Distinct prioritization of visual working memory representations for search and for recall

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Abstract

Despite the inherent limitations of visual working memory (VWM), it effectively supports numerous everyday behaviors – capabilities that are due, in part, to its flexibility. An observer can flexibly prioritize VWM representations to support at least two behavioral outcomes: An item can be prioritized to enhance its representational quality, thereby enhancing recall precision, and an item can be granted “template status,” allowing it to bias attention during visual search, speeding search for matching targets. Here we examined the relationship between these two forms of prioritization. Research has shown that a byproduct of granting an item template status is that its precision is enhanced; however, it is unclear if the inverse is also true: Does prioritizing an item for enhanced representational quality cause that item to bias attention? In the present study, participants remembered the colors of two squares for a subsequent recall task, and one was cued, indicating it was 80% likely to be the target of the memory test. To assess template status, a subset of trials ended in a visual search task in which a colored singleton distractor matched the color of the cued item in memory, the non-cued item, or an unrelated color. We found that, although the cue was effective at enhancing recall precision of the cued item, it had no systematic effect on which of the two memory items was granted template status. Thus, we conclude that the two forms of prioritization in VWM – prioritization for recall and for search – are distinct.

Keywords Visual working memory · Attention · Visual search

Visual working memory (VWM) – the brain’s short-term storage system for visual information – allows us to remember the equivalent of approximately 3–4 visual objects at a given time (Cowan, 2001; Ma, Husain, & Bays, 2014). Despite being restricted by a capacity limitation, VWM plays an important role in many aspects of cognition. Individual differences in VWM performance, for instance, are often highly correlated with measures of fluid intelligence (for a review see Brady, Konkle, & Alvarez, 2011). Despite its inherent limitations, VWM is capable of playing such roles due, in part, to its flexibility: Representations in VWM can be strategically *prioritized* based on the current goals of an individual in at least two different manners. First, during the search for a specific target in the environment, the target’s identity (referred to as the target template) is maintained in VWM and prioritized such that it uniquely interacts with attention, biasing attention towards visually similar inputs to aid search (Bundesen, 1990;

Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Wolfe, 1994). Second, when items in the environment vary in the extent to which they are relevant to a current task, VWM resources can be flexibly distributed across encoded items so that those that are most important are also best remembered (Dube, Emrich, & Al-Aidroos, 2017; Emrich, Lockhart, & Al-Aidroos, 2017). Here we investigated the relationship between these two forms of *prioritization* in VWM: Does prioritizing an item for enhanced representational quality also lead that item to uniquely bias attention during visual search?

Prioritization through state

A “dual-state” account has been proposed that describes a functional division within VWM that allows items to be encoded into different “states” based on their relevance to a current task (Olivers, Peters, Houtkamp, & Roelfsema, 2011). An item that is currently relevant – such as a representation serving as the template for a current visual search – will be encoded in an “active” state, allowing it to actively bias attention towards perceptually similar visual inputs in the environment. An item that is only prospectively relevant – such as a

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representation that may serve as a template for a later search task or as the object of an upcoming memory test, however, will be encoded in an “accessory” state, in which it cannot interact with attention until it becomes relevant.

The functional distinction between these two states is thought to be a result of the prioritization of the currently relevant item. Gunseli et al. (2014), for instance, measured two electrophysiological markers of VWM maintenance during a working memory task: Contralateral delay activity (CDA), reflecting the quantity of stored information, and the late positive complex (LPC), reflecting cognitive effort. In comparing these components across conditions in which the maintained item was used as a search template versus when it was used for simple recognition, they noted that both representations elicited a CDA, but they differed in the extent to which they elicited an LPC. The authors concluded that, though the representations were both stored in VWM, the search template was prioritized such that greater effort was invested in its maintenance. Similarly, a study directly comparing the electrophysiological profiles of currently versus prospectively relevant search templates was also consistent with the prioritization of the current (active) template over the prospective (accessory) item (de Vries, van Driel, & Olivers, 2017). Here, the researchers also noted no differences in CDA amplitude between the two conditions; however, they observed stronger suppression of alpha band activity (8–14 Hz activity; thought to reflect item selection and maintenance) contralateral to currently relevant memory items. The researchers concluded that, in addition to selection and maintenance, lateralized alpha power is *also* sensitive to the relative priority of VWM representations for search. Thus, the functional differences between active and accessory VWM representations are thought to be a byproduct of their relative priority.

