM task, instead combining them with mismatching distractors. This approach may have obscured the unique processing pattern of target-matching distractors, thereby leaving its conclusions still in support of the traditional view that "distractors lead to behavioral impairment" (Allen et al., 2017).

In sum, the present study aims to investigate the processing of target-matching distractors in VWM and their influence on target processing. This article adopts the lateralized VWM filtering paradigm developed by Feldmann-Wüstefeld and Vogel (2019). Through a unique spatial layout, this paradigm can, under conditions in which targets and distractors are presented simultaneously, independently extract ERP components including the posterior contralateral positivity (Ppc; previously termed EarlyPD by researchers and considered to reflect active suppression), which reflects the physical salience of stimuli; the N2pc, which reflects spatial attentional selection; and the CDA, which reflects VWM storage, thereby separating the cognitive processing of targets and distractors (Feldmann-Wüstefeld & Vogel, 2019). Based on this, the present article conducted two EEG experiments. Experiment 1 manipulated the number of matches between two distractors and two targets, setting up mismatching, partially matching, and matching conditions, to examine whether target-matching distractors (including the partially matching and matching conditions; the same below) can enter VWM through a selection mechanism and how they affect target memory performance. Given that, in Experiment 1, the probability of conditions containing target-matching distractors was relatively high (2/3), which might induce top-down strategic processing by participants, Experiment 2 further manipulated the presentation probability (high/low) of the mismatching and matching conditions to test the robustness of target-matching distractors in VWM processing and to reveal VWM

···provide further evidence for the selection and processing mechanisms of target-matching distractors.

2 Experiment 1: The Influence of Target-Matching Distractors on VWM Processing

2.1 Participants

G*Power 3.1 (Faul et al., 2009) was used to estimate the required sample size for this experiment. With the effect size set to medium, $f = 0.25$, the significance level set to $\alpha = 0.05$, and statistical power set to $1 - \beta = 0.80$, the minimum required sample size was calculated to be 28. Experiment 1 recruited 35 undergraduate students to participate, and they received compensation after the experiment. Seven participants were excluded because of excessive EEG artifacts, leaving 28 participants for the final statistical analyses, including 15 women. All participants were right-handed and were 18–26 years old ($M = 20.04$, $SD = 1.93$). All participants had normal or corrected-to-normal vision and had no color blindness or color weakness. This study was approved by the Ethics Committee of Sichuan Normal University, and informed consent was obtained from all participants before the experiment.

Labels in the flowchart: fixation point, 500–700 ms; stimulus array, 200 ms; mismatch; partial match; match; fixation point, 1000 ms; probe array, until response.

Figure 1. Flowchart of Experiment 1. The figure shows the three conditions in which the distractor was located in the lateral visual field; different stripe patterns in the stimuli indicate different colors, no stripes indicate gray, and identical stripe patterns indicate the same color.

2.2 Experimental Materials

All experimental stimuli were presented on a black background (RGB: 0, 0, 0). Following the experimental paradigm of Feldmann-Wüstefeld and Vogel (2019), geometric shapes composed of different colors were used as visual stimuli. Specifically, the target stimulus was a colored square with a visual angle of $0.9^\circ \times 0.9^\circ$, and the distractor stimulus was a colored circle with a diameter of 1°. The stimuli were presented at four locations 3.75° of visual angle from the center of the screen: to the left and right of the horizontal midline and above and below the vertical midline. The experiment adopted a lateralized presentation design. In each trial, the target stimulus and the distractor stimulus were presented on different axes: when the target

When the stimuli appeared on the horizontal midline, the distractor stimuli appeared on the vertical midline, and vice versa; the probability that targets and distractors appeared on the horizontal or vertical axis was equal. To balance perceptual input across the bilateral visual fields, gray circular neutral stimuli (RGB: 128, 128, 128) were always presented at positions centrally symmetric to

the colored targets and distractors. For example, when a target was located on the left, a gray circle was presented at the symmetric position on the right; if the distractor was located above, a gray circle was presented at the symmetric position below. Stimulus colors were selected from the following nine highly discriminable colors (RGB values): red [255, 0, 0], green [0, 255, 0], blue [0, 0, 255], yellow [255, 255, 0], magenta [255, 0, 255], cyan [0, 255, 255], dark green [20, 80, 20], purple [50, 0, 100], and orange [255, 128, 0].

2.3 Experimental Design and Procedure

The experimental program was written and run in PsychoPy 2022.2.5 (Peirce, 2007; Peirce et al., 2019). Stimuli were presented on a 24-inch monitor (resolution: 1920 × 1080; refresh rate: 60 Hz). EEG data were recorded during the experiment. Participants were instructed to maintain a comfortable seated posture and to minimize muscle activity and other physiological noise that could affect EEG signal acquisition.

The experiment used a single-factor within-subject design. The memory array always contained two targets (colored squares) and two distractors (colored circles). According to the number of color matches between distractors and targets, three experimental conditions were defined: a nonmatching condition (the colors of the two distractors were both different from the colors of the two targets in the current trial), a partially matching condition (the color of one distractor was the same as that of one of the targets, while the color of the other distractor differed from the targets), and a matching condition (the colors of the two distractors were respectively the same as the colors of the two targets). The three conditions were mixed and presented randomly in equal proportions. The experiment used lateralized presentation to separate the lateralized EEG activity elicited by targets and distractors. Specifically, in target-lateralized trials, the colored target stimuli were presented at the left and right horizontal positions, while the distractor stimuli were presented at the upper and lower vertical positions; in distractor-lateralized trials, the colored distractor stimuli were presented at the left and right horizontal positions, while the target stimuli were presented at the upper and lower vertical positions. By calculating the difference between contralateral and ipsilateral EEG activity (e.g., the Ppc [Early PD], N2pc, and CDA components), the cognitive processing of targets and distractors was dissociated (Feldmann-Wüstefeld & Vogel, 2019).

The procedure for a single trial is shown in Figure 1. At the beginning of each trial, a fixation point "+" was presented at the center of the screen (duration randomly varied between 500 and 700 ms). The memory array was then presented (200 ms), and participants were required to remember the colors of the targets while maintaining central fixation and ignoring the distractors. After the memory array disappeared, a retention interval followed (1000 ms). At the end of the retention interval, the probe array was presented, in which a probe color patch appeared at one of the target locations; the two target locations were probed with equal probability. Participants were asked to judge as quickly

as possible, while maintaining accuracy, whether the color at that location had changed. Color-change and no-change trials occurred randomly with equal probability. In change trials, the probe color was randomly selected from the preset color set and was not the same as the color of any colored stimulus in the memory array of the current trial. If the color had not changed, participants pressed the "F" key (left index finger); if it had changed, they pressed the "J" key (right index finger). After the keypress, the next trial began automatically. Before the formal experiment, participants were required to complete 16 practice trials with correctness feedback. Only when participants clearly understood the instructions,

Participants could proceed to the formal experiment only when their practice accuracy reached 70% or above; otherwise, they had to repeat the practice. The formal experiment comprised 1,152 trials, divided into 12 blocks, with short breaks allowed between blocks.

2.4 Data Analysis

All data were statistically analyzed using JASP 0.19.3.0. The significance level was set at $p < 0.05$, and post hoc tests were corrected using the Bonferroni method. In this article, statistical test results are annotated as follows: * indicates $p < 0.05$, ** indicates $p < 0.01$, and *** indicates $p < 0.001$. The 95% CI of the mean difference is reported.

