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Compensation mechanisms that improve distractor filtering are short-lived

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ABSTRACT

We investigated possible compensation mechanisms for improving filtering of distractors from entering visual Working Memory (WM). Participants preformed a change-detection task in which three targets, six targets, or three targets along with three distractors (the filtering trial) were randomly presented. In six experiments, we tried to reduce the filtering cost, calculated as the difference in accuracy between the three targets and the filtering condition, by either cueing the possible locations of the distractors using placeholders (that could be either fixed throughout the experiment or change every trial; i.e., location cue), or by providing the location cue coupled with a warning cue singling the upcoming filtering trial. Results revealed that the filtering cost was not reduced by a fixed location cue (Experiment 1 and Experiment 5). However, the fixed location cue coupled with a warning cue (Experiment 2 and Experiment 5) or a location cue that changed positions every trial (Experiment 6), were sufficient to reduce the filtering cost. Additionally, longer preparation interval for filtering trials did not further reduce the filtering cost (Experiment 3). We argue these findings support that in the context of visual WM, spatial filtering settings can only be held for a limited amount of time. Thus, these filtering settings must be reactivated in order to be effective and to reduce the filtering cost.

1. Introduction

Our cognitive system deals with a highly crowded environment, and cannot fully process all of the incoming stimuli. In order to guide behavior towards task related goals, one needs to focus attention towards the relevant information in the environment and filter out irrelevant information. However, filtering irrelevant information is not a prefect process, and attention can be involuntarily allocated to stimuli in the environment, even if they are irrelevant to the current task. Yet, completely ignoring irrelevant information may result in missing important changes in the environment that require adjustment of ongoing behavior (Lahav & Tsal, 2013; Tsal & Makovski, 2006). Over the years, research on filtering irrelevant information has mainly focused on studying the various conditions under which individuals demonstrate poor filtering ability, resulting in a decrement in task performance (i.e., filtering cost) in either accuracy, response speed or both (e.g., Anderson, Laurent, & Yantis, 2011; Eriksen & Eriksen, 1974; Folk, Leber, & Egeth, 2002, 2008; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; MacLeod, 1991; Stroop, 1935; Theeuwes & Godijn, 2002; Yantis, 1996). Therefore, it is important to understand which compensation mechanisms are available in order to overcome poor filtering of irrelevant information.

Many studies have shown that using cues that mark the relevant information can help focus attention to that information and improve performance (e.g., Luck, Hillyard, Mouloua, & Hawkins, 1996; Luria & Vogel, 2011; Posner, 1978, 1980; Posner, Snyder, & Davidson, 1980; Ravizza, Uitvlugt, & Hazeltine, 2016; Schmidt, Vogel, Woodman, & Luck, 2002). For example, Nakayama and Mackeben (1989) applied a visual search task in which a cue signaling target location was either visible throughout the trial (sustained cuing) or appeared shortly before the search array (transient cuing). Sustained cuing improved search performance, even when the cue was absent but the observer had knowledge about target location, suggesting a sustained component of attention that is subjected to voluntary control. Furthermore, transient cuing improved performance when the cue appeared only shortly before the search array, but not when it appeared at longer durations before target onset, and this improvement was not modulated by prior knowledge about target location. Nakayama and

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Mackeben suggested that this finding indicated a transient component of attention that can be summoned quickly to a location in the visual field but then cannot be sustained at that position. Overall, Nakayama and Mackeben (1989) provided evidence for at least two distinct attentional mechanisms that can aide performance in a crowded environment: a sustained component of attention that is subjected to voluntary control and an earlier transient component that is not subjected to voluntary control.

Note that in these studies the cues were used to mark possible targets positions, and not distractors. However, in everyday life when searching for a target, individuals often know the location of the irrelevant items instead of the location of the relevant items. For instance, when picking up your son from kindergarten, you know he does not like to swing, so you will probably not start looking for him on the swing or near it. Studies that did focus on cueing the distractors using visual search tasks and target identification tasks have shown that cuing implicitly or explicitly the location of the upcoming distractor reduced distractor processing interference (Arita, Carlisle, & Woodman, 2012; Beck & Hollingworth, 2015; Leber, Gwinn, Hong, & O'Toole, 2016; Munneke, Heslenfeld, Usrey, Theeuwes, & Mangun, 2011; Munneke, Van der Stigchel, & Theeuwes, 2008; Van der Stigchel, Heslenfeld, & Theeuwes, 2006; Van der Stigchel & Theeuwes, 2005; Watson & Humphreys, 1997). Conversely, cuing a feature of the distractor did not ameliorate performance (Beck & Hollingworth, 2015). Accordingly, the present study focused on highlighting the possible distractor spatial positions. Further studies showed that this reduction in distractor related interference was accompanied in an anticipatory activation in the occipital cortex contralateral to the expected distractor, with no additional activity in occipital cortex contralateral to the target (Ruff & Driver, 2006). These findings were taken to support an inhibitory attentional mechanism that can suppress expected distractor locations in a top-down manner, thus helping to optimize filtering of irrelevant information and select relevant information for further processing (Munneke et al., 2008; Watson & Humphreys, 1997).