Prioritization through resources

The priority of items within a memory array is typically determined following clear task instruction, such as explicitly assigning an item template status (Carlisle, Arita, Pardo, & Woodman, 2011; de Vries et al., 2017; Rajsic, Ouslis, Wilson, & Pratt, 2017; Vickery, King, & Jiang, 2005; Woodman & Arita, 2011), or using cues to identify the item(s) most likely to be the object of a subsequent memory test (Dube et al., 2017; Emrich et al., 2017; Hollingworth & Hwang, 2013; van Moorselaar, Theeuwes, & Olivers, 2014, Experiment 4). Recently, it has been shown that identifying an item as a template for an upcoming search not only causes that item to bias attentional selection, but it also causes that representation to be encoded with greater precision than those items that are accessory (Rajsic et al., 2017). Across two

experiments, Rajsic et al. (2017) had participants encode two colored forms for a subsequent memory test, and a cue indicated which of the two items should serve as the template for an intervening search task requiring a present/absent judgment. The researchers showed that the cued item was remembered with greater precision, suggesting that search templates received a greater share of VWM resources.

Identifying an item as most likely to be probed in an upcoming memory test has a similar effect on memory performance. In our recent work, we assigned priority to items in a memory array by using spatial (Emrich et al., 2017) and featural (Dube et al., 2017) cues to indicate which items were most likely to be probed in the upcoming memory test. When an item was cued (i.e., identified as high priority), this signaled to the participants that it would serve as the relevant item on an above-chance proportion of – but not all – trials, incentivizing the maintenance of the full set of items, and allowing for recall tests of both prioritized and non-prioritized items. Manipulating the probabilities assigned to these cues has reliable effects on memory performance: High priority items both are more likely to be successfully encoded into VWM, and are encoded with greater precision relative to lower priority items (Dube et al., 2017; Emrich et al., 2017). Specifically, VWM resources are distributed amongst the items as a function of their priority such that the most relevant items receive a larger share of the resources and are thus better remembered.

The current study

Prioritization in VWM takes at least two forms. An item can be prioritized by representing it in an active state, while representing concurrently maintained items in an accessory state. For example, assigning an item to be the template in a visual search causes that item to be represented in the active state, and biases attention towards matching representations (known as *attentional capture*). A representation can also be prioritized by assigning it a greater proportion of resources than concurrently maintained representations. For example, using a cue to indicate which item is most likely to be probed for recall causes it to be remembered more precisely. What is the relationship between these two forms of prioritization? While the results of Rajsic et al. (2017), showing that assigning an item template status both causes that item to bias attention *and* enhances the precision with which it is remembered, suggests a 1-to-1 relationship, such a conclusion is unwarranted until the reverse is also evaluated. Indeed, there is some evidence that the process of remembering an item for search (i.e., as a search template) is different to the process associated with VWM storage for recall (Carlisle & Woodman, 2011; Olivers & Eimer, 2011).

This reverse relationship was partially assessed by Hollingworth and Hwang (2013). They used a retro-cue with 80% validity to indicate which of two memory items should be prioritized for recall, and evaluated both recall performance and capture by various singletons in an intervening search task. They found that the cued item was more likely to be successfully recalled during the memory test, suggesting the cue altered priority for recall. They also found that there was no difference in search times when the singleton matched the color of the non-cued memory item relative to a novel color, suggesting the non-cued item was represented in an “accessory” state in memory. Thus, one interpretation of these results is that de-prioritizing a memory item for recall also causes that item to be de-prioritized for search (i.e., represented in an accessory state). Hollingworth and Hwang did not, however, observe any differences in the *precision* of the cued and non-cued representations in memory, nor did they measure the effects of singletons matching the *cued* memory item. As such, it is unclear whether their cues actually affected priority for search, or if both memory items were represented in an accessory state. Indeed, given that their cue was probabilistic in nature, it is likely that it did not affect priority for search (see Dube, Lumsden, & Al-Aidroos, 2018). Accordingly, in the present study we adjusted the paradigm used by Hollingworth and Hwang to address this limitation, and directly tested whether cueing an item to be remembered more precisely also causes that item to bias attention.