For the behavioral results, participants' mean accuracy under each condition was calculated. For reaction-time analyses, only trials with correct responses in the formal experiment were retained. Trials with reaction times shorter than 200 ms or longer than 3000 ms were excluded, and trials exceeding ± 3 standard deviations from the mean of each condition were further removed. Statistical tests were conducted using one-way repeated-measures analyses of variance.

EEG data were collected using an ANT Neuro EEG system. According to the extended international 10–20 system, scalp potentials were recorded with a 64-channel electrode cap. The ground electrode was placed at AFz, and the online reference electrode was placed at FCz. An electrode was placed 1 cm lateral to the outer canthus of the left eye to record horizontal electrooculography (HEOG). The impedance of all electrodes was kept below 5 kΩ, and the sampling rate was 500 Hz. EEG data processing was based on MATLAB and was conducted offline using the EEGLAB and ERPLAB toolboxes (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014). The data-processing procedure was as follows: (1) except for the horizontal electrooculogram (HEOG) channel, all data were re-referenced to the algebraic average of the bilateral mastoids M1 and M2; a 0.1–30 Hz band-pass filter was then applied. (2) The onset of the memory array was set as time zero, and EEG epochs from −200 to 1200 ms were extracted, with the 200 ms before stimulus onset used for baseline correction. (3) The Peak-to-Peak Threshold procedure in ERPLAB was used to mark epochs in which the amplitude of any channel exceeded 100 μV, and the

Step-Like Artifacts procedure was used to identify epochs in which the amplitude of the HEOG channel exceeded 32 μV. These epochs, together with trials with incorrect responses, were excluded from ERP analyses. (4) Participants with fewer than 150 valid trials in any condition were excluded. Ultimately, 28 participants were included in the analysis, with a mean valid-trial rate of 90.4% ($SD = 11.16\%$). (5) For ERP analyses, three pairs of electrodes in the parieto-occipital region were selected (PO3/PO4, PO5/PO6, PO7/PO8). Difference waves were obtained by subtracting ipsilateral ERPs from contralateral ERPs relative to stimulus presentation (for example, when the target was presented in the left visual field, the right-hemisphere electrodes were contralateral). After averaging data across multiple electrode pairs, the mean amplitudes of different ERP components within their corresponding time windows were extracted separately (Gao Zaifeng et al., 2012), and one-way repeated-measures analyses of variance were conducted.

For the Ppc and N2pc components, which showed clear peaks, a jackknife-based method was used to compute the latency at 50% of the maximum amplitude (Kiesel et al., 2008). According to the formula proposed by Ulrich and Miller (2001), the t value was corrected by dividing it by $(N - 1)$, and the significance level was then calculated (Ulrich & Miller, 2001). The latency tests in the present study showed no significant differences among conditions. As a sustained contralateral negative slow wave, the time window of the CDA is usually determined in conjunction with prior research and the characteristics of the current waveform.

was determined. The core objective of this study was to analyze the processing of distractors in the VWM task; therefore, the setting of the CDA window was based primarily on the waveform under the distractor-lateralized condition. In the study by Feldmann-Wüstefeld and Vogel (2019), the onset time of the distractor-elicited CDAp was approximately 40–80 ms later than the latency for targets (Feldmann-Wüstefeld & Vogel, 2019). In the two experiments reported here, when distractors were lateralized, the CDA they elicited was also clearly later than that elicited by targets (a sustained negative wave appeared at approximately 600 ms after stimulus onset). Therefore, the time window in which distractors elicited a significant negative wave (600–900 ms) was defined as the statistical analysis window. Meanwhile, to compare the storage of targets and distractors within the same processing time course, the CDA elicited by target lateralization was also analyzed using the same time window.

2.5 Results of Experiment 1

2.5.1 Behavioral Results

The reaction-time results showed that the mismatch condition ($M = 670.82$ ms, $SD = 149.64$), the partial-match condition ($M = 668.67$ ms, $SD = 158.06$), and the match condition ($M = 670.34$ ms, $SD = 149.06$) did not differ significantly. A one-factor repeated-measures ANOVA found no significant difference

Figure 2. Accuracy in Experiment 1. The bar chart shows accuracy (%) for the mismatch, partial-match, and match conditions, with a significance marker between the mismatch and partial-match conditions.

Figure 1: Figure 2. Accuracy in Experiment 1. The bar chart shows accuracy (%) for the mismatch, partial-match, and match conditions, with a significance marker between the mismatch and partial-match conditions.

in reaction time among the conditions ($F(2, 54) = 0.16$, $p = 0.849$, $\eta_p^2 = 0.01$).

A one-factor repeated-measures ANOVA was used to test differences in accuracy among the three conditions. The results showed a significant main effect of condition ($F(2, 54) = 4.33$, $p = 0.018$, $\eta_p^2 = 0.14$). Paired t-tests showed that accuracy in the mismatch condition ($M = 0.86$, $SD = 0.07$) was significantly lower than in the partial-match condition ($M = 0.89$, $SD = 0.05$; $t(27) = -2.441$, $p = 0.021$, Cohen' s $d = -0.46$, 95% CI $[-0.06, -0.01]$); there was no significant difference between the mismatch condition and the match condition ($M = 0.87$, $SD = 0.06$) ($t(27) = -1.70$, $p = 0.100$); and there was also no significant difference between the partial-match condition and the match condition ($t(27) = 1.70$, $p = 0.100$) (Figure 2).

Figure 2. Accuracy in Experiment 1

Under the partial-match condition, the probe could fall into two potential conditions: "probe matching item" and "probe mismatching item,"

respectively corresponded, under the probe partial-match condition, to target items whose colors matched/did not match the matching distractor item. Paired-samples t tests showed that the accuracy for probe-matching items ($M = 0.91$, $SD = 0.06$) was significantly higher than that for probe-nonmatching items ($M = 0.87$, $SD = 0.06$; $t(27) = 3.00$, $p = 0.006$, Cohen' s $d = 0.57$, 95% CI [0.01, 0.07]). Further comparisons showed that, when the probe matched the item, accuracy in the partial-match condition was significantly higher than in both the nonmatch condition ($t(27) = 3.63$, $p = 0.001$, Cohen' s $d = 0.69$, 95% CI [0.02, 0.08]) and the match condition ($t(27) = 2.31$, $p = 0.029$, Cohen' s $d = 0.44$, 95% CI [0.004, 0.07]). Conversely, when the probe did not match the item, accuracy in the partial-match condition did not differ significantly from that in either the nonmatch condition or the match condition ($ps > 0.05$).

2.5.2 EEG Results

(1) Analysis of ERP Components Evoked by Lateral Presentation of the Target

Ppc (137-177 ms): One-sample t tests showed that all three conditions elicited a significant Ppc component: the nonmatch condition ($M = 0.52\,\mu$V, $SD = 0.54$, $t(27) = 5.13$, $p < 0.001$, Cohen' s $d = 0.97$); the partial-match condition ($M = 0.39\,\mu$V, $SD = 0.69$, $t(27) = 2.96$, $p = 0.006$, Cohen' s $d = 0.56$); and

Figure 3. Raw waveforms evoked by target-object lateralization (left) and distractor-object lateralization (right) in Experiment 1.

