The Effect of Processing Demands of Working Memory Representation Precision on Attentional Guidance

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Abstract

Using an attentional capture paradigm, the present study investigated the influence of working memory representation precision processing demands on attentional guidance through behavioral and event-related potential (ERP) experiments. Behavioral results revealed that under low-precision processing demand conditions, only one working memory representation guided attention, and attentional capture generated by working memory representations in a high-activation state was greater than that in a low-activation state; conversely, under high-precision processing demand conditions, two working memory representations guided attention, and no difference in attentional capture was observed between working memory representations in high- and low-activation states. ERP results demonstrated that NSW and LPC evoked under high-precision processing demand conditions were larger than those under low-precision processing demand conditions; under high-precision processing demand conditions, distractors matching memory items elicited larger N2 and smaller N2pc compared to non-matching conditions, whereas under low-precision processing demand conditions, no difference in N2 and N2pc was observed between distractors that matched or did not match memory items. The study suggests that the mechanism by which working memory representation precision processing demands influence attentional guidance may be that under high-precision processing demands, working memory representations consume increased cognitive resources, resources allocated to search targets decrease, and attention captured by distractors increases.

Full Text

The Influence of Working Memory Representation Precision Requirements on Attentional Guidance

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Abstract

Using the attentional capture paradigm, this study investigated how the precision requirements of working memory (WM) representations influence attentional guidance through behavioral and event-related potential (ERP) experiments. Behavioral results revealed that under low-precision requirements, only one WM representation guided attention, with high-activation representations producing greater attentional capture than low-activation ones. Conversely, under high-precision requirements, two WM representations guided attention simultaneously, with no difference in capture magnitude between high- and low-activation states. ERP results showed that high-precision conditions elicited larger NSW (negative slow wave) and LPC (late positive component) than low-precision conditions. Under high-precision requirements, distractors matching memory items evoked larger N2 and smaller N2pc components compared to non-matching distractors, whereas under low-precision requirements, no such differences emerged for N2 and N2pc. These findings suggest that precision requirements affect attentional guidance by increasing cognitive resource consumption during WM representation, thereby reducing resources available for target search and enhancing attentional capture by distractors.

Keywords: working memory representation, attentional capture, activation state, distractor inhibition

1 Introduction

Attention and working memory constitute two fundamental aspects of human cognitive processing. Attention reflects the selection of information for further processing, while working memory involves the temporary storage and manipulation of information. On one hand, attention selects information to be encoded into working memory and allocates attentional resources during WM processing (Hu et al., 2016; Shen et al., 2015). On the other hand, representations maintained in working memory can guide attention and influence subsequent attentional tasks (Downing & Dodds, 2004).

In recent years, researchers have extensively examined how WM representations influence attentional guidance using two primary paradigms: target search and attentional capture. In the target search paradigm, WM representations match the search target, facilitating attentional orienting to the goal. Studies using this approach have found that WM representations can activate sensory neurons before the search task appears, granting matching stimuli a competitive advantage and producing WM-based attentional guidance that facilitates visual search (Desimone & Duncan, 1995; Soto et al., 2005). Houtkamp and Roelfsema (2009) compared search performance with one versus two targets, finding that searching for two targets impaired performance relative to searching for one, producing a dual-target search cost predictable by single-template models. This suggests that only one WM representation guides attention at any given time. Ort et al. (2017) used eye-tracking technology to examine cognitive control in dual-target search, revealing that when only one target appeared in the search array, saccade latencies were longer when the target changed between trials than when it remained constant. However, with two targets in the search array, target change did not affect saccade latency, indicating that only one target template could be activated at a time during dual-target search, with template switching requiring cognitive control that produces dual-target costs. In contrast, Beck and Hollingworth (2017) presented two search targets sequentially, each corresponding to a separate search array, and found that when the first target reappeared in the second search array, fixation probabilities were equal for both targets, suggesting that two WM representations could simultaneously guide attention. Other researchers using ERP technology, with the N2-posterior contralateral component (N2pc) as an index of attentional resource allocation, found no difference in N2pc amplitude between single- and dual-target searches, suggesting that attentional resources can be flexibly distributed across targets and that multiple WM representations can guide attention concurrently (Berggren & Eimer, 2018). Kerzel and Witzel (2019) investigated how resource allocation in WM influences attentional guidance, finding that single- and dual-target searches produced equivalent benefits from spatial cues. However, after distinguishing between targets and distractors, only targets facilitated search, and targets were remembered with higher precision than distractors. This indicates that when WM resources are equally distributed between two representations, both can guide attention simultaneously; when resources are unequally distributed, only the representation receiving more resources guides attention. Overall, target search paradigm studies demonstrate that pre-stored WM representations can facilitate subsequent attentional guidance, with WM resource allocation influencing the number of representations that guide attention.

In the attentional capture paradigm, WM representations match distractors in the search task, requiring inhibition of attention to matching distractors. Research using this paradigm has yielded controversial findings regarding how WM representations influence attentional guidance. Some studies (Woodman & Luck, 2007; Arita et al., 2012; Wen et al., 2018) found that distractors matching WM representations do not attract attention. Woodman and Luck (2007) required participants to remember a colored square before searching for the orientation of a colored Landolt ring, finding no difference in search reaction times regardless of whether distractors matched the memory item, suggesting that WM-matching distractors do not automatically capture attention. When participants were explicitly informed that WM representations would never become search targets, search reaction times were faster when WM-matching distractors appeared than when no distractors appeared, indicating effective inhibition of attentional capture by matching distractors (Arita et al., 2012; Wen et al., 2018). Other studies found that distractors matching WM representations can attract attention when memory and test items are difficult to discriminate (Hollingworth & Beck, 2016; van Moorselaar et al., 2014). Van Moorselaar et al. (2014) used a cueing paradigm to place one item in a high-activation state and employed same-category colors for memory testing, investigating how the number of WM representations influences attentional guidance. They found that with one memory item, reaction times were longer when distractors matched the memory item than when they did not, producing a WM-based attentional capture effect. With multiple memory items and a cue, only the cued item produced WM-based attentional capture, suggesting that when WM representations match distractors, only one high-activation representation guides attention at a time. Hollingworth and Beck (2016) used memory test items that were difficult to discriminate from memory items to investigate how many WM representations can simultaneously guide attention, finding that when two items were held in memory and two distractors matched the memory items, the attentional capture effect was larger than when one item was held in memory and one distractor matched. This suggests that when WM representations match search distractors, attention can be guided by two WM representations simultaneously.