Across two experiments, we had participants encode the colors of two simultaneously presented squares, while concurrently cueing the item that was most likely to be probed in a subsequent memory test. On a subset of trials, rather than probing memory, the trial ended with a visual search task in which a color-singleton distractor could either match the identity of the high-priority (i.e., cued) item, the low-priority (i.e., non-cued) item, or could be novel to the trial. If cueing an item for recall also grants its representation template status, then we would observe greater attentional capture (i.e., slower response times) in the search condition in which a distractor matched the color of the cued item relative to when it matched the color of the non-cued item. In line with our previous work, participants remembered this high-priority item more precisely than the low-priority item (Experiment 1) and performed better on tests of the high-priority item in a change detection task (Experiment 2); however, across both experiments, we observed no evidence that the VWM representation of the high-priority item biased attention to a greater degree than the low-priority representation. Thus, despite using the cue to prioritize representations in VWM, the provision of the cue did not also lead that item to uniquely bias attention. In fact, in both Experiment 1 and Experiment 2 we observed attentional biasing by both VWM representations independent of the cue.

Experiment 1

Methods

Participants

Forty-seven undergraduate students from the University of Guelph between the ages of 18 and 27 years ($M = 20.22$) participated for partial course credit. All participants provided informed consent and reported having normal or corrected-to-normal vision and no color blindness.

Stimuli and apparatus

Participants viewed experimental stimuli from a distance of 57 cm, fixed with a head and chin rest. Stimuli were colored squares and white Landolt squares presented on a gray background via a $1,280 \times 1,024$ CRT monitor with a refresh rate of 75 Hz. Colors were selected randomly from a 360° color wheel, as in Dube et al. (2017), with the constraint that colors drawn on a given trial were separated by a minimum of 50° on the wheel.

Procedure

An example trial is depicted in Fig. 1. Each trial began with the 360-ms presentation of a memory array consisting of two colored squares (1.2° in width and height) placed randomly in two of eight possible locations spaced equally around an invisible circle with a diameter of 5.5° , with a line extending from the central fixation point (0.07° radius) toward the item that was most likely to be probed in a subsequent memory test. The validity of the cue was 80%. Following a delay of 800 ms, jittered from trial-to-trial by ± 200 ms, the trial ended in one of two ways. On *memory trials*, the outlines of the two squares reappeared on the screen, surrounded by a 360° color wheel. One of the two squares was probed (highlighted by a thick black line), and participants were to click the color on the wheel that best corresponded with the color of the probed item at initial presentation. On *search trials*, rather than a memory test, the trial instead ended with a visual search task. On these trials, eight Landolt squares (0.44° in width and height) were presented equally spaced in a circle around fixation (with the same eccentricity as the memory array): seven were oriented such that their gaps appeared on either the top or the bottom, and one – the target – such that its gap was on either the left or the right. Participants were to locate the target and indicate its gap position via keypress response with their left hand. On a majority of the search trials, one of the search distractors appeared as a color singleton, the color of which either matched the high-priority item in memory (the cued item in the memory array), or the color of the low-priority item (the non-cued item in the memory array), or was a novel color for that trial.

Fig. 1 Example trial sequence. The trial ended in either a memory test or a visual search. The example shows a valid-cue memory trial, and a high-priority match search distractor. Actual stimuli were presented on a gray background

On some trials, no singleton was presented. Overall, participants completed 540 experimental trials, 360 of which were memory trials and 180 were search trials (45 trials per each of the four singleton conditions: high-priority match, low-priority match, novel, and no singleton).

Analysis

Here we assess VWM performance using a three-parameter mixture model (Bays, Catalao, & Husain, 2009) to decompose participants' raw response errors (i.e., the degree of distance between the color of the probed item and the participant's response). This model asserts that there are three separate components that contribute to such response errors: a uniform distribution that reflects the proportion of random guesses (guess rate; P_{guess}); a von Mises distribution that reflects responses centered on the correct target color (the standard deviation of which is inversely related to representational precision; SD_{MM}), and a von Mises distribution that reflects the proportion of responses centered around the non-probed memory item (i.e., swap trials; P_{swap}). Errors were decomposed using Maximum Likelihood Estimation via MATLAB and the MemToolBox library (Suchow, Brady, Fougner, & Alvarez, 2013). It is worth noting that a number of models have been proposed to decompose data such as these (van den Berg, Shin, Chou, George, & Ma, 2012; Zhang & Luck, 2008). While the differences between these models are critical when evaluating questions about the architecture of VWM and its capacity, in the present study our question instead surrounds the effects of different forms of prioritization. As such, our analyses of participants' recall performance primarily uses the most commonly implemented