Figure 2: Figure 3. Raw waveforms evoked by target-object lateralization (left) and distractor-object lateralization (right) in Experiment 1.

the match condition ($M = 0.51\,\mu$V, $SD = 0.66$, $t(27) = 4.08$, $p < 0.001$, Cohen' s $d = 0.77$). A repeated-measures analysis of variance showed that the main effect of condition was not significant ($F(2, 54) = 0.98$, $p = 0.383$, $\eta_p^2 = 0.035$). (For the raw waveforms, see Figure 3; for the difference waves, see Figure 4; for the statistical results, see Figure 5.)

Figure 3. Raw waveforms evoked by target-object lateralization (left) and distractor-object lateralization (right) in Experiment 1.

N2pc (260–308 ms): One-sample t tests showed that the partial-match and match conditions elicited significant N2pc components. The nonmatch condition did not reach significance ($M = -0.17\,\mu$V, $SD = 0.75$, $t(27) = -1.23$, $p = 0.231$, Cohen' s d

$= -0.23$); partial-match condition ($M = -0.37\,\mu$V, $SD = 0.85$, $t(27) = -2.33$, $p = 0.028$, Cohen' s $d = -0.44$); match condition ($M = -0.34\,\mu$V, $SD = 0.84$, $t(27) = -2.17$, $p = 0.039$, Cohen' s $d = -0.41$). Repeated-measures analysis of variance showed that the main effect of condition was not significant ($F(2, 54) = 2.33$, $p = 0.107$, $\eta_p^2 = 0.08$).

CDA (600–900 ms): One-sample t-tests showed that all conditions elicited significant CDA components. Mismatch condition ($M = -1.20\,\mu$V, $SD = 0.76$, $t(27) = -8.38$, $p < 0.001$, Cohen' s $d = -1.58$); partial-match condition ($M = -1.10\,\mu$V, $SD = 0.81$, $t(27) = -7.19$, $p < 0.001$, Cohen' s $d = -1.36$); match condition ($M = -0.85\,\mu$V, $SD = 0.93$, $t(27) = -4.86$, $p < 0.001$, Cohen' s $d = -0.92$). Repeated-measures analysis of variance showed that the main effect of condition was significant ($F(2, 54) = 5.06$, $p = 0.010$, $\eta_p^2 = 0.16$). Post hoc tests found that the CDA amplitude in the match condition was smaller than that in the mismatch condition ($t(27) = 3.01$, Cohen' s $d = 0.41$, $p = 0.017$, 95% CI [0.05, 0.64]); there were no significant differences among the remaining conditions ($ps > 0.05$).

Target-lateralized

Difference wave (contralateral − ipsilateral), [μV]; time [ms].
Marked time windows: Ppc 137–177 ms; N2pc 260–308 ms; CDA 600–900 ms.
Legend: green = mismatch; blue = partial match; orange = complete match.

Distractor-lateralized

Difference wave (contralateral − ipsilateral), [μV]; time [ms].
Marked time windows: Ppc 134–173 ms; N2pc 256–297 ms; CDA 600–900 ms.
Legend: green = mismatch; blue = partial match; orange = complete match.

Figure 4. Difference waveforms elicited by target lateralization and distractor lateralization in Experiment 1

(2) **Analysis of ERP components elicited by distractor-lateralized presentation**

Ppc (134-173 ms): One-sample t-tests showed that, in the match condition ($M = 0.32\,\mu$V, $SD = 0.66$, $t(27) = 2.58$,

$p = 0.016$, Cohen' s $d = 0.49$) elicited a significant Ppc component, whereas the mismatch condition ($M = 0.14\,\mu$V, $SD = 0.46$, $t(27) = 1.65$, $p = 0.111$, Cohen' s $d = 0.31$) and the partial-match condition ($M = 0.18\,\mu$V, $SD = 0.70$, $t(27) = 1.38$, $p = 0.180$, Cohen' s $d = 0.26$) did not reach significance. The repeated-measures analysis of variance showed that the main effect of condition was not significant ($F(2, 54) = 1.07$, $p = 0.351$, $\eta_p^2 = 0.04$).

N2pc (256-297 ms): One-sample t tests showed that both the partial-match and match conditions elicited a significant N2pc. Partial-match condition ($M = -0.44\,\mu$V, $SD = 0.76$, $t(27) = -3.09$, $p = 0.005$, Cohen' s $d = -0.58$); match condition ($M = -0.47\,\mu$V, $SD = 0.83$, $t(27) = -3.01$, $p = 0.006$, Cohen' s $d = -0.58$); the mismatch condition did not elicit a significant N2pc ($M = -0.002\,\mu$V, $SD = 0.66$, $t(27) = -0.01$, $p = 0.999$, Cohen' s $d = 0.002$). The repeated-measures analysis of variance showed a significant main effect of condition ($F(2, 54) = 10.85$, $p < 0.001$, $\eta_p^2 = 0.29$); post hoc tests showed that the N2pc amplitude elicited by the mismatch condition was significantly lower than that in the partial-match condition ($t(27) = 4.07$, $p = 0.001$, Cohen' s $d = 0.59$, 95% CI $[0.16, 0.72]$) and the match condition ($t(27) = 4.22$, $p < 0.001$, Cohen' s $d = 0.62$, 95% CI $[0.19, 0.75]$); there was no significant difference between the partial-match and match conditions ($p > 0.99$).

Figure panels: Ppc (137-177 ms), N2pc (260-308 ms), CDA (600-900 ms); Ppc (134-173 ms), N2pc (256-297 ms), CDA (600-900 ms). The y-axis is amplitude (μV); the conditions are mismatch, partial match, and match.

Figure 5. Statistical test plots for each ERP component in Experiment 1 (upper panels: target lateralization; lower panels: distractor lateralization)

CDA (600-900 ms): One-sample t tests showed that the mismatch condition did not elicit a significant CDA ($M = -0.10\,\mu$V, $SD = 0.33$, $t(27) = -1.59$, $p = 0.125$, Cohen' s $d = -0.30$); whereas the partial-match condition ($M = -0.39\,\mu$V,

$SD = 0.46$, $t(27) = -4.55$, $p < 0.001$, Cohen' s $d = -0.86$) and the matching condition ($M = -0.50\mu V$, $SD = 0.54$, $t(27) = -4.87$, $p < 0.001$, Cohen' s $d = -0.92$) both elicited significant CDA. A repeated-measures analysis of variance showed a significant main effect of condition ($F(2, 54) = 7.05$, $p = 0.002$, $\eta_p^2 = 0.21$). Post hoc tests showed that the CDA amplitude in the nonmatching condition was significantly lower than that in the partial-matching condition ($t(27) = 2.89$, $p = 0.022$, Cohen' s $d = 0.65$, 95% CI $[0.04, 0.55]$) and the matching condition ($t(27) = 3.32$, $p = 0.008$, Cohen' s $d = 0.89$, 95% CI

[0.09, 0.71]); there was no significant difference between the partial-matching and matching conditions ($t(27) = 1.00$, $p = 0.986$, Cohen' s $d = 0.24$, 95% CI $[-0.17, 0.39]$).