These conflicting findings may relate to WM resource investment. Studies varying the discriminability between memory and test items involve different levels of WM resource investment (Zhang & Luck, 2011). When memory and test items differ substantially and are easy to discriminate, minimal WM resources suffice for the memory task, and WM representations do not guide attention. When memory and test items are similar and difficult to discriminate, more resources must be invested in WM representations to complete the memory task, enabling them to guide attention. In cueing paradigm studies, cued items receive more WM resources than non-cued items, with only cued items capturing attention. The amount of WM resource investment may influence both attentional template establishment and distractor inhibition during search. Research shows that when WM items serve as search targets rather than merely being held for memory tests, more resources are required to establish attentional templates, thereby guiding attention (Gunseli et al., 2014). Additionally, cognitive control over matching distractors during search is resource-dependent; when resources are abundant, cognitive control operates more effectively, and distractor inhibition is stronger (Dube et al., 2016; Wen et al., 2018). Since WM resource allocation influences attentional guidance by multiple WM representations when they match search targets (Kerzel & Witzel, 2019), does WM resource allocation also influence attentional guidance when WM representations match search distractors?

The present study manipulated cognitive resource investment during WM representation by controlling the discriminability between memory and test items, thereby varying the precision requirement of WM representations (Zhang & Luck, 2015; Li et al., 2019), to investigate how WM representations influence attentional guidance in the attentional capture paradigm. WM representation precision refers to the accuracy of WM representations; increasing the precision requirement demands greater cognitive resource investment during WM processing (Bays & Husain, 2008; Machizawa et al., 2012). The study comprised four experiments: Experiment 1 presented one memory item to examine how single-item WM representation precision requirements influence attentional guidance. Since higher precision requirements consume more WM resources (Bays & Husain, 2008), fewer resources remain for suppressing distractors during search, increasing distractor interference. Therefore, Hypothesis 1 predicted that WM-based attentional capture would be greater under high than low precision requirements. Experiment 2 presented two memory items and used a cueing paradigm to vary representation activation states, examining whether the effects observed in Experiment 1 were due to changes in activation state rather than precision requirements. Under high precision requirements, both representation number and precision demands increase resource consumption, leaving insufficient resources for attentional tasks regardless of activation state, resulting in substantial interference from both high- and low-activation items. Under low precision requirements, the cue renders the cued item highly activated, making it more difficult to inhibit and producing greater interference. Therefore, Hypothesis 2 predicted that under high precision requirements, attentional capture would not differ between high- and low-activation items, whereas under low precision requirements, high-activation items would produce greater capture than low-activation items. Experiment 3 presented one or two memory items while controlling the number of matching distractors in the search task to investigate how many WM representations can simultaneously guide attention. Since both representation number and precision requirements increase resource consumption, insufficient resources remain for attentional tasks, producing substantial distractor interference. Therefore, Hypothesis 3 predicted that under high precision requirements, two WM representations could guide attention simultaneously, whereas under low precision requirements, only one representation would guide attention. Experiment 4 employed ERP technology, using the N2 component (reflecting conflict monitoring and cognitive control; Heil et al., 2000) and N2pc (reflecting attentional resource allocation; Eimer, 1996) to further explore the mechanism underlying precision requirement effects. Since high precision requirements consume more cognitive resources during visual search, leaving fewer resources for distractor inhibition, Hypothesis 4 predicted that high precision requirements would elicit larger N2 and smaller N2pc compared to low precision requirements.

2 Experiment 1: The Influence of Single-Item WM Representation Precision Requirements on Attentional Guidance

Following previous research (Zhang & Luck, 2015), we manipulated precision requirements by varying the discriminability between memory and test items to investigate how single-item WM representations influence attentional guidance under high versus low precision demands. Since participants might phonologically encode memory items under low precision requirements, potentially affecting attentional guidance (Olivers, 2009), Experiment 1 also manipulated phonological encoding to examine its influence on WM-based attentional guidance under inhibited versus promoted encoding conditions.

2.1.1 Participants

Using G*Power 3.1, we calculated a required sample size of 19 for a statistical power of 0.80, $\alpha = 0.05$, and medium effect size ($f = 0.25$) (Cohen, 1992). Twenty university students (6 male, mean age = 18.95 ± 0.89 years) participated. All had normal or corrected-to-normal vision, no color blindness, no psychiatric history, and no prior experience with similar experiments. Participants received compensation after the experiment.

2.1.2 Apparatus and Materials

Experimental programs were developed using E-prime 1.1 and presented on a computer monitor (resolution: 1024 × 768, refresh rate: 60 Hz). WM task materials consisted of colored squares (1.32° × 1.32°) selected from a perceptually homogeneous CIELab color circle (hereinafter "color wheel") (Zhang & Luck, 2008; see Figure 1 [Figure 1: see original paper]; L = 70, a = 20, b = 38). The color wheel comprised 180 colors. Memory items were four colors selected from the wheel, with any two colors separated by at least 48°. Test item colors were also selected from the wheel, differing from memory items by either 15° or 96°.

Visual search task materials consisted of eight square frames with gaps (0.88° × 0.88°, line width: 0.15°, hereinafter "frames") evenly distributed on a virtual circle (radius: 3.66°) centered on the screen. Frame gaps could face up, down, left, or right; in each trial, only one frame had a horizontal gap, serving as the search target. In each search array, seven frames were white and one was colored; the colored frame never served as the target and its color was randomly selected from memory and test item colors.

2.1.3 Experimental Design

We employed a 2 (precision requirement: high, low) × 2 (phonological encoding: inhibited, promoted) × 3 (matching condition: baseline, non-matching, matching) within-subjects design. Following previous research (Zhang & Luck, 2015), high precision requirement trials used test items differing by 15° on the color wheel, while low precision requirement trials used test items differing by 96°. Phonological encoding conditions included inhibition (articulatory suppression task) and promotion (color naming task) (Souza & Skóra, 2017). Matching conditions referred to the color relationship between memory items and search distractors: in baseline trials, all search frames were white; in non-matching trials, the colored distractor' s color differed from the memory item; in matching trials, the colored distractor' s color matched the memory item. We recorded accuracy and reaction times (RTs) for both memory detection and visual search tasks.

2.1.4 Procedure

Participants sat approximately 57 cm from the monitor. The trial procedure is illustrated in Figure 2 [Figure 2: see original paper]. In the phonological inhibition condition, four random digits appeared first, and participants were instructed to repeat them aloud throughout the trial. After beginning repetition, participants pressed the spacebar, and a colored square (memory item) appeared centrally for 300 ms. Participants memorized its color, and after a 700 ms fixation period, either a visual search task or memory test was presented. In search trials, participants rapidly located the frame with a leftward or rightward gap among eight frames and responded via keypress ("1" for left gap, "2" for right gap). In memory test trials, two colored squares (1.10° × 1.10°) appeared 0.73° to the left and right of center, and participants indicated which color matched the memory item ("1" for left match, "2" for right match). The phonological promotion condition followed the same procedure except that a "+" preceded the memory item, and participants verbally named the color immediately upon seeing it.

