Retrospective attention facilitates short and long-term memory across age

Jonathan Strunk, Lauren Morgan, Sarah Reaves, Paul Verhaeghen, Audrey Duarte

School of Psychology, Georgia Institute of Technology, Atlanta, Georgia, USA

Acknowledgements: This research was supported in part by a NIA Ruth L. Kirschstein National Research Service Award (NRSA) Institutional Research Training Grant, Grant # 5T32AG000175. We thank all of our research participants.

Correspondence to:

Jonathan Strunk, M.S.

654 Cherry St NW, Atlanta Georgia, 30332-0170

jstrunk@gatech.edu

Objectives

Declines in both short and long-term memory are typical of healthy aging. Recent findings suggest that retrospective attentional cues (“retro-cues”) that indicate the location of to-be-probed items enhance both short (STM) and long-term memory (LTM) performance in young adults. Whether older adults can also use retro-cues to facilitate both STM and LTM memory is unknown.

Method

Young and older adults performed a visual STM task in which spatially informative retro-cues or non-informative neutral-cues were presented during STM maintenance of real-world objects. We tested participants’ memory for retro-cued and neutral-cued objects at both at short and long delays in order to measure the effect of retrospective attention on STM and LTM.

Results

Older adults showed reduced STM and LTM capacity compared to young adults. However, they showed similar magnitude retro-cue memory benefits as young adults at both STM and LTM delays.

Discussion

To the best of our knowledge, this is the first study to investigate whether retro-cues improve both STM and LTM in older adults. Our results support the idea that retrospective attention can be an effective means by which older adults can improve their short and long-term memory performance, even in the context of reduced memory capacity.

Keywords: Retro-cues, visual, objects, improvement

INTRODUCTION

Short Term Memory (STM) is a capacity limited system that represents information after it is no longer available through sensory input. The contents of STM can be modified through selective attention (Posner, 1980). Bottom-up selective attention enables involuntarily orienting toward unexpected, salient stimuli. Attention can also be oriented voluntarily in a top-down manner toward any stimulus relevant to current task demands. If attention can be directed to facilitate STM performance, it may prove useful in enhancing the quantity or quality of STM in people with impoverished memory capacity.

STM capacity declines with healthy aging and may contribute to age-related impairments in other cognitive domains (Verhaeghen, 2013). Although the exact nature of this memory deficit is debated, older adults' reduced ability to use top-down attentional processing to control the contents of STM is likely a contributing factor (L Hasher & Zacks, 1988; May, Hasher, & Kane, 1999). Inhibition deficit theory proposes that STM impairments arise from difficulties limiting memory access to task-relevant information and deleting no longer relevant information from STM maintenance (Connelly, Hasher, & Zacks, 1991; Gazzaley & Nobre, 2012; L. Hasher, Quig, & May, 1997; Oberauer, Wendland, & Kliegl, 2003; Rozek, Kemper, & McDowd, 2012). The retro-cue paradigm can be used to investigate the relationship between attention and STM in aging. Participants are shown an array of to-be-remembered items. After a delay, a retroactive spatial cue (e.g. a small arrow) is presented briefly indicating the location of the to-be-probed item. Results from such studies reveal greater accuracy and faster response times for retro-cue than neutral trials (Griffin & Nobre, 2003; Makovski & Jiang, 2007; Makovski, Sussman, & Jiang, 2008; Matsukura, Luck, & Vecera, 2007).

A handful of studies have investigated the effects of retro-cueing on STM in older adults (Duarte et al., 2013; Gilchrist, Duarte, & Verhaeghen, 2016; Newsome et al., 2015; Souza,

2016). Previously, we cued participants to attend to 2-4 colored squares presented briefly (200 ms) to the left or right visual field (Duarte et al., 2013). Spatial retro-cues were presented during retention. Retro-cues improved STM accuracy for young but not older adults. We speculated that older adults might have been unable to use spatial attention cues to improve STM performance. However, one recent study using spatial cues in addition to relatively long array and probe presentation times identified similar retro-cue memory benefits for both young and older adults (Souza, 2016). Furthermore, in another study we found that STM performance in both young and older adults benefitted from non-spatial, verbal retro-cues (Gilchrist et al., 2016). Collectively, the evidence to date suggests that older adults' STM benefits from retrospective attentional cueing for spatial and non-spatial cues.

