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Research Report

The lasting memory enhancements of retrospective attention

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ABSTRACT

Behavioral research has shown that spatial cues that orient attention toward task relevant items being maintained in visual short-term memory (VSTM) enhance item memory accuracy. However, it is unknown if these retrospective attentional cues ("retro-cues") enhance memory beyond typical short-term memory delays. It is also unknown whether retro-cues affect the spatial information associated with VSTM representations. Emerging evidence suggests that processes that affect short-term memory maintenance may also affect long-term memory (LTM) but little work has investigated the role of attention in LTM. In the current event-related potential (ERP) study, we investigated the duration of retrospective attention effects and the impact of retrospective attention manipulations on VSTM representations. Results revealed that retro-cueing improved both VSTM and LTM memory accuracy and that posterior maximal ERPs observed during VSTM maintenance predicted subsequent LTM performance. N2pc ERPs associated with attentional selection were attenuated by retro-cueing suggesting that retrospective attention may disrupt maintenance of spatial configural information in VSTM. Collectively, these findings suggest that retrospective attention can alter the structure of memory representations, which impacts memory performance beyond short-term memory delays.

1. Introduction

Visual Short Term Memory (VSTM) is a capacity limited system that represents visual information after it is no longer available through sensory input. Although capacity is limited and varies by individual, studies have discovered that VSTM capacity and accuracy can be enhanced via spatially informative, retrospective cues ("retro-cues") (Makovski and Jiang, 2007; Makovski et al., 2008, 2007). In these studies, the retro-cue (a small arrow, for example) is presented briefly during the delay period between array presentation and memory probe and indicates which item will later be probed at test. Behavioral results from such studies reveal greater accuracy and faster response times for retro-cue trials that are similar to performance benefits seen when orienting attention before a perceptual array (Griffin and Nobre, 2003; Makovski and Jiang, 2007).

There are a few suggested mechanisms for how retrospective attention enhances VSTM performance. One explanation is that, as item representations compete with one another in VSTM, the retro-cue isolates the important "to-be-probed" item, which causes the other items in VSTM to become task-irrelevant and consequently reduces effective memory load (Matsukura et al., 2007). Consistent with this account, research has shown greater retro-cue memory benefits at larger set sizes where interitem interference is higher compared to smaller set sizes (Duarte et al., 2013; Kuo et al., 2012; Lepsien and Nobre, 2007). Another, non-mutually exclusive explanation is that retro-cues reduce the number of comparisons needing to be made between the probe item and representations held in VSTM (Makovski et al., 2008).

The temporal resolution of electroencephalography (EEG) lends itself well to investigating how retrospective attention enhances VSTM performance. An event related potential (ERP) of particular relevance for investigating VSTM maintenance is the "contralateral delay activity" (CDA). The CDA is hypothesized to reflect the same persistent delay period activity observed in the extrastriate cortex in fMRI studies (Anderson et al., 2011; McCollough et al., 2007; Vogel and Machizawa, 2004). The CDA presents as sustained negative-going activity over posterior electrodes in the contralateral hemisphere with respect to the visual field in which task-relevant items were presented. The amplitude of the CDA increases with the number of items accurately held in VWM, but reaches an asymptote at an individual's own working memory capacity, supporting the idea that it reflects VWM maintenance (McCollough et al., 2007). Only two studies have investigated the effects of retrospective attention on VSTM maintenance as measured by the CDA (Duarte et al., 2013; Kuo et al., 2012). Both studies found memory performance benefits for retro-cue trials were more pronounced at higher set sizes, consistent with the idea that retro-

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cues reduce effective memory load. The ERP results also corroborated the load-reduction hypothesis by revealing that CDA magnitude was reduced after the presentation of retro-cues particularly at the larger set sizes. We additionally found a reduction in P3b latency and amplitude associated with probe items following retro-cues, supporting the hypothesis that retro-cues may also enhance memory performance by reducing the demands on memory updating processes (Duarte et al., 2013).

While an increasing number of studies have investigated interactions between attention and VSTM, relatively little work has assessed the duration of attentional manipulations. Specifically, there have been no studies investigating whether retro-cue effects persist beyond short-term memory delays. Studies manipulating retrospective attention have typically use colored squares, unnamable shapes, or other repeating stimuli. These kinds of stimuli make it impossible to test memory beyond short-term delays. In the present study, we used images of unique, namable objects as stimuli, which allowed us to test memory at both short-term and long-term delays. We were particularly interested in assessing the duration of retro-cue effects because emerging evidence suggests that processes that affect short-term memory maintenance may also affect long-term memory (LTM). Specifically, sustained ERPs measured during short-term memory delay periods can distinguish items that are later remembered from those that are forgotten, supporting the idea that STM maintenance contributes to LTM performance (Khader et al., 2007). Although no work has investigated the lasting effects of retrospective attention, a reasonable prediction is that short-term memory improvements afforded by retrospective attention persist in LTM performance. To this end, our first goal in the current study was to assess the effects of retro-cuing on both VSTM and LTM performance and the relationship between LTM and ERPs measured during VSTM maintenance.