The experiment comprised 48 practice trials and 720 experimental trials, divided into four blocks based on precision requirement and phonological encoding condition: high-precision/inhibition, high-precision/promotion, low-precision/inhibition, and low-precision/promotion. Each block contained 90 memory test trials and 90 search trials (30 each of matching, non-matching, and baseline conditions). Trials were randomized within blocks, and block order was counterbalanced. Participants rested for 2 minutes after every 90 trials. The entire experiment lasted approximately 60 minutes.

2.2 Results

2.2.1 Working Memory Task A 2 (precision requirement) × 2 (phonological encoding) repeated-measures ANOVA on WM accuracy (see Table 1) revealed a significant main effect of precision requirement, $F(1, 19) = 26.98$, $p < 0.001$, $p^2 = 0.59$, with lower accuracy under high ($M = 0.93$, 95% CI: [0.91, 0.95]) versus low precision requirements ($M = 0.99$, 95% CI: [0.98, 0.99]). The main effect of phonological encoding was also significant, $F(1, 19) = 4.96$, $p = 0.038$, $p^2 = 0.21$, with lower accuracy under inhibition ($M = 0.95$, 95% CI: [0.94, 0.97]) versus promotion ($M = 0.97$, 95% CI: [0.95, 0.98]). The interaction was not significant, $F(1, 19) = 0.63$, $p = 0.44$.

2.2.2 Visual Search Task A 2 (precision requirement) × 2 (phonological encoding) × 3 (matching condition) repeated-measures ANOVA on search accuracy (see Table 2) revealed no significant main effects or interactions (all $ps > 0.10$).

For search RTs, we excluded incorrect trials (0.89% of total) and outliers beyond M ± 2.5 SD (1.22% of total). The ANOVA on remaining RTs (see Table 2) revealed no significant main effects of precision requirement, F(1, 19) = 0.07, p = 0.80, or phonological encoding, F(1, 19) = 0.08, p = 0.79, but a significant main effect of matching condition, F(2, 38) = 55.42, p < 0.001, p^2 = 0.74. RTs were longer in matching (M = 525 ms, 95% CI: [452, 598]) versus non-matching (M = 466 ms, 95% CI: [399, 532], p < 0.001) and baseline conditions (M = 431 ms, 95% CI: [358, 505], p < 0.001), and longer in non-matching versus baseline conditions (p < 0.001). The precision requirement × matching condition interaction was significant, F(2, 38) = 6.63, p = 0.003, p^2 = 0.26; other interactions were non-significant (all ps > 0.05).

We calculated the WM-based attentional capture effect as RT difference between matching and non-matching conditions. A 2 (precision requirement) × 2 (phonological encoding) ANOVA revealed a significant main effect of precision requirement, F(1, 19) = 9.20, p = 0.007, p^2 = 0.33, with larger capture effects under high (M = 83 ms, 95% CI: [54, 111]) versus low precision requirements (M = 36 ms, 95% CI: [11, 60]). The main effect of phonological encoding was also significant, F(1, 19) = 4.78, p = 0.041, p^2 = 0.20, with smaller capture effects under inhibition (M = 45 ms, 95% CI: [29, 61]) versus promotion (M = 73 ms, 95% CI: [42, 105]). The interaction was not significant, F(1, 19) = 0.02, p = 0.89 (see Figure 3 [Figure 3: see original paper]A).

2.3 Discussion

Experiment 1 manipulated WM representation precision requirements to examine their influence on single-item WM guidance. The memory task results confirmed our manipulation: accuracy was lower under high versus low precision requirements, indicating that higher precision demands increased task difficulty and consumed more WM resources (Bays & Husain, 2008), thereby reducing memory performance. Additionally, accuracy was lower under phonological inhibition versus promotion, consistent with previous findings (Souza & Skóra, 2017) and demonstrating that phonological encoding benefits WM performance.

Visual search results showed larger WM-based attentional capture effects under high versus low precision requirements. The non-significant interaction between precision requirement and phonological encoding indicates that encoding strength did not moderate the precision effect, confirming that capture differences were not due to differential phonological encoding. Compared to low precision conditions, high precision requirements likely allocated more resources to WM representations, promoting occipital activation through increased rehearsal (Zhao et al., 2020), which enhanced the competitive advantage of matching distractors and increased their attentional capture. Additionally, since participants knew memory items might appear as distractors, they could exert top-down control over memory-based inhibition (Dube et al., 2016). Under low precision requirements, abundant cognitive resources enabled effective adjustment to inhibit matching distractors, reducing capture. Under high precision requirements, greater resource consumption left fewer resources for inhibiting matching distractors, increasing capture.

Previous research suggests that only high-activation WM representations guide attention, while low-activation representations do not (van Moorselaar et al., 2014). Experiment 1 presented only one memory item; under high precision requirements, the need for greater resources may have placed the representation in a more activated state. To test whether precision effects were mediated by activation state changes, we designed Experiment 2.

3 Experiment 2: The Influence of WM Representation Precision Requirements and Activation States on Attentional Guidance

Using a cueing paradigm to manipulate WM representation activation states, Experiment 2 examined how precision requirements and activation states jointly influence attentional guidance.

3.1.1 Participants

Using G*Power 3.1, we calculated a required sample size of 16 for power = 0.80, $\alpha = 0.05$, and medium effect size (f = 0.25) (Cohen, 1992). Sixteen university students (5 male, mean age = 19.38 ± 0.89 years) participated. All had normal or corrected-to-normal vision, no color blindness, no psychiatric history, and no prior experience with similar experiments.

3.1.2 Apparatus and Materials

Memory items consisted of two colored squares, with an arrow cue ($0.1° \times 1.9°$) presented simultaneously. Other materials were identical to Experiment 1.

3.1.3 Experimental Design

We employed a 2 (precision requirement: high, low) × 4 (matching condition: baseline, non-matching, high-priority matching, low-priority matching) within-subjects design. Precision requirements were identical to Experiment 1. The cued item was designated high-priority; the non-cued item was low-priority. Matching conditions referred to color relationships between memory items and search distractors: baseline (all white frames), non-matching (colored distractor differed from both memory items), high-priority matching (colored distractor matched the high-priority item), and low-priority matching (colored distractor matched the low-priority item). We recorded accuracy and RTs for both memory detection and visual search tasks.

3.1.4 Procedure

The trial procedure is illustrated in Figure 2. During memory encoding, two memory items appeared at positions 180° apart on a virtual circle (radius: 2.34°) centered on the screen, with a central arrow cue pointing to one item. The cued item had an 80% probability of being tested. During memory test, two test items appeared 0.73° to the left and right of the corresponding memory item location. Other procedures were identical to Experiment 1.