STM studies typically use repeating stimuli like colored shapes, which prevents memory assessment beyond short-term delays. Given emerging neural evidence suggesting that neural mechanisms that support STM also LTM (e.g. Axmacher, Haupt, Cohen, Elger, & Fell, 2009; Khader, Ranganath, Seemuller, & Rosler, 2007; Ranganath, Cohen, & Brozinsky, 2005), it is reasonable to predict that retro-cues may facilitate not just STM but also LTM performance. For example, neuroimaging evidence shows that activity in the medial temporal lobe and lateral prefrontal cortex during STM maintenance predicts LTM accuracy (Ranganath et al., 2005). Furthermore, high STM load interferes with medial temporal LTM encoding mechanisms (Axmacher et al., 2009). Collectively, these findings suggest interdependence between attention, STM, and LTM processes. We recently investigated this possibility in young adults by testing participants' memory for the real world objects (e.g. animals, tools) at both short and long delays (Reaves, Strunk, Phillips, Verhaeghen, & Duarte, 2016). Specifically, spatially-informative retro-cues presented during the STM delay period indicated the location of which array object would

be probed at STM. For the LTM task, participants were shown objects that were presented as probes in the STM phase along with new objects. They decided if they recognized the objects and in which position they were previously presented in the STM arrays. Retro-cues improved both STM and LTM accuracy. Furthermore, event-related potentials (ERPs) measured during STM maintenance predicted subsequent LTM accuracy. Given that aging impairs memory at both short and long delays, an interesting question for the current study is whether older adults receive LTM benefits from retrospective attentional cueing. In the current study, we investigated whether older adults would be able to use retrospective attention to enhance both STM and LTM performance.

DESIGN AND METHODS

Participants

Thirty-two young adults between the ages of 18 and 24 and 39 older adults between the ages of 60 and 79 were recruited from the Georgia Institute of Technology and the Atlanta community. All participants gave written informed consent required by the Georgia Institute of Technology Institutional Review Board. 7 young adults were excluded due an incomplete dataset (i.e. 6 did not return for the second session, 1 corrupt data file). 9 older adults did not return for the second session. Consequently, 25 young and 30 older adult participants' data were included in all analyses. All participants were right handed, native English speakers with normal or corrected to normal vision, and reported no psychiatric or neurological disorders. Participants were compensated with one extra credit per hour of participation for a psychology class or \$10.00 per hour. A \$20.00 bonus was given to all participants who completed both experimental sessions. For the included participants, demographics and neuropsychological results are shown

in **Table 1**. EEG data were recorded for all participants but are not presented in the current manuscript.

Neuropsychological Assessment

A 25-minute neuropsychological assessment battery was administered between the short-term memory and long-term memory tasks during each session. Tests included measures of working memory capacity, including the Symmetry Span (Unsworth, Heitz, Schrock, & Engle, 2005) and Running Letter Span (Unsworth et al., 2005), and long-term memory from the Memory Assessment Scale (J. Williams, 1991).

Materials

762 color images of real world objects were collected from Hemera Technologies Photo-Objects DVDs, Bank of Standardized Stimuli (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010), and Massive Memory (Brady, Konkle, Alvarez, & Oliva, 2008) databases, and Google Images. Each object subtended 1.39 degrees of visual angle with participants seated 2 feet from the monitor.

Design

Prior to beginning each session of the experiment, participants engaged in a 20-minute practice of the tasks in which the pace increased up to the experimental pace by the end of practice.

The experiment was divided into two sessions separated by a two-week delay. Each session contained 88 short-term memory trials and 132 long-term memory trials for a total of 176 short-term memory trials and 264 long-term memory trials. We included fewer new than old objects as the main question of interest was whether retro-cueing effects are observed in LTM

for previously presented STM probes (i.e. old items)¹. Objects in the unreferenced hemi-field of the short-term task in the first session were reused as cued hemi-field objects in the second session to obtain a sufficient number of trials for analysis. In a separate behavioral study, we found that participants' memory for the reused objects was not better than chance after two weeks. Behavioral data were combined across testing sessions.