A second goal of the present study was to investigate the spatial nature of memory representations and whether memory for spatial configural information would be affected by retrospective attention. Emerging evidence suggests that at least some spatial information from the original display is maintained in VSTM representations (Jiang et al., 2000; Kuo et al., 2009). ERP evidence suggests that participants search for targets in VSTM representations in the same manner in which they would search through a perceptual display. Specifically, the posterior-maximal N2pc that is thought to reflect spatial biasing of attention in extrastriate cortex during visual search (Hopf et al., 2004; Hopf et al., 2000) shows a similar latency and scalp distribution whether participants were searching for a target item in a VSTM representations or a perceptual display (Kuo et al., 2009). If spatial information is preserved in short-term memory representations, N2pc effects to the VSTM test probe in trials without a spatially informative retro-cue should be similar to those observed during target selection during visual search. If retro-cues result in discontinued maintenance of uncued “distractor” items, one might predict that the spatial configuration of the array would no longer be task-relevant, as only the cued item would require active maintenance. Consequently, the N2pc, which is observed only when distractors accompany targets in visual arrays (Luck and Hillyard, 1994), and memory for spatial location of cued items may be reduced following retro-cues relative to spatially uninformative “neutral” cues. Alternatively, it is possible that spatial retro-cues enhance memory for an item's location perhaps via a mental “refreshing” type of mechanism (Johnson et al., 2007) while at the same time reducing maintenance of the array's spatial configuration. This prediction would be consistent with results showing that retro-cueing enhances the quality or “precision” of VSTM representations (Makovski and Pertzov, 2015; Williams et al., 2013), although several studies have found no such effect (Murray et al., 2013; Souza et al., 2014). In this case, memory for spatial location of cued items may be enhanced while the N2pc may be reduced following retro-cues relative to uninformative cues.

In sum, we pursued several goals in the present study aimed at better understanding the lasting effects of attention manipulations. First, we investigated the duration of retrospective attention effects on memory by testing both short-term and long-term delays, and the relationship between ERPs associated with VSTM maintenance and LTM performance. Second, we investigated the spatial nature of VSTM representations and the influence of retrospective attention on these representations by measuring recognition memory both for items and their locations from the array and ERP correlates of spatially-biased attentional selection.

A schematic for all three of the experimental tasks in shown in Fig. 1. For the VSTM task, we employed a novel design in which we tested participants' memory for the same concrete objects at both short-term and long-term delays. Each trial began with an arrow cue that indicated whether the participant should encode objects in either the left or right visual field. Next, an array of colored real world objects (e.g. fruit and computer) was briefly presented in each visual field. For half of the trials, spatially informative “retro-cues” were presented during the delay period that directed the participant's attention toward the location of the to-be-probed item. Participants subsequently decided whether a centrally presented probe object matched one that had been previously presented in the array. For the LTM task, participants were shown objects that were presented as probes during the VSTM task as well as new objects and asked to decide if they recognized them and in which position they were previously presented in the VSTM task. Finally, participants performed a visual search task in which they searched for a target object in an array of objects. This allowed us to compare N2pc components associated with target selection during visual search with those associated with VSTM probes in order to better determine whether visual search operations also contribute to VSTM performance.

2. Results

2.1. Behavioral results

2.1.1. VSTM performance

Item accuracy was estimated using Pr, i.e. p(hits)-p(false alarms) where chance performance is zero (Snodgrass and Corwin, 1988). Item accuracy for neutral cue trials was 0.72 while accuracy for retro-cue trials was 0.86. Mean response time for correct neutral cue trials was 418.79 ms while reaction time for correct retro-cue trials was 374.34 ms. Accuracy for retro-cue trials was significantly higher [$t(1,18)=6.108$, $p<0.001$] and reaction times significantly faster [$t(1,18)=8.266$, $p<0.001$] than for neutral cue trials.

If similar processes support performance in visual search and VSTM tasks, we might predict a relationship between performance measures in these tasks. We computed correlations between the size of the retro-cue effect for both accuracy and response time (i.e. retro Pr–neutral Pr, and neutral RT–retro RT) for short-term memory with accuracy and RT measures for the visual search task. The mean level of accuracy for the visual search task was 89% and the mean response time for correct trials was 1201 ms. None of these correlations were significant [$r(18)$'s < 0.4, p's > 0.1]. It is perhaps worth noting that there was a trend for participants who were faster in correctly identifying the target objects in the search task to also show a larger retro-cue RT effect in the VSTM task [$r(18)=0.4$, $p=0.1$]. It is possible that this correlation might be more evident in a larger sample of participants. Nonetheless, this pattern is supportive of the idea that search operations may