The experiment comprised 32 practice trials and 640 experimental trials, divided into two blocks based on precision requirement. Each block contained 160 memory test trials and 160 search trials (40 each of baseline, non-matching, high-priority matching, and low-priority matching). Trials were randomized within blocks, and block order was counterbalanced. Participants rested for 2 minutes after every 80 trials. The entire experiment lasted approximately 60 minutes.

3.2 Results

3.2.1 Working Memory Task A 2 (precision requirement) × 2 (item priority) repeated-measures ANOVA on WM accuracy (see Table 1) revealed significant main effects of precision requirement, $F(1, 15) = 15.68$, $p = 0.001$, $p^2 = 0.51$, with lower accuracy under high ($M = 0.79$, 95% CI: [0.74, 0.83]) versus low precision requirements ($M = 0.87$, 95% CI: [0.85, 0.89]), and item priority, $F(1, 15) = 25.64$, $p < 0.001$, $p^2 = 0.63$, with higher accuracy for high-priority ($M = 0.90$, 95% CI: [0.87, 0.92]) versus low-priority items ($M = 0.76$, 95% CI: [0.71, 0.81]). The interaction was not significant, $F(1, 15) = 0.06$, $p = 0.80$.

A parallel ANOVA on WM RTs revealed significant main effects of precision requirement, $F(1, 15) = 23.96$, $p < 0.001$, $p^2 = 0.62$, with longer RTs under high ($M = 789$ ms, 95% CI: [731, 846]) versus low precision requirements ($M = 683$ ms, 95% CI: [642, 724]), and item priority, $F(1, 15) = 28.83$, $p < 0.001$, $p^2 = 0.66$, with faster RTs for high-priority ($M = 655$ ms, 95% CI: [619, 691]) versus low-priority items ($M = 817$ ms, 95% CI: [749, 884]). The interaction was not significant, $F(1, 15) = 1.07$, $p = 0.32$.

3.2.2 Visual Search Task A 2 (precision requirement) × 4 (matching condition) repeated-measures ANOVA on search accuracy (see Table 2) revealed a significant main effect of matching condition, $F(3, 45) = 4.71$, $p = 0.006$, $p^2 = 0.24$. Accuracy in high-priority matching ($M = 0.98$, 95% CI: [0.97, 0.99]), low-priority matching ($M = 0.97$, 95% CI: [0.96, 0.99]), and non-matching ($M = 0.98$, 95% CI: [0.96, 0.99]) conditions did not differ (all $ps > 0.12$) but was lower than baseline ($M = 0.99$, 95% CI: [0.98, 0.998], all $ps < 0.022$). No other effects were significant (all $ps > 0.42$).

For search RTs, we excluded incorrect trials (0.73% of total) and outliers beyond $M \pm 2.5$ SD (0.90% of total). The ANOVA revealed a significant main effect of matching condition, $F(3, 45) = 18.41$, $p < 0.001$, $p^2 = 0.55$. RTs were longer in high-priority matching (M = 612 ms, 95% CI: [508, 717]) versus non-matching (M = 574 ms, 95% CI: [470, 678], $p = 0.002$) and baseline (M = 534 ms, 95% CI: [416, 652], $p < 0.001$) conditions. Low-priority matching RTs (M = 602 ms, 95% CI: [495, 709]) were also longer than non-matching and baseline conditions (both ps < 0.009). Non-matching RTs were longer than baseline ($p = 0.004$), but high- and low-priority matching conditions did not differ ($p = 0.29$). The precision requirement × matching condition interaction was marginally significant, F(3, 45) = 2.69, $p = 0.058$, $p^2 = 0.15$.

A 2 (precision requirement) × 2 (matching condition: high-priority matching, low-priority matching) ANOVA on WM-based attentional capture effects revealed non-significant main effects (both ps > 0.10) but a significant interaction, F(1, 15) = 10.24, $p = 0.006$, $p^2 = 0.41$. Simple effects analysis showed that under high precision requirements, capture effects did not differ between high-priority (M = 36 ms, 95% CI: [6, 67]) and low-priority matching (M = 52 ms, 95% CI: [18, 87]), F(1, 15) = 1.65, $p = 0.22$. Under low precision requirements, however, capture effects were larger for high-priority (M = 41 ms, 95% CI: [19, 62]) versus low-priority matching (M = 5 ms, 95% CI: [-22, 31]), F(1, 15) = 11.97, $p = 0.003$ (see Figure 3 [Figure 3: see original paper]B).

3.3 Discussion

Building on Experiment 1, Experiment 2 added a cue indicating which of two memory items would more likely be tested, examining how precision requirements and activation states jointly influence attentional guidance. WM task results replicated Experiment 1: accuracy was lower under high versus low precision requirements. The cued (high-priority) item was more likely to be tested and thus maintained in a high-activation state. Analyses of WM performance by activation state revealed higher accuracy and faster RTs for high- versus low-priority items, confirming effective cue manipulation.

Visual search results showed that under low precision requirements, distractors matching high-activation items produced greater attentional capture than those matching low-activation items, consistent with van Moorselaar et al. (2014). However, under high precision requirements, capture effects did not differ between high- and low-activation items, diverging from van Moorselaar et al. (2014) but aligning with Dube and Al-Aidroos (2019). Researchers have suggested that compared to change detection tasks, continuous report tasks impose higher precision demands on WM representations (Zhang & Luck, 2011), indicating that inconsistent findings regarding activation state effects may stem from uncontrolled precision requirements. Higher precision demands increase WM resource consumption (Bays & Husain, 2008; Machizawa et al., 2012), reducing resources available for cognitive control. Consequently, distractors matching both high- and low-activation items capture attention. Experiment 2 found that activation state influenced attentional guidance only under low precision requirements. Could this relate to the number of representations guiding attention? Experiment 3 addressed this question by increasing the number of salient distractors in the search task to allow simultaneous matching with two WM representations.

4 Experiment 3: The Influence of Multiple-Item WM Representation Precision Requirements on Attentional Guidance

Using the paradigm from Experiment 1, Experiment 3 manipulated both the number of WM representations and precision requirements to examine how multiple WM representations influence attentional guidance.

4.1.1 Participants

Using G*Power 3.1, we calculated a required sample size of 12 for power = 0.80, $\alpha = 0.05$, and medium effect size (f = 0.25) (Cohen, 1992). Sixteen university students (5 male, mean age = 19.38 ± 0.89 years) participated. All had normal or corrected-to-normal vision, no color blindness, no psychiatric history, and no prior experience with similar experiments.

4.1.2 Apparatus and Materials

Memory items consisted of one or two colored squares. The search task could present two colored frames. Other materials were identical to Experiment 1.