2.6 Discussion of Experiment 1

Experiment 1 used a lateralized VWM filtering paradigm capable of dissociating neural activity elicited by targets and distractors, with the aim of investigating the processing mechanism of target-matching distractors in VWM and their influence on memory performance. The results showed that, compared with nonmatching distractors, target-matching distractors elicited stronger activity related to attentional selection and a sustained negativity during the maintenance period. However, contrary to the predictions of the traditional resource-competition view, target-matching distractors did not lead to impaired behavioral performance. Instead, in the partial-matching condition, participants'memory performance was significantly higher than in the nonmatching condition.

First, the ERP results revealed that target-matching distractors captured attention and entered VWM. When distractors were presented laterally, the ERP in the early time window showed a positive activity, the Ppc (an ERP component regarded as reflecting stimulus salience) (Fortier-Gauthier et al., 2012), suggesting that early perceptual registration was completed at this stage. Subsequently, nonmatching distractors did not elicit N2pc or CDA, indicating that they did not receive further attentional allocation or cognitive processing. After completing early perceptual registration, target-matching distractors (in both the partial-matching and matching conditions) immediately elicited a significant N2pc component. N2pc is generally taken to mark the spatial selection and capture of attention (Luck & Hillyard, 1994a, 1994b). This result indicates that although the shape of the matching distractors did not meet the task requirements, because they carried the target' s memory feature (color), they captured attention as potential targets.

More importantly, target-matching distractors elicited significant CDA. By contrast, nonmatching distractors did not elicit reliable CDA. Because CDA is typically associated with sustained maintenance processing in VWM, this result suggests that, after being selected by attention, target-matching distractors further entered the processing stage related to VWM maintenance. In other words, nonmatching distractors were not further processed after early perceptual registration, whereas target-matching distractors, because they carried a target-defining feature, received attentional selection and further entered the stage of representational maintenance. At the same time, under the target-lateralized condition, the CDA elicited in the matching condition was significantly lower than that in the nonmatching condition. This result indicates that when distractors shared the color feature with the targets, target-related maintenance activity changed. This "one waxes as the other wanes" phenomenon suggests that the storage of target-matching distractors occupied cognitive resources used for processing the targets. According to existing slot models or flexible-resource

models of VWM (Bays & Husain, 2008; Fukuda et al., 2010; Luck & Vogel, 1997; Vogel et al., 2005), this occupation of resources should lead to a decrease in accuracy.

However, the behavioral results did not support the predictions of the traditional view. There was no significant difference in accuracy between the matching and nonmatching conditions, and the value was slightly higher in the matching condition than in the nonmatching condition (0.87 vs. 0.86). More importantly, accuracy in the partial-matching condition was significantly higher than in the nonmatching condition. This indicates that although target-matching distractors received attentional selection and sustained processing, they did not impair target memory performance in the way traditionally assumed for irrelevant distractors. Further analysis of the partial-matching condition provided more direct evidence for this interpretation. In this condition, only one target had the same color as the distractor; therefore, it was possible to distinguish probe-matching items from probe-nonmatching items. The results showed that accuracy for probe-matching items was significantly higher than that for probe-nonmatching items. When the probed item was a matching item, accuracy in the partial-matching condition was significantly higher than in both the nonmatching and matching conditions; whereas when the probed item was a nonmatching item, there was no significant difference between the partial-matching condition and the other conditions. This result suggests that the behavioral advantage in the partial-matching condition mainly came from the target item that shared its color with the distractor, rather than from an overall improvement across all targets.

This finding suggests that target–distractor color matching may provide a processing benefit for specific target items. Specifically, a matching distractor may enhance the representational strength of that color during encoding by matching a target' s color feature, or provide additional feature cues for target judgment during the maintenance/retrieval stage. Thus, when the probed item was the target whose color matched the distractor, participants showed higher accuracy. It should be noted that this result cannot directly prove that a matching distractor "promoted" target storage, but it indicates that after entering the processing system, a matching distractor does not necessarily produce resource-competition-related impairment; instead, it may engage in functionally more complex interactions with target representations.

In summary, Experiment 1 demonstrated that, relative to nonmatching distractors, target-matching distractors have a processing advantage. In the VWM filtering task, nonmatching distractors did not elicit reliable N2pc or CDA, indicating that they did not receive processing related to attentional selection and memory encoding; by contrast, matching distractors elicited significant N2pc and CDA, indicating that they received further processing because they carried target-relevant color features. Contrary to the traditional view that distractors impair target memory, Experiment 1 found that target-matching distractors entered VWM and did not lead to a decline in target performance; instead,

under the partial-matching condition, they showed a potential facilitatory effect on target items sharing the same color feature. Nevertheless, Experiment 1 still had potential confounding factors. Because trials containing a matching feature (the matching and partial-matching conditions) accounted for 2/3 of all trials, participants may have developed a strategic processing tendency—namely, expecting the distractor color to be task-relevant and therefore preferentially attending to color-matching items rather than to targets. To rule out the potential influence of such strategic factors and to directly compare processing differences between matching and nonmatching distractors, Experiment 2 removed the partial-matching condition. On this basis, by manipulating the presentation probabilities of the two distractor types, it examined whether the processing advantage for matching distractors observed in Experiment 1 could emerge stably when probability expectation was controlled.

3 Experiment 2: Effects of the Presentation Probability of Target-Matching Distractors on VWM Processing

3.1 Participants

According to G*Power 3.1, with a medium effect size set at $f = 0.25$, $\alpha = 0.05$, and $1 - \beta = 0.80$, the calculated minimum required sample size was 24. Experiment 2 recruited 28 university student volunteers. The experiment was conducted in two stages; each formal experimental session lasted approximately 50 minutes, and the interval between the two sessions was no less than 48 hours. Participants received compensation after completing the experiment. During statistical analysis, data from 4 participants were excluded (because of excessive EEG artifacts or failure to participate in the second session), leaving 24 participants (14 female) for the final analysis. All participants were right-handed, aged 18–26 years ($M = 20.25$, $SD = 1.92$), had normal or corrected-to-normal vision, and had no color blindness or color weakness. This experiment was approved by the Ethics Committee of Sichuan Normal University, and informed consent was obtained from all participants.

3.2 Experimental Design and Procedure

Experiment 2 used the same experimental materials as Experiment 1. The "partial match" condition from Experiment 1 was removed, and a 2 (distractor type: match/nonmatch) × 2 (presentation probability: high/low) within-subject design was adopted. The experiment was conducted in two sessions; in each session, participants completed one set of condition combinations ("nonmatch-high probability" and "match-low probability condition" ; "nonmatch-low probability" and "match-high probability condition"). The experimental order was counterbalanced across participants. Each set contained 960 trials, including 672 trials in the high-probability condition (70%) and 288 trials in the low-probability condition (30%); conditions were randomly intermixed within each set.

3.3 Data Analysis

Participants' reaction times and accuracy rates were calculated for each experimental condition. ERP components were computed as the mean amplitude within predefined time windows, and statistical tests were performed using two-factor repeated-measures analyses of variance. During ERP data preprocessing, trials with incorrect behavioral responses and trials with excessive artifacts were excluded. Data from any participant with fewer than 150 valid trials in any condition were excluded. The final analysis included 24 participants, with a mean valid-trial rate of 86.0% (SD = 10.74%). In Experiment 2, because the target-lateralized N2pc component did not show a clear independent peak, half-peak latency measurement was not applicable. For components that are sustained or lack a clear peak, mean amplitude is typically more robust than peak value or half-peak latency; the time window can be determined based on prior research and the grand-average waveform (Luck, 2014). Therefore, for the target-lateralized N2pc in Experiment 2, 250–320 ms was used as the analysis window for mean amplitude, whereas 240–320 ms was used as the analysis time window for the distractor-lateralized component. All other statistical analysis procedures were kept consistent with Experiment 1.