model and reported parameters: P_{guess} , SD_{MM} , as well as the standard deviation of the raw response distributions (SD_{response}), as an assumption free measure of VWM performance.

Results

We removed participants based on separate memory and search performance criteria. We removed participants for whom memory data in one or more condition had a model fit characterized as an outlier. Specifically, we removed model estimates if SD_{MM} fell above 105° (i.e., the value associated with random color selection). Given that the removal of a single condition resulted in the loss of 50% of a participant's data (i.e., the outlying SD_{MM} estimate and corresponding P_{guess} estimate), a single outlying model fit necessitated the removal of all of the participant's data. This resulted in the removal of eight participants. Further, we removed participants with a search error rate above 40%, resulting in the removal of an additional five participants. Analyses were carried out on a final sample of 34 participants.

Memory performance

We compared memory performance on validly cued trials (i.e., trials that probed the high-priority item) versus invalidly cued trials (i.e., trials that probed the low-priority item) across SD_{response} as well as all three model parameters: P_{guess} , SD_{MM} , and P_{swap} . The standard deviations of the raw response distributions (SD_{response}) corresponding to trials that probed the high- ($M = 38.26$, $SE = 2.47$) versus low-priority ($M = 46.05$, $SE = 2.86$) memory item for recall differed significantly,

Fig. 2 Guess rate (P_{guess}) and standard deviation (SD_{MM}) results from the three-parameter mixture model. **(a)** Probability of a random guess for high- vs. low-priority items. **(b)** Standard deviations across probe types.

$t(33) = -3.846, p < .001$, such that variability was greater (and, thus, precision was lower) in the low-priority probe condition. Parameter estimates for P_{guess} as well as SD_{MM} also differed significantly between high- and low-priority items (Fig. 2a and b, respectively). Specifically, P_{guess} was significantly lower when participants were asked to recall the high-priority item than when asked to recall the low-priority item, $t(33) = -2.96, p < .01$. Similarly, SD_{MM} estimates were significantly lower when participants were asked to recall the high-priority item than when asked to recall the low-priority item, $t(33) = -2.41, p = .022$. On average, P_{swap} (i.e., the mistaken reporting of the color of the non-probed item) accounted for less than 1% of all trials, and did not significantly differ for high- and low-priority trials, $t(33) = -0.61, p = 0.55$. Thus, as predicted, participants were able to use the cue to prioritize the relevant item such that it was more likely to be encoded, and more precisely remembered, than the low priority item.

Visual Search

Accuracy Overall, search target discrimination accuracy was high ($M = 91.34\%$). A four-way (Singleton Condition: High Priority Match, Low Priority Match, Novel, and No Distractor) repeated measures ANOVA on accuracy scores yielded no significant main effect of singleton condition, $F(3,33) = 1.492, p = 0.221$. As such, accuracy did not systematically vary by condition (see Table 1 for a summary).

Reaction times See Fig. 3 for a summary of reaction times. We trimmed visual search reaction times for each

Table 1 Mean target detection accuracy (and SD) across conditions and experiments (%)

Singleton conditions				
Experiment	HP Match	LP Match	Novel	No Distractor
1	93.88 (0.05)	92.37 (0.07)	93.04 (0.06)	91.67 (0.07)
2	92.10 (0.08)	93.33 (0.08)	93.70 (0.08)	94.40 (0.09)