4.1.3 Experimental Design

We employed a 2 (precision requirement: high, low) × 2 (memory load: 1 item, 2 items) × 4 (matching condition: baseline, match-0, match-1, match-2) within-subjects design. Precision requirements were identical to Experiment 1. Memory load referred to the number of colored squares to be remembered. Matching conditions referred to color relationships between memory items and search distractors: baseline (all white frames), match-0 (two colored distractors, neither matching memory items), match-1 (one distractor matched a memory item), and match-2 (both distractors matched memory items). We recorded accuracy and RTs for both memory detection and visual search tasks.

4.1.4 Procedure

The trial procedure is illustrated in Figure 2. During memory encoding, one or two memory items appeared on a virtual circle (radius: 2.34°) centered on the screen; when two items were presented, they were positioned 180° apart. During memory test, two test items appeared 0.73° to the left and right of the corresponding memory item location. Other procedures were identical to Experiment 1.

The experiment comprised 28 practice trials and 840 experimental trials, divided into two blocks based on precision requirement. Each block contained 210 memory test trials and 210 search trials (30 each of memory-1 baseline, memory-1 match-0, memory-1 match-1, memory-2 baseline, memory-2 match-0, memory-2 match-1, and memory-2 match-2). Trials were randomized within blocks, and block order was counterbalanced. Participants rested for 2 minutes after every 84 trials. The entire experiment lasted approximately 70 minutes.

4.2 Results

4.2.1 Working Memory Task A 2 (precision requirement) × 2 (memory load) repeated-measures ANOVA on WM accuracy (see Table 1) revealed significant main effects of precision requirement, F(1, 15) = 71.13, $p < 0.001$, $p^2 = 0.83$, with lower accuracy under high (M = 0.84, 95% CI: [0.82, 0.87]) versus low precision requirements (M = 0.93, 95% CI: [0.91, 0.95]), and memory load, F(1, 15) = 77.23, $p < 0.001$, $p^2 = 0.84$, with higher accuracy for memory-1 (M = 0.95, 95% CI: [0.94, 0.97]) versus memory-2 (M = 0.81, 95% CI: [0.78, 0.85]). The interaction was significant, F(1, 15) = 12.52, $p = 0.003$, $p^2 = 0.46$. Simple effects analysis showed that accuracy was higher for memory-1 versus memory-2 under both high, F(1, 15) = 70.56, $p < 0.001$, and low precision requirements, F(1, 15) = 58.85, $p < 0.001$.

4.2.2 Visual Search Task A 2 (precision requirement) × 7 (memory load-matching condition) repeated-measures ANOVA on search accuracy (see Table 2) revealed no significant effects (all $ps > 0.18$).

For search RTs, we excluded incorrect trials (0.78% of total) and outliers beyond M ± 2.5 SD (1.06% of total). The ANOVA revealed a significant main effect of memory load-matching condition, F(6, 90) = 13.10, $p < 0.001$, $p^2 = 0.47$, and a significant interaction with precision requirement, F(6, 90) = 2.55, $p = 0.025$, $p^2 = 0.15$. The main effect of precision requirement was not significant, F(1, 15) = 0.22, $p = 0.64$.

A 2 (precision requirement) × 3 (memory load-matching condition: memory-1 match-1, memory-2 match-1, memory-2 match-2) ANOVA on WM-based attentional capture effects revealed a marginally significant main effect of precision requirement, F(1, 15) = 3.92, $p = 0.067$, $p^2 = 0.21$, with larger capture effects under high (M = 65 ms, 95% CI: [41, 89]) versus low precision requirements (M = 37 ms, 95% CI: [11, 63]). The main effect of memory load-matching condition was significant, F(2, 30) = 3.74, $p = 0.035$, $p^2 = 0.20$. Capture effects were larger in memory-2 match-2 (M = 72 ms, 95% CI: [43, 102]) versus memory-2 match-1 (M = 27 ms, 95% CI: [-1, 55], $p < 0.001$). Memory-1 match-1 (M = 54 ms, 95% CI: [26, 82]) did not differ from memory-2 match-1 or memory-2 match-2 (both $ps > 0.19$). The interaction was significant, F(2, 30) = 5.54, $p = 0.009$, $p^2 = 0.27$.

Simple effects analysis revealed that under high precision requirements, the memory load-matching condition effect was significant, F(2, 30) = 5.17, $p = 0.012$, with larger capture effects in memory-2 match-2 (M = 101 ms, 95% CI: [62, 140]) versus memory-2 match-1 (M = 52 ms, 95% CI: [27, 77], $p = 0.003$)

and memory-1 match-1 (M = 43 ms, 95% CI: [7, 78], p = 0.020), which did not differ from each other (p = 0.67). Under low precision requirements, the memory load-matching condition effect was also significant, F(2, 30) = 3.93, p = 0.031, with larger capture effects in memory-2 match-2 (M = 44 ms, 95% CI: [5, 83]) and memory-1 match-1 (M = 66 ms, 95% CI: [32, 100]) versus memory-2 match-1 (M = 2 ms, 95% CI: [-39, 44], both ps < 0.031). Memory-2 match-2 and memory-1 match-1 did not differ (p = 0.42) (see Figure 3 [Figure 3: see original paper]C).

4.3 Discussion

Experiment 3 examined how WM representation number influences attentional guidance under different precision requirements. WM task results replicated previous experiments: accuracy was lower under high versus low precision requirements. Visual search results showed that under low precision requirements, capture effects did not differ between memory-1 match-1 and memory-2 match-2 conditions, both being larger than memory-2 match-1, consistent with the single-template hypothesis: only one WM representation guides attention under low precision requirements. Thus, in Experiment 2’ s low-precision condition, when multiple representations were held in WM, only the high-activation representation guided attention. Under high precision requirements, however, capture effects were larger in memory-2 match-2 versus memory-2 match-1 and memory-1 match-1 conditions, consistent with the multiple-template hypothesis (Fan et al., 2019; Hollingworth & Beck, 2016): multiple WM representations can guide attention under high precision requirements. Therefore, in Experiment 2’ s high-precision condition, multiple WM representations guided attention regardless of activation state.

What mechanism underlies the influence of WM representation precision requirements on attentional guidance? Experiment 4 employed ERP technology to compare cognitive resource investment during WM and search tasks under different precision requirements, further exploring the mechanism of precision effects on attentional capture.

5 Experiment 4: The Mechanism Underlying WM Representation Precision Effects on Attentional Guidance–ERP Evidence

Experiment 4 examined the mechanism using ERP components including the negative slow wave (NSW) and late positive component (LPC), which reflect WM storage resources and top-down control during maintenance (Kursawe & Zimmer, 2015; Li et al., 2015; Gao et al., 2011), as well as N2 and N2pc, which reflect conflict monitoring/cognitive control and attentional resource allocation, respectively (Heil et al., 2000; Eimer, 1996).