3.4 Results of Experiment 2

3.4.1 Behavioral Results The reaction-time results showed that the nonmatch–high probability condition had M = 664.13 ms, SD = 165.04; the match–high probability condition had M = 672.89 ms, SD = 157.62; the match–low probability condition had M = 660.90 ms, SD = 167.08; and the nonmatch–low probability condition had M = 677.24 ms, SD = 155.28. A two-factor repeated-measures analysis of variance found that distractor type

The main effect of distractor type, the main effect of probability, and the interaction between distractor type and probability were all nonsignificant, $ps > 0.05$.

Figure 6. Accuracy in Experiment 2
*Visible plot labels: y-axis, "Accuracy (%)" ; x-axis, "Mismatch" and "Match" ; legend, "High probability" and "Low probability" ; significance marker, "**" .**

Descriptive statistics for accuracy under each condition showed the following: mismatch–high-probability condition (M = 0.88, SD = 0.08), match–high-probability condition (M = 0.91, SD = 0.06), match–low-probability condition (M = 0.92, SD = 0.07), and mismatch–low-probability condition (M = 0.88, SD = 0.08). A repeated-measures ANOVA revealed a significant main effect of distractor type, $F(1, 23) = 15.16$, $p < 0.001$, $\eta_p^2 = 0.40$ (Figure 6). Further comparisons showed that accuracy in the mismatch condition (M = 0.88, SD = 0.08) was significantly lower than that in the match condition (M = 0.91, SD = 0.06), $t(23) = -3.89$, $p < 0.001$, Cohen's $d = -0.47$, 95%CI[−0.05, −0.02]. The main effect of probability and the interaction were both nonsignificant, $ps > 0.05$.

3.4.2 EEG Results

(1) Analysis of ERP components elicited by lateralized target presentation

Ppc (146–178 ms): One-sample t tests showed that significant Ppc components were elicited in the mismatch-high-probability condition ($M = 0.36\mu$V, $SD = 0.53$, $t(23) = 3.31$, $p = 0.003$, Cohen' s $d = 0.68$), the match-high-probability condition ($M = 0.48\mu$V, $SD = 0.55$, $t(23) = 4.28$, $p < 0.001$, Cohen's $d = 0.87$), and the mismatch-low-probability condition ($M = 0.32\mu$V, $SD = 0.57$, $t(23) = 2.75$, $p = 0.011$, Cohen' s $d = 0.56$). The match-low-probability condition ($M = 0.29\mu$V, $SD = 0.74$, $t(23) = 1.92$, $p = 0.067$, Cohen' s $d = 0.39$) elicited a marginally significant Ppc. A repeated-measures ANOVA showed that the main effect of probability was nonsignificant, $F(1, 23) = 2.33$, $p = 0.141$, $\eta_p^2 = 0.09$; the main effect of distractor type was nonsignificant, $F(1, 23) = 0.39$, $p = 0.541$, $\eta_p^2 = 0.02$; and the interaction was nonsignificant, $F(1, 23) = 0.94$, $p = 0.343$, $\eta_p^2 = 0.04$. (For the original waveforms, see Figure 7; for the difference waves, see Figure 8; for the statistical results, see Figure 9.)

N2pc (250–320 ms): One-sample t-tests showed that significant N2pc was elicited in the mismatch-high-probability condition ($M = -0.31\,\mu$V, $SD = 0.72$, $t(23) = -2.08$, $p = 0.048$, Cohen' s $d = -0.43$), the match-high-probability condition ($M = -0.31\,\mu$V, $SD = 0.69$, $t(23) = -2.18$, $p = 0.040$, Cohen' s $d = -0.44$), and the match-low-probability condition ($M = -0.65\,\mu$V, $SD = 0.75$, $t(23) = -4.24$, $p < 0.001$, Cohen' s $d = -0.87$). The N2pc elicited in the mismatch-low-probability condition ($M = -0.24\,\mu$V, $SD = 0.79$, $t(23) = -1.47$, $p = 0.160$, Cohen' s $d = -0.30$) was not significant. Repeated-measures analysis of variance showed that the main effect of probability was not significant ($F(1, 23) = 3.03$, $p = 0.095$, $\eta_p^2 = 0.12$); the main effect of distractor type was significant ($F(1, 23) = 6.09$, $p = 0.021$, $\eta_p^2 = 0.21$); and the interaction was significant, $F(1, 23) = 4.64$, $p = 0.042$, $\eta_p^2 = 0.17$. Simple-effects analysis found that the match-low-probability condition elicited an N2pc with a larger amplitude than the match-high-probability condition, $\Delta M = -0.34\,\mu$V, $t(23) = -2.98$, $p = 0.007$, 95% CI $[-0.57, -0.10]$.

Figure 7. Raw waveforms elicited by the target-object lateral side (left) and the distractor-object lateral side (right) in Experiment 2.

Figure labels: target lateral side; distractor lateral side; mismatch-high probability; match-low probability; mismatch-low probability; match-high probability; contralateral; ipsilateral; Amplitude (μV); Times (ms).

CDA (600–900 ms): Single-sample t tests showed that all conditions elicited a significant CDA: mismatch-high-probability condition ($M = -1.16\ \mu$V, $SD = 1.09$, $t(23) = -5.24$, $p < 0.001$, Cohen' s $d = -1.07$); match-high-probability condition ($M = -1.07\ \mu$V, $SD = 0.86$, $t(23) = -6.09$, $p < 0.001$, Cohen' s $d = -1.24$); mismatch-low-probability condition ($M = -1.08\ \mu$V, $SD = 0.84$, $t(23) = -6.26$, $p < 0.001$, Cohen' s $d = -1.28$); match-low-probability condition ($M = -1.14\ \mu$V, $SD = 0.99$, $t(23) =$

-5.61, $p < 0.001$, Cohen' s $d = -1.15$). Repeated-measures analysis of variance showed that the main effect of probability was not significant, $F(1, 23) = 0.01$, $p = 0.927$, $\eta_p^2 < 0.001$; the main effect of distractor type was not significant, $F(1, 23) = 0.03$, $p = 0.863$, $\eta_p^2 = 0.001$; and the interaction was not significant, $F(1, 23) = 0.25$, $p = 0.622$, $\eta_p^2 = 0.01$.

[Figure labels: target lateralization; difference wave (contralateral − ipsilateral); [μV]; [ms]; Ppc 146-178; N2pc 250-320; CDA 600-900; distractor lateralization; difference wave (contralateral − ipsilateral); Ppc 134-174; N2pc 240-320; CDA 600-900. Legend: mismatch-high probability; match-low probability; mismatch-low probability; match-high probability.]