Here, high and low priority refer to the items that were most and least likely to be probed for recall, respectively. Error bars in all figures represent adjusted within-subject standard error (Morey, 2008)

participant to 2.5 standard deviations of the condition mean, resulting in the loss of, on average, <1% of trials. We subjected search reaction times on correct trials to a four-way (Singleton Condition: High Priority Match, Low Priority Match, Novel, and No Distractor) repeated measures ANOVA, yielding a significant main effect of distractor type, $F(3,33) = 3.07, p = 0.031, \eta_p^2 = 0.085$. Individual t-tests yielded no statistically significant difference between the high-priority match ($M = 0.993, SE = .123$) and low-priority match ($M = 0.995, SE = .133$) search conditions, $t(33) = -0.132, p = 0.896$. Reaction times in the high-priority match condition differed statistically significantly from both the novel condition, $t(33) = 2.04, p = .049$, and the no-distractor condition, $t(33) = 1.90, p = .050$, as did reaction times in the low-priority match condition; $t(33) = 2.04, p = .048$, and $t(33) = 2.88, p = .007$, respectively. Thus, we observed no evidence that the high- and low-priority items in memory differed in the extent to which they interacted with attentional selection during search. To more fully assess the null difference between high- and low-priority matching search conditions, we conducted a Bayesian t-test using the recommended priors (JASP Team, 2018; Rouder, Speckman, Sun, Morey, & Iverson, 2009) that compared the null

Fig. 3 Reaction times across all singleton conditions in Experiment 1: high-priority (HP) match, low-priority (LP) match, novel, and no distractor

model against the alternative, and found a Bayes factor (BF_{01}) of 5.40, providing converging evidence that the cue in the present study did not alter priority for search.

Discussion

The results of Experiment 1 suggest that, although the cued item in the memory array was effectively prioritized for recall, as evidenced by enhanced memory performance on tests of the cued representation, the cue did not determine which representation would guide subsequent attention. That is, we observed no differences between response times on high-priority-match and low-priority-match singleton distractor conditions. Notably, however, we also observed no statistically significant difference between response times between novel and no-distractor search conditions, suggesting that perhaps we did not have enough stimulus energy to observe capture in the novel search condition. As such, we conducted Experiment 2 to replicate the main findings from Experiment 1, and to assess whether increasing the contrast between singletons and the display background would lead to the more conventional finding that even novel distractors somewhat capture attention.

Experiment 2

Methods

Methods for Experiment 2 were identical to those of Experiment 1 with the exceptions noted below.

Participants

Participants were a new set of 40 undergraduate students from the University of Guelph between the ages of 17 and 22 years ($M = 18.27$).

Stimuli and apparatus

Experimental stimuli remained the same; however, the background was changed to black and search stimuli (Landolt squares) were changed to gray. Responses were collected via an Xbox gamepad controller for maximal response time sensitivity.

Procedure and analysis

Each trial in Experiment 2 began the same way as in Experiment 1 (i.e., with the presentation of a two-item memory array and simultaneous cue that was 80% valid). Trials ending in a visual search task were also unchanged from Experiment 1. Trials ending in a memory test,

however, were adjusted such that participants completed a change-detection task instead of the partial report task detailed in Experiment 1, and change-detection accuracy served as our measure of memory performance. We opted to switch to a change-detection task in order to increase power in our design: Given that participants can respond much more quickly in this task, we were able to increase the number of trials in the experiment. This change also afforded us the ability to collect responses via the Xbox controller rather than a mouse, which allowed for greater sensitivity in recording response times.

On memory trials, 600–1,000 ms after the removal of the memory array, the originally presented squares reappeared in the same spatial locations as at initial presentation. One of the squares was only an outline, and the other was colored in. On 50% of memory trials, this color was the same as it was at initial presentation (no change trials), and on the other 50% of trials it was instead filled in with a color selected 30° from its original color on the color wheel (change trials). Participants were instructed to indicate if this color had changed since its initial presentation via button-press response on an Xbox gamepad controller. On search trials, participants used the right and left bumpers on the gamepad to indicate gap location on the target item, and on memory trials participants used the 'A' and 'B' buttons to indicate no change or change in item color, respectively. Participants completed a total of 600 trials, 200 of which ended in a search task (50 trials per singleton distractor condition).

Results

We again removed participants based on separate visual search and memory performance criteria. We removed participants with greater than 40% error rates on the change detection trials, resulting in the removal of four participants. The threshold for removal based on visual search error rates was the same as in Experiment 1 (i.e., 40%), and resulted in the removal of an additional eight participants. Analyses were carried out on a final sample of 28 participants.