Short-term memory task.

The paradigm is shown in **Figure 1**. Each trial began with a precue that indicated the side

of the screen to which participants should attend. Half of the trials were presented with a left cue and half with a right cue. Two objects were presented in each side of the array in two of three possible locations. A “place-holder” scrambled object was presented on both sides of the

¹ The greater number of old than new probes at LTM could potentially bias responses toward “old” responses. Importantly, this bias would not be expected to influence retro-cueing effects.

array to keep perceptual load balanced across the hemi-fields. The memory array had a radius subtending 3.21 degrees of visual angle. Retro-cues indicated the location of to-be probed objects. Neutral cues were not spatially informative having no arrowheads on any of the points of the fixation cross. Cues subtended 1.39 degrees of visual angle. Half of the trials were retro-cued and the other half were neutral-cued. Half of the trials were match trials in which the probe was previously presented in the cued hemi-field and cued vertical location, and the other half were non-match trials in which the probe was not presented in either hemifield. No objects were presented as probes from a previously uncued hemifield or vertical position. Thus, retro-cued were 100% valid. The task and timing were the same for young and older adults except the probe was presented for 200 ms for the young adults and 500 ms for the older adults. These short presentation times were chosen to optimize our ability to measure lateralized ERPs, which are not presented here. The probe duration was increased for older adults as piloting showed they found the task too difficult with a shorter probe duration. Trials were presented in a pseudorandom order such that no more than four trials of one type (match, non-match, neutral, retro-cue, left, right) were presented consecutively. Participants responded with the index and middle fingers of their right hand pressing one button for match and another for non-match. Hits and misses were defined as “match” and “non-match” responses, respectively, to match trials. Correct rejections and false alarms were defined as “non-match” and “match” responses, respectively, to non-match trials. The task was divided into 8 mini blocks of 11 trials with a 10 second break between each block to minimize fatigue.

Long-term memory task.

All probes from the STM task were presented, along with half as many new objects. Old and new trials were presented in a pseudorandom order such that no more than four trials of the

same type were presented consecutively. First, participants decided whether the object was old or new. LTM hits and misses were defined as “old” and “new” responses, respectively, to objects that were classified as hits or correct rejections during the STM phase. LTM correct rejections and false alarms were defined as “new” and “old” responses, respectively, to new objects not presented during the STM task. Second, participants decided whether the object was presented on the left or right side of the array in the STM task. Third, participants decided which of the three vertical positions the object occupied (top, middle, or bottom). The second and third questions were used to assess location memory and presented to the participant regardless of their response to the old/new question in order to keep motor responses consistent across trials. Participants responded with the index, middle, and ring fingers of their right hand. The task was divided into 4 blocks of 33 trials with a 30 second break between each block. For older adults, the probe was presented for 500 ms (young adults: 200 ms), and all other task timing was consistent across age groups.

RESULTS

Neuropsychological test results

Neuropsychological test scores are shown in **Table 1**. Older participants were more educated than the young adults, and performed similarly on List Recognition and Verbal Span Forward tasks. On all other neuropsychological tasks, young adults performed significantly better than older adults.

Short-term memory performance

Mean proportions of hit rates for match trials and correct rejection rates for non-match trials are shown for neutral-cue and retro-cue conditions in **Table 2**. Hits and misses were defined as “match” and “non-match” responses, respectively, to match trials. Correct rejections

and false alarms were defined as “non-match” and “match” responses, respectively, to non-match trials. Item accuracy was estimated using Pr , i.e. $p(\text{hits}) - p(\text{false alarms})$; in this metric, chance performance is zero (Snodgrass & Corwin, 1988). Pr estimates and mean reaction times (RTs) for hits and correct rejections are shown in **Table 2**. Due to variability in whether participants waited to respond to the response prompt, reaction times for the short-term task were calculated from the probe onset and not the response prompt. We ran a separate analysis using only those trials that the participants responded after the response prompt and the results did not change.