Figure 8. Difference waveforms elicited by target lateralization and distractor lateralization in Experiment 2

(2) Analysis of ERP components elicited by distractor lateralization

Ppc (134-174 ms): Single-sample t tests showed that the mismatch-high-probability condition ($M = 0.43$ μV, $SD = 0.51$, $t(23) = 4.16$, $p < 0.001$, Cohen' s $d = 0.85$), and the match-high-probability condition ($M = 0.30$ μV, $SD = 0.46$, $t(23) = 3.19$,

$p = 0.004$, Cohen' s $d = 0.65$), and the mismatch-low-probability condition ($M = 0.35\mu$V, $SD = 0.80$, $t(23) = 2.12$, $p = 0.045$, Cohen' s $d = 0.43$) both elicited a significant Ppc, whereas the Ppc elicited by the match-low-probability condition ($M = 0.24\mu$V, $SD = 0.69$, $t(23) = 1.70$, $p = 0.102$, Cohen' s $d = 0.35$) was not significant. The repeated-measures ANOVA showed that the main effect of probability was not significant, $F(1, 23) = 0.45$, $p = 0.519$, $\eta_p^2 = 0.019$; the main effect of distractor type was not significant, $F(1, 23) = 2.25$, $p = 0.150$, $\eta_p^2 = 0.09$; and the interaction was not significant, $F(1, 23) = 0.02$, $p = 0.898$, $\eta_p^2 < 0.01$.

N2pc (240-320 ms): The one-sample t tests showed that the mismatch-high-probability condition ($M = -0.05\mu$V, $SD = 0.63$, $t(23) = -0.39$, $p = 0.697$, Cohen' s $d = -0.08$) and the mismatch-low-probability condition ($M = -0.22\mu$V, $SD = 0.68$, $t(23) = -1.59$, $p = 0.126$, Cohen' s $d = -0.32$) did not elicit a significant N2pc; the match-high-probability condition ($M = -0.55\mu$V, $SD = 0.60$, $t(23) = -4.51$, $p < 0.001$, Cohen' s $d = -0.92$) and the match-low-probability condition ($M = -0.51\mu$V, $SD = 0.71$, $t(23) = -3.51$, $p = 0.002$, Cohen' s $d = -0.72$) elicited a significant N2pc. The repeated-measures ANOVA showed that the main effect of probability was not significant, $F(1, 23) = 0.34$, $p = 0.564$, $\eta_p^2 = 0.015$; the main effect of distractor type was significant, $F(1, 23) = 13.21$, $p = 0.001$, $\eta_p^2 = 0.37$, with the amplitude in the match condition significantly higher than that in the mismatch condition, $\Delta M = -0.39\mu$V, $t(23) = -3.64$, Cohen' s $d = -0.59$, $p = 0.001$, 95% CI $[-0.61, -0.17]$; the interaction between probability and condition was not significant, $F(1, 23) = 1.23$, $p = 0.279$, $\eta_p^2 = 0.05$.

Figure 9. Statistical-test plots of ERP components in Experiment 2 (upper

Statistical-test plots for ERP components in Experiment 2. Upper panels: Ppc (146–178 ms), N2pc (250–320 ms), and CDA (600–900 ms) for target lateralization; lower panels: Ppc (134–174 ms), N2pc (240–320 ms), and CDA (600–900 ms) for distractor lateralization. The y-axis is amplitude (μV); x-axis conditions are mismatch and match; green denotes high probability and blue denotes low probability.

Figure 3: Statistical-test plots for ERP components in Experiment 2. Upper panels: Ppc (146–178 ms), N2pc (250–320 ms), and CDA (600–900 ms) for target lateralization; lower panels: Ppc (134–174 ms), N2pc (240–320 ms), and CDA (600–900 ms) for distractor lateralization. The y-axis is amplitude (μV); x-axis conditions are mismatch and match; green denotes high probability and blue denotes low probability.

panels: target lateralization; lower panels: distractor lateralization)

CDA (600–900 ms): The one-sample t tests showed that the match-low-probability condition ($M = -0.37\mu$V, $SD = 0.71$, $t(23) = -2.35$, $p = 0.028$, Cohen' s $d = -0.48$) and the match-high-probability condition ($M = -0.46\mu$V, $SD = 0.47$, $t(23)$

$= -4.85$, $p < 0.001$, Cohen' s $d = -0.99$) elicited a significant CDA; the nonmatching-high-probability condition ($M = -0.07\mu V$, $SD = 0.54$, $t(23) = -0.64$, $p = 0.531$, Cohen' s $d = -0.13$) and the nonmatching-low-probability condition ($M = -0.25\mu V$, $SD = 0.71$, $t(23) = -1.70$, $p = 0.102$, Cohen' s $d = -0.35$) did not elicit a significant CDA. A repeated-measures analysis of variance showed a significant main effect of condition, $F(1, 23) = 6.14$, $p = 0.021$, $\eta_p^2 = 0.21$, with amplitudes in the matching condition higher than those in the nonmatching condition, $\Delta M = -0.26\mu V$, $t(23) = -2.48$, Cohen' s $d = -0.41$, $p = 0.021$, 95% CI $[-0.47, -0.04]$; the main effect of probability was not significant, $F(1, 23) = 0.08$, $p = 0.770$, $\eta_p^2 = 0.004$, and the interaction between probability and condition was not significant, $F(1, 23) = 2.73$, $p = 0.112$, $\eta_p^2 = 0.11$.

3.5 Discussion of Experiment 2

Experiment 2 manipulated the presentation probability of distractor type (high/low) to examine whether the target-gain effect produced by the target-matching distractor observed in Experiment 1 originated from a strategic processing bias generated by participants' probability expectations. The results confirmed the robustness of the processing advantage for target-matching distractors: although probability expectations modulated the allocation of attention to the target (N2pc), they did not change the finding that target-matching distractors captured attention (N2pc) and entered VWM storage (CDA), and they further verified the behavioral facilitation effect brought about by such distractors.

First, the behavioral results showed a stable "processing advantage for target-matching distractors." Regardless of whether the matching condition appeared with high or low probability (70%/30%), accuracy was significantly higher than in the nonmatching condition, and no interaction between probability and distractor type was found. This finding reduces the plausibility of an explanation based on "strategic processing." If participants relied on a processing strategy, then under the low-probability condition (in which participants expected the distractor to be nonmatching with high probability), they should have been more inclined to suppress the distractor, thereby weakening or eliminating the benefit brought by the matching distractor. The results showed that even at a relatively low presentation probability, the target-matching distractor could still use its matching features to provide a target benefit. This indicates that the behavioral benefit produced by feature consistency between the target and distractor does not depend entirely on top-down strategic preparation (Awh et al., 2012).

Second, the ERP results revealed that expectation had different effects on the attentional and storage stages. On the one hand, the ERPs elicited by distractor processing were not significantly modulated by presentation probability. Experiment 2 replicated the processing pattern of Experiment 1: the matching distractor first elicited the Ppc component reflecting stimulus salience, followed by significant N2pc and CDA components. This confirms that it is a stable cognitive phenomenon that target-matching distractors can capture attention and be encoded into VWM. On the other hand, attentional selection of the target was regulated by probability. The N2pc amplitude elicited when the target was lateralized showed a significant interaction between probability and condition: the target in the matching–low-probability condition elicited a larger N2pc amplitude than in the matching–high-probability condition. However, this fluctuation at the early attentional level did not affect the later storage stage (CDA) or final behavioral performance. The CDA and behavioral results showed that, regardless of probability, target-matching conditions elicited stable CDA when the distractor was lateralized, and behavioral accuracy in the matching condition was significantly higher than in the nonmatching condition. This "early sensitivity, late stability" pattern further suggests that the benefit brought by target-matching distractors extends at least to

VWM maintenance-related processing stage, and is ultimately manifested in behavioral performance; however, the present results still cannot fully distinguish the contributions of the encoding stage and the retrieval stage.