5.1.1 Participants

Based on previous research (Li et al., 2019) reporting an effect size of $p^2 = 0.22$ for N2 amplitude in WM load × distractor congruency interactions, we used G*Power 3.1 to calculate a required sample size of 5 for power = 0.80 and $\alpha = 0.05$. Seventeen university students participated; all had normal or corrected-to-normal vision, no color blindness, no psychiatric history, and no prior experience with similar experiments. One participant was excluded due to excessive movement artifacts, leaving 16 participants (6 male, mean age = 19.44 ± 1.59 years) in the final analysis.

5.1.2 Apparatus and Materials

Materials were identical to Experiment 1.

5.1.3 Experimental Design

We employed a 2 (precision requirement: high, low) × 3 (matching condition: baseline, non-matching, matching) within-subjects design. We recorded accuracy and RTs for WM and search tasks, as well as EEG data.

5.1.4 Procedure

The trial procedure is illustrated in Figure 2. The articulatory suppression task was modified to a silent rehearsal task (Luria et al., 2010), requiring participants to mentally repeat the digits throughout each trial. The search display duration was extended to 2000 ms with no response-terminated offset, ensuring ERP components were not contaminated by stimulus offset. Because N2pc is a lateralized component, search targets appeared only on the left or right sides, with targets and distractors never appearing on the same side. To balance manual responses, participants used “F” and “J” keys. Other procedures were identical to Experiment 1.

The experiment comprised 24 practice trials and 960 experimental trials, divided into two blocks based on precision requirement. Each block contained 240 memory test trials and 240 search trials (80 each of baseline, non-matching, and matching). Trials were randomized within blocks, and block order was counterbalanced. Participants rested for 2 minutes after every 96 trials. The entire experiment lasted approximately 80 minutes.

5.1.5 ERP Recording and Analysis

EEG was recorded using a NeuroScan CURRY 7 system with a 64-channel electrode cap according to the 10-20 international system. Vertical and horizontal electrooculograms were recorded from electrodes above and below the left eye and at the outer canthi of both eyes, respectively. All electrodes were referenced to the left mastoid online, with the right mastoid recorded as an active channel; offline analysis used the average of both mastoids as reference. Electrode impedances were kept below 10 KΩ. Online filtering used a 100 Hz low-pass filter with DC sampling at 1000 Hz. Offline analysis used Scan 4.5 software, with DC correction, artifact correction via regression-based algorithms, and 30 Hz low-pass filtering.

NSW Analysis: We baseline-corrected using the 200 ms pre-stimulus interval and analyzed the 600-1000 ms post-stimulus window at parieto-occipital electrodes (PO7, PO8, Oz) (Yang et al., 2015). Trials with amplitudes exceeding $±$100 V or incorrect responses were excluded, resulting in rejection rates of 46.77% and 36.64% for high- and low-precision conditions, respectively, with 256 and 304 valid trials remaining. Waveforms are shown in Figure 4 [Figure 4: see original paper].

LPC Analysis: We baseline-corrected using the 200 ms pre-stimulus interval and analyzed the 450-1000 ms post-stimulus window at frontal electrodes (F3, Fz, F4, FC3, FCz, FC4) (Li et al., 2010). Exclusion criteria were identical to NSW analysis, with rejection rates of 46.77% and 36.64% for high- and low-precision conditions, respectively, and 256 and 304 valid trials remaining. Waveforms are shown in Figure 5 [Figure 5: see original paper].

N2 Analysis: We baseline-corrected using the 100 ms pre-stimulus interval and analyzed the 250-350 ms post-stimulus window at fronto-central electrodes (Fz, FCz, Cz) (Li et al., 2019), using a $±$20 ms window around each participant’ s peak negative amplitude. Trials with amplitudes exceeding $±$100 V or incorrect responses were excluded. Rejection rates were 23.59%, 20.23%, and 25.94% for baseline, non-matching, and matching conditions under high precision, respectively, with 61, 64, and 59 valid trials remaining; and 20.78%, 21.64%, and 22.81% for corresponding conditions under low precision, with 63, 63, and 62 valid trials remaining. Waveforms are shown in Figure 6 [Figure 6: see original paper]A-B.

N2pc Analysis: We calculated N2pc as the difference between contralateral and ipsilateral electrode activity relative to target location, then averaged across trials. We baseline-corrected using the 100 ms pre-stimulus interval and analyzed the 260-360 ms post-stimulus window at PO7 and PO8 electrodes (Berggren & Eimer, 2018). Trials with amplitudes exceeding $±$100 V or incorrect responses were excluded. Rejection rates were 20.70%, 20.16%, and 19.45% for baseline, non-matching, and matching conditions under high precision, respectively, with 63, 64, and 64 valid trials remaining; and 14.69%, 17.97%, and 17.79% for corresponding conditions under low precision, with 68, 66, and 66 valid trials remaining. Waveforms are shown in Figure 7 [Figure 7: see original paper]A-B.

5.2 Results

5.2.1 Behavioral Results A paired-samples t-test on WM accuracy (see Table 1) revealed lower accuracy under high (M = 0.89, 95% CI: [0.86, 0.93]) versus low precision requirements (M = 0.98, 95% CI: [0.97, 0.99]), t(15) = 7.89,

$p < 0.001$, Cohen’ s d = 3.41.

A 2 (precision requirement) × 3 (matching condition) repeated-measures ANOVA on search accuracy (see Table 2) revealed significant main effects of precision requirement, F(1, 15) = 9.19, p = 0.008, $p^2 = 0.38$, with lower accuracy under high (M = 0.95, 95% CI: [0.93, 0.98]) versus low precision requirements (M = 0.97, 95% CI: [0.96, 0.99]), and matching condition, F(2, 30) = 7.39, p = 0.002, $p^2 = 0.33$. Accuracy was lower in matching (M = 0.95, 95% CI: [0.93, 0.97]) versus non-matching (M = 0.97, 95% CI: [0.95, 0.99], p = 0.011) and baseline (M = 0.97, 95% CI: [0.95, 0.99], p = 0.003) conditions, which did not differ (p = 0.77). The interaction was not significant, F(2, 30) = 1.96, p = 0.16.

For search RTs, we excluded incorrect trials (1.79% of total) and outliers beyond M ± 2.5 SD (1.24% of total). The ANOVA revealed a significant main effect of matching condition, F(2, 30) = 25.87, $p < 0.001$, $p^2 = 0.63$, with longer RTs in matching (M = 810 ms, 95% CI: [774, 846]) versus non-matching (M = 751 ms, 95% CI: [718, 785], $p < 0.001$) and baseline (M = 756 ms, 95% CI: [719, 792], $p < 0.001$) conditions, which did not differ (p = 0.62). No other effects were significant (all ps > 0.16).