Memory performance

See Fig. 4a for a summary of change detection results. We compared change detection accuracy on valid trials (i.e., trials on which the high-priority, or cued, item in memory was probed at test) and invalid trials (i.e., trials on which the low-priority, or non-cued, item in memory was probed at test). A paired samples t-test indicated that accuracy on valid trials ($M = 75.40$, $SE = .01$) was statistically significantly greater than accuracy on invalid trials ($M = 69.50$, $SE = .02$), $t(27) = -5.05$, $p < .001$. Thus, as in Experiment

1, the cued representation was effectively prioritized for use in the memory test.

Visual search

Accuracy Overall, search target discrimination accuracy was high ($M = 93.36\%$). A one-way (Singleton Condition: High Priority Match, Low Priority Match, Novel, and No Distractor) repeated measures ANOVA on accuracy scores yielded no significant main effect of singleton condition, $F(3,27) = 1.09$, $p = 0.355$. As such, accuracy did not systematically vary by condition (see Table 1 for a summary across both experiments).

Reaction times See Fig. 4b for a summary of reaction times. We trimmed visual search reaction times for each participant to 2.5 standard deviations of the condition mean, resulting in the loss of, on average, <1% of trials. We again subjected search reaction times on correct trials to a four-way (Singleton Condition: High Priority Match, Low Priority Match, Novel, and No Distractor) repeated measures ANOVA, yielding a significant main effect of distractor type, $F(3,27) = 13.90$, $p < 0.001$, $\eta_p^2 = 0.34$. A t-test yielded no statistically significant difference between the high-priority match ($M = 1.08$, $SE = .03$) and the low-priority match ($M = 1.07$, $SE = .03$) search conditions, $t(27) = 0.45$, $p = 0.656$. Reaction times in the high-priority match condition differed statistically significantly from both the novel condition ($M = 1.04$, $SE = .03$), $t(27) = 2.73$, $p = .011$, and the no-distractor condition ($M = 1.01$, $SE = .03$), $t(27) = 5.95$, $p < .001$, as did reaction times in the low-priority match condition; $t(27) = 2.02$, $p = .05$, and $t(27) = 5.31$, $p < .001$, respectively. Reaction times in the novel distractor condition were statistically significantly longer than in the no-distractor condition, $t(27) = 3.17$, $p = .004$. To more fully assess the null difference between high- and low-priority matching search conditions, we again conducted a Bayesian t-test using the recommended priors (JASP Team, 2018; Rouder et al., 2009) that compared the null model against the alternative, and found a Bayes factor (BF_{01}) of 4.52, providing converging evidence that the cue

in the present study did not alter priority for search. Thus, we again observed no evidence that the high- and low-priority items in memory differed in the extent to which they interacted with attentional selection during search.

General discussion

Across two experiments we demonstrate that the prioritization that underlies granting an item template status in VWM is not the same as assigning high priority to an item for an upcoming memory test. Despite having similar effects on memory performance, prioritizing a representation for recall does not inherently grant that item template status in VWM. That is, a cue signaling which item is most relevant for a memory test does not determine which representation will guide attention.

The limits of probabilistic cues

This work highlights an important point about the use of probabilistic cues to bias item state in VWM (i.e., cues that are less than 100% valid). Indeed, in recent work we have shown that, despite being used in previous research as a means to influence item state, probabilistic *retro-cues* are insufficient to activate the cued item in VWM (Dube et al., 2018). Despite reliably influencing memory performance in the present study, items in VWM identified as high priority for an upcoming memory test consistently failed to bias attentional selection to a greater degree than those identified as low priority during visual search for a static target – a search condition that is conducive to allowing a memory item to occupy the active position (Carlisle et al., 2011; Woodman, Luck, & Schall, 2007). It has, however, repeatedly been shown that when *only one* memory item is maintained for later use, that item *only* bias attention during visual search for a static target (Olivers et al., 2006; van Moorselaar et al., 2014; but see Beck, Hollingworth, & Luck, 2012), and we have similarly shown that a memory item that is retroactively cued as the object of the upcoming memory test with 100% validity also biases attention during visual search (likely due to the removal of

Fig. 4 (a) Accuracy across valid and invalid change detection trials. (b) Reaction times across all singleton conditions: high-priority (HP) match, low-priority (LP) match, novel, and no distractor

the non-cued item from memory; Dube et al., 2018). Thus, when more than a single item is held in memory, it is not simply the distribution of VWM resources across items that determines which items bias attention—there is something inherently different about prioritizing an item for use as a search template that allows that item to interact with attentional selection.