Finally, in Experiment 2, behavioral performance in the matching condition was significantly higher than in the mismatching condition, whereas in Experiment 1 no significant difference was observed between the matching and mismatching conditions. It should be noted that, in Experiment 1, when the working-memory load approached the upper limit of capacity (2 target items + 2 matching distractors), the "representational gain" brought about by target-matching distractors may have counteracted the "resource cost" (Fukuda et al., 2010). When

the targets were lateralized in Experiment 1, the CDA reflecting target storage was significantly reduced in the matching condition relative to the mismatching condition, indicating that target-storage resources were occupied. This would ordinarily predict a decline in behavioral performance; however, because target-matching distractors, after entering VWM, enhanced the target representations, behavioral performance ultimately was neither impaired nor significantly improved. In addition, in Experiment 2, the intermediate condition of "partial match" was removed, reducing uncertainty in the task context and enabling participants to maintain target representations more robustly (when targets were lateralized, there was no significant difference in CDA between the matching and mismatching conditions). As a result, the "representational gain" produced by matching distractors was observed in the behavioral outcomes.

In sum, Experiment 2 controlled the presentation probability of distractor types. The results do not support the view that representational gain is mainly driven by probability expectation or strategic bias; instead, they confirm that target-matching distractors can capture attention and enter VWM, serving as a gain factor for target memory and stably facilitating VWM performance. These findings reveal the flexibility of the VWM selection mechanism: when nontarget information in the environment contains task-relevant features, VWM can shift from "excluding irrelevant information" to "using relevant features" to improve memory performance.

4 General Discussion

Through two experiments, the present study examined the processing time course of target-matching distractors in visual working memory and their influence on target-memory performance. The results showed that although the attributes of target-matching distractors constitute nontarget information, because they carry features of the target memory, they can capture attention and be encoded into VWM storage. Crucially, this intrusion of nontarget information did not impair VWM performance as predicted by the traditional "resource competition model." On the contrary, target-matching distractors provided a "gain" for the targets and promoted target recognition performance.

4.1 Target-matching distractors: the dynamic time course of capturing attention and entering VWM

Previous studies on mismatching distractors have generally argued that the superior VWM performance of individuals with high VWM capacity derives from efficient suppression of distractors (Gaspelin et al., 2017; Vogel et al., 2005). However, the ERP evidence in the present study reveals the dynamic process by which target-matching distractors facilitate target memory. The ERP results showed that positive activity, Ppc, could be observed in the early time window; this component mainly reflects early perceptual registration of physical salience, but it was not modulated by distractor type. The matching effect in the present

study was mainly reflected in the subsequent stages of attentional selection and memory maintenance. Target-matching distractors elicited a significant N2pc, indicating that they successfully captured spatial attention; finally, they elicited a stable CDA, reflecting their entry into the VWM storage-processing stage. Compared with previous resear

Unlike the distractor processing observed in studies (Feldmann-Wüstefeld & Vogel, 2019; Liesefeld et al., 2017; Liu et al., 2024), the present study observed a stable CDA component when distractors were presented laterally, providing electrophysiological evidence that target-matching distractors can stably enter the storage stage of VWM.

4.2 Dissociation Between Behavioral Outcomes and Neural Activity: The Trade-off Between Resource Competition and Target Gain

According to the classic resource-competition hypothesis, a distractor-elicited CDA indicates that the distractor occupies limited storage resources and should therefore lead to a decline in target-memory performance (Bays & Husain, 2008; Ma et al., 2014). However, the behavioral results and neural indices in the present study were dissociated. Although target-matching distractors received processing during the storage stage—as reflected in Experiment 1 by the reduced target CDA amplitude under the matching condition—the target-matching distractors that entered the storage stage were not meaningless "distracting information." During the maintenance stage, they may enhance the stability of memory representations (Lin & Luck, 2009); during the decision stage, they provide additional representational cues for target recognition. In Experiment 1, the gain brought by these representational cues compensated for the loss in target performance caused by resource competition, such that accuracy in the matching condition not only did not decline, but also showed no significant difference from the non-matching condition, and even improved significantly under some matching conditions. In Experiment 2, the EEG results showed that target storage processing was not significantly affected—the amplitude of the target-elicited CDA did not differ significantly across conditions. At this point, matching distractors did not produce obvious competition with target processing, and the "target-gain" effect emerged more robustly: behaviorally, accuracy in the matching condition was significantly higher than in the non-matching condition.

4.3 Flexibility in the Selection Mechanism of Visual Working Memory: Inhibition vs. Utilization

The present study refines the theoretical account of how matching distractors are processed within the selection mechanism of VWM. The traditional view holds that salient non-target information needs to be inhibited from entering VWM; otherwise, it will impair target-memory performance (Vogel et al., 2005). However, this paper finds that the selection mechanism does not rigidly inhibit all irrelevant information, but instead exhibits dynamic adaptability and flexibility.

When facing completely irrelevant distractors (non-matching non-target information), the cognitive system excludes them from further attentional selection and storage processing; whereas for distractors carrying task-relevant features (matching non-target information), the cognitive system adopts a "selection and utilization" strategy, allowing them to enter VWM so that the target information they contain can be used to support task completion. This flexibility may explain why individuals with high VWM capacity are, in some situations, more readily captured by target-matching distractors (Zhong et al., 2024). This may not be a "loophole" in cognitive control, but rather reflects that individuals with high VWM possess a more flexible selection mechanism, enabling them to extract potential target cues from the environment according to task demands and thereby improve task performance.

4.4 Trade-off Between Bottom-Up and Top-Down Processing: Modulation of Attention by Presentation Probability

N2pc is regarded as an ERP index reflecting the shifting and orienting of spatial attention. It can represent top-down attentional engagement driven by task goals, and it can also reflect bottom-up attentional capture driven by stimuli (Theeuwes, 2010). The results of Experiment 2 showed that when the target was lateralized, the low-probability matching condition elicited an N2pc with a significantly larger amplitude than did the high-probability matching condition. This suggests that when participants were faced with matching distractors presented with lower probability, they strategically allocated more top-down attentional resources to the target.

resources to strengthen target processing. However, the ERP pattern elicited by distractor lateralization shows that this increased top-down input, intended to protect target processing, did not weaken the distractor' s capture of attention. The matching distractor still elicited a significant N2pc, and its amplitude was not significantly modulated by presentation probability. This finding supports the view that two mechanisms jointly influence attentional selection: a top-down mechanism regulates the allocation of attention to the target, whereas a bottom-up mechanism drives attentional capture by the distractor.