A paired-samples t-test on WM-based attentional capture effects revealed larger effects under high (M = 70 ms, 95% CI: [55, 85]) versus low precision requirements (M = 47 ms, 95% CI: [31, 63]), t(15) = 2.24, p = 0.041, Cohen’ s d = 0.56.

5.2.2 ERP Results **NSW**: A paired-samples t-test on NSW amplitude at PO7, PO8, and Oz revealed larger negativity under high (M = -0.97 V, 95% CI: [-1.78, -0.16]) versus low precision requirements (M = -0.25 V, 95% CI: [-1.06, 0.56]), t(15) = 2.23, p = 0.042, Cohen’ s d = 0.56 (see Figure 4).

LPC: A paired-samples t-test on LPC amplitude at F3, Fz, F4, FC3, FCz, and FC4 revealed larger positivity under high (M = -0.92 V, 95% CI: [-1.65, -0.18]) versus low precision requirements (M = -1.79 V, 95% CI: [-2.86, -0.73]), t(15) = 2.16, p = 0.048, Cohen’ s d = 0.56 (see Figure 5).

N2: A 2 (precision requirement) × 3 (matching condition) repeated-measures ANOVA on N2 amplitude at Fz, FCz, and Cz revealed a significant interaction, F(2, 30) = 6.32, p = 0.005, $p^2 = 0.30$. Simple effects analysis showed that under high precision requirements, N2 was larger in matching (M = 1.87 V, 95% CI: [-0.55, 4.29]) versus non-matching (M = 2.59 V, 95% CI: [0.01, 5.17], p = 0.002) and baseline (M = 2.58 V, 95% CI: [0.21, 4.95], p = 0.032) conditions, which did not differ (p = 0.97). Under low precision requirements, matching condition did not affect N2, F(2, 30) = 1.39, p = 0.26 (see Figure 6 [Figure 6: see original paper]D).

N2pc: A 2 (precision requirement) × 3 (matching condition) repeated-measures ANOVA on N2pc amplitude at PO7 and PO8 revealed significant main effects of matching condition, F(2, 30) = 10.29, $p < 0.001$, $p^2 = 0.41$, and a significant interaction, F(2, 30) = 5.59, p = 0.009, $p^2 = 0.27$. N2pc was smaller (less negative) in matching (M = 0.62 V, 95% CI: [-0.16, 1.40]) versus non-matching (M = -0.48 V, 95% CI: [-1.01, 0.05], p = 0.002) and baseline (M = -0.72 V, 95% CI: [-1.14, -0.30], p = 0.004) conditions, which did not differ ($p > 0.05$). Simple effects analysis showed that under high precision requirements, matching condition significantly affected N2pc, F(2, 30) = 18.02, $p < 0.001$, with smaller N2pc in matching (M = 0.88 V, 95% CI: [0.07, 1.68]) versus non-matching (M = -0.50 V, 95% CI: [-1.12, 0.12], p = 0.002) and baseline (M = -1.14 V, 95% CI: [-1.86, -0.43], $p < 0.001$) conditions, and smaller N2pc in non-matching versus baseline (p = 0.033). Under low precision requirements, matching condition did not affect N2pc, F(2, 30) = 2.36, p = 0.11 (see Figure 7 [Figure 7: see original paper]D).

5.3 Discussion

Experiment 4 used ERP technology to analyze cognitive resource investment during WM maintenance and visual search under different precision requirements. Compared to low precision requirements, high precision requirements elicited larger NSW and LPC during the WM maintenance phase. NSW reflects resource investment in WM storage (Yang et al., 2015), indicating that high precision requirements consumed more WM resources than low precision requirements, consistent with previous research (Machizawa et al., 2012). Studies show that representing high-precision visual stimuli requires activation of primary visual cortex for perceptual processing (Ester et al., 2013) and allocation of perceptual attentional resources to memory items (Zhang & Luck, 2015). High-precision WM storage often involves enhanced functional connectivity between prefrontal cortex and primary visual cortex (Zhao et al., 2020), with prefrontal cortex effectively tracking sensory changes and exerting top-down control to modulate visual cortex activation and enhance representation stability (Feredoes et al., 2011; Morcos & Harvey, 2016). LPC reflects top-down control during WM storage (Li et al., 2015; Gao et al., 2011), and Experiment 4’s results indicate that high precision requirements consumed more cognitive control resources than low precision requirements, consistent with previous findings (He et al., 2015).

ERP results during search also revealed that under high precision requirements, distractors matching memory items elicited larger N2 and smaller N2pc compared to non-matching distractors, whereas under low precision requirements, no such differences emerged. N2 reflects cognitive resources invested in conflict detection and resolution (Kanske & Kotz, 2010), while N2pc reflects attentional orienting or resource allocation to targets (Berggren & Eimer, 2018; Eimer, 1996). These results demonstrate differential resource investment and allocation for distractor inhibition and target search across precision requirements.

6 General Discussion

Using the attentional capture paradigm, we manipulated WM representation precision requirements by varying memory-test item discriminability to investigate how resource investment during WM representation influences attentional guidance. Experiment 1 presented one memory item to examine precision effects on WM guidance. Experiment 2 presented two memory items and used cueing to manipulate activation states, examining how precision requirements affect attentional guidance across different activation states. Experiment 3 presented one or two memory items while controlling the number of matching distractors, investigating how many WM representations can simultaneously guide attention. Experiment 4 employed ERP technology to analyze NSW, LPC, N2, and N2pc components during WM maintenance and visual search, exploring the mechanism of WM-based attentional guidance. Results demonstrated that precision requirements influence WM guidance and the number of representations that can simultaneously guide attention, with interactive effects between precision requirements and activation states on attentional capture. Cognitive resources required for different tasks varied across WM representation and search processes.

6.1 The Influence of Resource Investment During WM Representation on Attentional Guidance

In attentional capture paradigms, colored distractors serve as salient stimuli that produce stimulus-driven attentional capture. When colored distractors match WM representations, both stimulus-driven and WM-based attentional capture occur, interfering with target search (Al-Aidroos et al., 2012). Thus, greater capture by matching versus non-matching distractors reflects the coordination between WM-based guidance and cognitive control. In Experiment 1, we manipulated precision requirements: under high precision requirements, the two test colors differed minimally on the color wheel, requiring participants to invest more resources in precise WM processing to perform the memory task; under low precision requirements, the large color difference allowed accurate performance with minimal resource investment. Results showed larger WM-based attentional capture under high versus low precision requirements. The primary reason is that when WM representation consumes substantial cognitive resources, fewer resources remain for distractor inhibition, increasing interference. Conversely, when WM representation consumes minimal resources, sufficient cognitive control resources remain for effective distractor inhibition, reducing interference.