In the context of visual WM, it has been argued that the ability to filter out irrelevant information, and more specifically the ability to prevent irrelevant information from entering the limited visual WM workspace underlies individual differences in visual WM capacity (Awh & Vogel, 2008; Fukuda & Vogel, 2009, 2011; Gaspar, Christie, Prime, Jolicœur, & McDonald, 2016; Jost, Bryck, Vogel, & Mayr, 2011; Jost & Mayr, 2016; McNab & Klingberg, 2008; Owens, Koster, & Derakshan, 2012; Vogel & Awh, 2008). For example, Vogel, McCollough, and Machizawa (2005, Experiment 2) used a bilateral change-detection task in which participants were briefly presented with a memory array consisting of colored squares, followed by a retention interval (of about 1 s), and then a test array in which participants indicated whether the test array was identical or different from the remembered memory array (i.e., when one of the squares changed its color). An arrow cue presented before the memory array pointed to the left or to the right side of the display, or pointed to one of the quarters on the left or the right side of the display (e.g., top left quarter). The arrow cue singled participants whether they should memorize all items on that side (e.g., to memorize all colored squares on the left side of the display), or memorize only part of the items on that side (e.g., to memorize only the colored squares at the top left quarter of the screen which served as targets), and ignore the rest of the items on that side (i.e., colored squares at the bottom left quarter of the screen which served as distractors).

Therefore, participants were cued about the spatial area in which targets were about to appear and were cued about the appearance of the upcoming filtering trial (i.e., targets along with distractors). Participants performed the task while a neural marker that reflects the number of items encoded and maintained in visual WM was recorded (i.e., Contralateral Delayed Activity; CDA; Luria, Balaban, Awh, & Vogel, 2016; McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004; Vogel et al., 2005). Vogel et al. (2005) results showed that high-capacity individuals successfully filtered out the distractors, such that their CDA amplitude did not differ when comparing a condition with two targets with a condition with two targets and two distractors. Conversely, low-capacity individuals were not able to filter out the irrelevant items from entering the visual WM workspace, and their CDA amplitude in a condition that included two targets and two distractors was higher than a condition with two targets.

This study and other studies which provided cues in change-detection visual WM tasks, provided cues about possible targets positions (Ravizza et al., 2016; Schmidt et al., 2002; Woodman, Vecera, & Luck, 2003), and not about possible distractors positions. Hence, it is not clear whether cues that mark the distractors can compensate and by that improve the ability to filter out irrelevant information from entering the limited visual WM workspace, and this was the purpose of the current study.

We investigated whether a location cue (i.e. placeholders) that marked the locations of distractors, or a combination of a location cue and a filtering warning trial cue singling the upcoming filtering trial (i.e., the appearance of targets along with distractors), can improve filtering performance in a visual WM task. In six experiments, participants performed a change-detection task in which either three targets, six targets, or three targets along with three distractors appeared in the memory array. We sought to test whether performance in the filtering condition will improve when the cue is present relative to cue absent blocks, such that the filtering cost, which was calculated as the difference in accuracy between the three targets condition and the three targets with three distractors condition, will be smaller in cue present blocks relative to filtering cost in cue absent blocks. In addition, given the arguments associating filtering ability with individual differences in WM capacity (Vogel et al., 2005), we sought to test whether using these cues for filtering distractors will be more beneficial for individuals with high or low visual WM capacity, such that their filtering cost for cue present blocks will be smaller.

To anticipate the results, the location cue did not reduce the filtering cost when the distractors' locations were fixed throughout the experiment (Experiment 1 and Experiment 5). However, using the fixed location cue coupled with a filtering trial warning cue was able to reduce the filtering cost (Experiment 2 and Experiment 5). We argue that these findings support that in the context of visual WM, spatial filtering settings of the distractors can only be held for a limited amount of time. Thus, to compensate for poor filtering of irrelevant information from entering the limited visual WM workspace, the filtering settings need to be reactivated. When only the fixed location cue was used, the filtering settings contained constant distractor positions throughout the experiment. To reduce the filtering cost, the filtering settings had to be continuously active throughout the whole cue present trials (i.e., filtering and non-filtering trials) to enable the compensation mechanisms to suppress the distractors.

We suggest that filtering settings about spatial locations of the distractors could only be activated for a limited amount of time, which is why the fixed location cue was not sufficient to reduce the filtering cost. Nonetheless, when the fixed location cue was combined with a warning cue, singling participants the appearance of the upcoming distractors along with targets, it enabled the reactivation of the filtering settings for filtering trials, resulting in a reduced filtering cost. After replicating the effect ruling out certain confounds, we moved to test a prediction derived by such a *short-lived* compensation mechanism.