4.5 Interpretation of ERP Components: Ppc (Early PD), PD, CDAp, and CDA

Feldmann-Wüstefeld and Vogel (2019) interpreted the early contralateral positivity in the ERP results as active suppression of the distractor (Early PD). However, this interpretation has difficulty accounting for the early positivity that likewise appeared when the "target was lateralized" (Feldmann-Wüstefeld & Vogel, 2019). Therefore, the present article defines this component as Ppc. Ppc reflects the early bottom-up perceptual process in the primary visual cortex in response to physically salient stimuli, and it does not depend on the task relevance of the stimulus (Chen et al., 2023; Fortier-Gauthier et al., 2012; Jannati et al., 2013). In the present article, regardless of whether the target or the dis-

tractor was lateralized, positive activity was observed in the early time window, and most conditions elicited a significant or marginally significant Ppc. This result is more consistent with the view that this component reflects the perceptual system' s response to physical salience, rather than active suppression of distractors.

In addition, the ERP component PD, which reflects distractor suppression, was not observed in the present study. This may have resulted from the joint action of the following mechanisms. First, the distractor load was relatively low: in the study by Feldmann-Wüstefeld and Vogel (2019), when the distractor load was low (only two distractors), the PD component was not always reliable. No significant Pd was found in their Experiment 1 ($M = 0.11\,\mu\text{V}, p = 0.183$), whereas a significant PD was observed in Experiment 2 ($M = 0.22\,\mu\text{V}, p = 0.019$) (Feldmann-Wüstefeld & Vogel, 2019). Second, task-relevant feature selection: according to Gaspelin and Luck (2018), distractors that mismatch in both color and shape are readily ignored by the cognitive system, and therefore do not require the recruitment of additional active suppression resources (Gaspelin & Luck, 2018). Third, changes in processing priority (Chen et al., 2023): because the matching distractor shared target features, it acquired higher processing priority, altering the order in which stimuli were processed. As a result, the mismatching distractor occupied a lower priority in the competition and consequently did not trigger the distractor-suppression mechanism.

At the same time, unlike previous studies showing that distractors can elicit sustained cortical suppression (CDAp), the present study did not observe a significant CDAp under any condition. Instead, the matching distractor elicited a negative component similar to that elicited by the target (CDA), suggesting that it entered a processing stage related to VWM maintenance. By contrast, because the mismatching distractor had lower processing priority, it may have naturally decayed before entering VWM encoding; therefore, it neither triggered a distractor-suppression component (PD) nor elicited late sustained suppression (CDAp).

Finally, the CDA component analyzed in the present article is referred to in some studies as the sustained posterior contralateral negativity (SPCN, Sustained Posterior Contralateral Negativity) (Jolicoeur et al., 2008; Jolicoeur et al., 2006; Luria et al., 2016). Some studies regard SPCN as an electrophysiological index of sustained spatial attentional allocation (Gibb et al., 2016; Holmes et al., 2014).

On this basis, from the perspective of sustained attention, the present study also offers a potential explanation: target-matching distractors carry target color features; at an early stage they receive perceptual processing and spatial attentional selection, manifested as Ppc and N2pc. Subsequently, their representations receive maintenance-related attentional allocation, manifested as a sustained posterior contralateral negativity. Because the matching distractors share key features with the target, this sustained attentional allocation is not simply a competition for target resources, but rather provides a gain to the

target representation through the co-activation of features.

In sum, the present experiment supports the view that matching distractors can promote target processing, but it has limitations in dissociating working-memory maintenance from internal sustained attention. Future research may adopt more sophisticated experimental designs to further clarify the cognitive process by which matching distractors facilitate target processing. It may also manipulate continuous changes in feature similarity to explore the boundary at which a distractor shifts from providing "gain" to the target to producing "cost."

5 Conclusion

This study demonstrates that target-matching distractors exhibit a distinctive processing pattern in visual working memory: they can be stably captured by attention and encoded into VWM. More importantly, the entry of this non-target information into VWM does not impair target performance; instead, it provides "gain" for the target and facilitates behavioral performance on the target. This finding refines traditional VWM selection models, suggesting that the VWM system has a high degree of flexibility: efficient selection not only keeps irrelevant information "outside the door," but also involves "accommodating and storing" potentially target-relevant information.

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Processing of Target-Matching Distractors in Visual Working Memory: Attentional Capture and Storage Gain

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Abstract Visual working memory (VWM) has a strictly limited capacity, necessitating efficient selection mechanisms to prevent irrelevant information from consuming cognitive resources available for targets. Traditional theoretical models propose that once distractors bypass the attentional filter and enter storage, they are assumed to compete with target representations and consequently impair memory performance. However, it remains unclear whether this assumption also applies when distractors share defining features with targets, that is, when they are target-matching distractors. Unlike feature-mismatching distractors, target-matching distractors may engage distinct processing mechanisms due to their feature similarity to the targets. This study investigated the processing of target-matching distractors and their behavioral consequences, testing the hypothesis that they may not be completely filtered out and may interact with target storage in a manner that differs from the traditional resource-competition account.

To isolate the cognitive processing of targets and distractors, we employed a lateralized VWM filtering paradigm across two experiments. Experiment 1 included 28 participants (mean age = 20.04 years), who performed a change-detection task involving memory arrays composed of two target squares and two distractor circles. The experimental conditions manipulated the number of distractors that shared colors with the targets: mismatch (zero), partial match (one), and full match (two). Electroencephalographic (EEG) activity was recorded to examine event-related potentials (ERPs), including the N2pc, an index of attentional selection; the positivity posterior contralateral (Ppc), and contralateral delay activity (CDA), an index of storage-related maintenance. Experiment 2 included 24 participants and adopted a 2 (distractor type: match vs. mismatch) × 2 (presentation probability: high vs. low) within-subjects design. By manipulating the probability of matching trials, this experiment tested whether the effects observed in Experiment 1 reflected strategic processing biases.

In Experiment 1, accuracy was significantly higher in the partial-match condition than in the mismatch condition ($p = 0.021$). Electrophysiologically, both partial-match and full-match distractors elicited significant N2pc and CDA components, suggesting that they captured attention

and engaged storage-related maintenance processes. In contrast, mismatch distractors did not elicit reliable N2pc or CDA components, and early Ppc activity was not consistently modulated by feature matching. Experiment 2 replicated this pattern, demonstrating the robustness of these effects. Accuracy was significantly higher in the match condition ($M = 0.91$) than in the mismatch condition ($M = 0.88$, $p < 0.001$, Cohen' s $d = 0.47$), regardless of presentation probability. ERP analyses further showed that presentation probability modulated early allocation of attention to targets, as reflected by target-elicited N2pc amplitude, but did not alter the storage-related pattern; target-matching distractors consistently elicited reliable N2pc and CDA components, whereas mismatch distractors did not. Together, these findings suggest that target-matching distractors

entered storage-related processing but facilitated, rather than impaired, target memory performance.

This study demonstrates that target-matching distractors are processed in a distinctive manner in VWM. Specifically, these distractors are not rigidly suppressed; instead, they are flexibly accommodated by the selection system when they share task-relevant features with targets. Crucially, the inclusion of such task-irrelevant but feature-relevant information in storage-related processing does not necessarily impair performance. Rather, feature overlap between targets and distractors may facilitate target memory. These findings refine traditional accounts of distractor suppression by suggesting that VWM filtering is not purely exclusionary, but is sensitive to the potential relevance of incoming information.

Keywords attention, visual working memory, selection mechanisms

Note: Figure translations are in progress. See original paper for figures.