In the attentional capture paradigm involving WM representation followed by search, resource consumption involves three components: (1) WM representation processing consumes WM resources (Emrich et al., 2010); (2) distractor inhibition during search consumes cognitive control resources (Sawaki & Luck, 2010); and (3) target search consumes attentional resources (Kahneman, 1973). Precision requirement variations primarily affect resource consumption during WM representation, which subsequently influences search performance. Experiment 4' s ERP findings revealed that high precision requirements elicited larger NSW and LPC during WM storage, reflecting greater investment in WM storage and top-down control. On one hand, high precision requirements may activate primary visual cortex more strongly for perceptual feature processing of memory items (Ester et al., 2013; Zhao et al., 2020), consuming more WM processing resources and eliciting larger NSW. On the other hand, high precision requirements demand more representation rehearsal and refreshing, consuming more executive attention resources (Hitch et al., 2020) and eliciting larger LPC.

When participants encounter a conflict between matching distractors and search targets, they must make a selection. N2 is associated with conflict monitoring and attentional control, with larger N2 amplitude indicating greater resource investment in monitoring and resolving conflict (Heil et al., 2000). N2 analysis showed that under high precision requirements, inhibiting matching distractors required more resources than inhibiting non-matching distractors, whereas under low precision requirements, no such difference emerged. When WM representation precision requirements increase, maintaining information storage continues to activate primary visual cortex (Ester et al., 2013), and this activation grants matching distractors a competitive advantage, increasing conflict between WM-matching items and search targets. Consequently, under high precision requirements, search displays containing previously represented items elicited larger N2 than other conditions. Under low precision requirements, minimal visual cortex activation during storage prevented distractors from gaining processing advantages, reducing conflict and eliminating N2 differences. From an inhibitory perspective, since participants knew WM items would not become search targets, they could inhibit represented items after search display onset. Under high precision requirements, greater WM resource consumption reduced inhibitory capacity, so matching distractors still produced substantial conflict with search targets, eliciting larger N2. Under low precision requirements, minimal resource consumption left sufficient resources for inhibiting matching distractors, reducing conflict and N2 amplitude.

During visual search, participants must inhibit distractors while locating targets among multiple items, a process requiring cognitive resources. N2pc reflects attentional resource allocation to targets during visual search, with larger N2pc amplitude indicating greater resource investment (Berggren & Eimer, 2018; Eimer, 1996). Under high precision requirements, WM representation of memory items consumed substantial cognitive resources, and matching distractors captured more attention, requiring greater resource investment for distractor inhibition and leaving fewer resources for target search, thereby reducing N2pc amplitude. Under low precision requirements, minimal resource consumption during WM representation enabled effective inhibition of matching distractors while leaving sufficient resources for target search, producing N2pc amplitudes comparable to other conditions.

Alternative explanations for precision requirement effects on attentional guidance include: (1) Precision requirements may alter the scope of perceptual attention, affecting perceptual processing of search targets. Previous research shows that high WM precision loads narrow attentional focus (Li et al., 2019). In visual search, after distractors capture attention under high precision requirements, it may be more difficult to expand attentional scope to process targets, slowing search and increasing attentional capture. (2) Precision requirements may affect neural coding noise, altering representation precision and thus the match between WM representations and distractors. Research shows that when memory and test items differ substantially (low precision requirements), categorical encoding may increase neural coding noise, produce memory biases, and reduce representation precision (Panichello et al., 2019; Schurgin et al., 2020). Consequently, under low versus high precision requirements, reduced WM representation precision may hinder matching with distractors and decrease attentional capture. These alternative explanations warrant further investigation.

6.2 The Influence of WM Representation Activation State and Number on Attentional Guidance

Do WM representation activation state and number influence attentional guidance? Experiments 2 and 3 addressed this question. Experiment 2 presented two memory items and used a cue to indicate which item would more likely be tested, placing it in a high-activation state. Results showed that under low precision requirements, distractors matching high-activation items produced greater attentional capture than those matching low-activation items; under high precision requirements, no such difference emerged. The likely explanation is that under low precision requirements, WM tasks consumed fewer resources, leaving sufficient resources for distractor inhibition. Compared to low-activation representations, high-activation representations reside in the focus of executive processing, are more stable, and are less susceptible to interference (Cowan, 2011), making matching distractors more difficult to inhibit and thus capturing more attention. Under high precision requirements, greater WM resource consumption leaves insufficient resources for distractor inhibition. Research shows that for high-fidelity WM representations, maintaining two objects approaches WM capacity limits (Gao et al., 2013), leaving inadequate resources for inhibition. Consequently, both high- and low-activation matching distractors capture substantial attention.

Experiment 3 presented one or two memory items while controlling the number of colored distractors and their match to memory items. Results showed that under high precision requirements, two WM representations could guide attention simultaneously, whereas under low precision requirements, only one representation guided attention. On one hand, different precision requirements alter cognitive resource investment during WM representation, affecting distractor inhibition. Under high precision requirements, presenting two memory items that both match distractors increases resource consumption through both representation number and precision demands, leaving insufficient resources for distractor inhibition during search. Consequently, two WM-matching distractors capture attention, consistent with the multiple-template hypothesis (Beck et al., 2012). Under low precision requirements, minimal resource investment during WM representation leaves sufficient resources for inhibiting multiple matching distractors, achieving inhibition comparable to single-distractor conditions, consistent with the single-template hypothesis (Olivers et al., 2011). On the other hand, different precision requirements alter WM representation precision, affecting attentional capture by matching distractors. Duncan and Humphreys (1989) proposed that the degree of match between perceptual items and stored attentional templates determines attentional selection, with better matches more likely to become attentional targets. Under low precision requirements, increasing WM representation number reduces representation precision (Bae & Luck, 2017), decreasing the match between distractors and WM representations and reducing attentional capture, resulting in single-template guidance. Under high precision requirements, greater resource investment in representation rehearsal and refreshing enhances representation precision, facilitating matches between distractors and WM representations and promoting attentional capture, resulting in multiple-template guidance.

How resources are allocated between WM representation and subsequent distractor inhibition during search may underlie the single-template versus multiple-template debate. In attentional capture paradigms, when WM representation consumes minimal resources, sufficient resources remain for distractor inhibition, yielding single-template guidance. When WM representation consumes substantial resources, leaving inadequate resources for distractor inhibition, multiple-template guidance emerges.

7 Conclusion

In attentional capture paradigms, high WM representation precision requirements produce greater attentional capture by WM-matching items than low precision requirements. The underlying mechanism involves altered cognitive resource allocation: high precision requirements increase resource consumption during WM representation, reducing resources available for target search and increasing attentional capture by distractors.

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