What makes a template special?

The recent investigations of the mechanisms underlying active-state attentional biases have examined the differences in the electrophysiological profiles of search templates versus non-search-templates (i.e., simple recognition templates, and templates for use in a prospective search; de Vries et al., 2017, and Gunseli, Meeter, and Olivers, 2014). In each of these studies, the researchers noted important differences in these profiles. Gunseli and colleagues identified differences in the effort exerted to maintain template versus non-template representations, and de Vries and colleagues identified greater lateralized alpha suppression in response to a currently versus a prospectively relevant template. Based on the results of the current experiment, it is likely that these differences may also be evident when comparing templates for search to high-priority – but non-template – memory representations. That is, perhaps the prioritization of a template is achieved via adjustments to posterior alpha band oscillations, whereas the prioritization of an item for a subsequent memory test is not. More work is required to fully understand the distinctions between such items in memory.

The distinction between prioritizing for recall and for template status

Here we observed no evidence that prioritizing a memory item based on its relevance to an upcoming memory test has any bearing on whether that item uniquely interacts with attention during visual search. Is it ever the case that prioritizing an item for recall will cause that item to also be prioritized for search? One the one hand, we know that the answer is yes: When a cue indicates with 100% validity which item in the memory array will need to be recalled, that item is represented in an active state and biases attention (Olivers et al., 2011). On the other hand, the present results suggest that this previously observed effect may reflect only an indirect relationship, rather than a direct causal one. That is, a 100% valid cue may prompt the removal of the non-cued item from memory, creating the classic condition in which VWM-driven capture is observed (i.e., with a single item in memory).

Interestingly, beyond our main finding that high versus low recall priority did not affect search times, we also note that, with an 80% valid cue, both high-priority matching distractors and low-priority matching distractors appeared to capture

attention. While such a finding would seem to contradict past claims that at most one item can be represented in an active state in VWM at a time (van Moorselaar et al., 2014), this pattern has been reported previously in a design with the same memory load (see van Moorselaar et al., 2014, Fig. 5), and it may reflect participants alternating from time to time between which of the two items will occupy the active position. If, for example, the participant chooses differently on each trial (i.e., sometimes the high-priority item, and sometimes the low-priority item), then it may appear as though *both* are interacting with attention. According to this interpretation, from trial-to-trial, participants in our task chose (either consciously or subconsciously) which item to represent in an active state, and, interestingly, cueing one item for recall had no effect on this choice. This finding is also contradictory to the one described by Hollingworth and Hwang (2013). In their study, they noted that only the prioritized representation was in the “active” state. It is, however, likely that this was not the case: we now know that a probabilistic retro-cue is not sufficient to cause a cued representation to bias attention. It is unclear why observers did not adopt the same strategy of arbitrary selection of a memory item to be active in their study, though this is likely due to methodological differences (i.e., the use of a current, rather than retrospective, cue in the present paradigm, as well as our alternating, rather than intervening, search task). An additional interpretation centers on the recent challenge to the idea that only one item in memory can guide attention at a time. A number of recent papers provide evidence that two representations may simultaneously bias attention during visual search (Bahle, Beck, & Hollingworth, *in press*; Beck & Hollingworth, 2017; Chen & Du, 2017). By this account, exacerbated attentional capture in both the high-priority match and the low-priority match distractor conditions are a consequence of *both* items acting as a template guiding search. Though both interpretations are theoretically very different, the takeaway for the current study remains the same: The cue does not influence which item biases attention during search, either because the observer arbitrarily chooses an item to serve as a template, or because *both* items are granted template status. Thus, there would seem to be minimal to no direct relationship between prioritizing for recall and prioritizing for search.

Conclusion

To conclude, assigning priority for recall to items in a memory array benefits memory performance for the high-priority item; however, this prioritization is not sufficient to also grant the prioritized item template status. Despite enhanced memory performance, the prioritized item does not uniquely interact with attentional selection in a subsequent visual search.

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