We assessed the effects of retro-cueing on Pr estimates shown in **Table 2** with a Cue (neutral-cue, retro-cue) x Group (young, old) ANOVA. The ANOVA revealed significant main effects of Group [$F(1,53) = 23.2, p < 0.001, \eta^2 = 0.31$] and Cue [$F(1,53) = 38.5, p < 0.001, \eta^2 = 0.42$]. The Cue x Group interaction was also significant [$F(1,53) = 4.8, p = 0.032, \eta^2 = 0.08$]. As can be seen in the table, the main effect of Group reflects the fact that overall, memory accuracy was greater for young than older adults, across cue conditions. The main effect of Cue reflects reliable retro-cue memory benefits for both age groups.

The Cue x Group interaction could suggest that retro-cue benefits were larger for young than older adults. However, the large group difference in the neutral-cue “baseline” condition could potentially exaggerate any perceived group difference in retro-cue utilization.

Additionally, Pr estimates comprise both hits and false alarms, thus the retro-cue effect could be due to benefits for correctly identified “match” items, correctly rejected “non-match” items, or both. Therefore, we investigated retro-cue benefits using proportional estimates (i.e. (retro-cue hits/neutral-cue hits), (retro-cue correct rejections/neutral-cue correct rejections)) for these separate response categories with a Response (hits, correct rejections) x Group (young, old) ANOVA. The ANOVA revealed a main effects of Response [$F(1,53) = 16.2, p < 0.001, \eta^2 =$

0.23], a marginal effect of Group [$F(1,53) = 2.95, p = 0.09, \eta^2 = 0.05$], but no significant interaction [$F(1,53) = 1.22, p = 0.27, \eta^2 = 0.02$]. As can be seen in **Figure 2**, the main effect of Response reflects the greater retro-cue effects for hits than correct rejections for both age groups. Thus, the retro-cue effect observed in corrected memory accuracy (Pr) was largely due to benefits for correctly identified “match” items.

In order to assess the effect of retro-cueing on reaction times, we conducted a Cue (neutral-cue, retro-cue) x Response (hits, correct rejections) x Group (young, old) ANOVA on RTs shown in **Table 2**. A main effect of Group confirmed that older adults were slower than young adults [$F(1,53) = 20.7, p < 0.001, \eta^2 = 0.28$]. The main effect of Cue [$F(1,53) = 35.6, p < 0.001, \eta^2 = 0.40$] confirmed that participants were faster to respond to retro-cued than neutral-cued trials. The lack of Cue x Group interaction suggests that the retro-cue benefit for reaction times was similar across age groups [$F(1,53) < 1, \eta^2 = 0.005$]. Finally, a Cue x Response interaction [$F(1,53) = 6.3, p = 0.015, \eta^2 = 0.11$] was observed, reflecting the larger retro-cue benefit for response times for hits than for correct rejections. The results were unchanged when the same ANOVA was conducted on log-transformed RTs in order to correct for age group differences in slowing (Faust, Balota, Spieler, & Ferraro, 1999).

Long-term memory performance

All objects presented as probes during STM, regardless of a subject’s response, were also presented as probes at LTM. However, for all subsequent analyses, we only consider probes that were correctly endorsed as “matches”, i.e. STM hits, or correctly rejected as “non-matches” i.e. correct rejections during STM. Thus, any retro-cue benefits observed at LTM would be driven by a persistent retro-cue effect for STM hits or STM correct rejections and not by the greater proportion of correct trials for retro-cue than neutral-cue trials at STM. The same analyses for all

probes, regardless of whether STM responses were correct or not, yielded a similar pattern of results as to what is presented below, albeit somewhat reduced in significance. LTM hits and misses were defined as “old” and “new” responses, respectively, to objects that were classified as hits or correct rejections during the STM phase. LTM correct rejections and false alarms were defined as “new” and “old” responses, respectively, to new objects not previously presented during the STM task. Mean proportions of LTM hit rates for STM hit trials and STM correct rejection trials are shown for neutral-cue and retro-cue conditions in **Table 3**. Item recognition was also estimated using Pr. Mean reaction times (RTs) for long-term memory hits are also shown in **Table 3**. Mean reaction times (RTs) for long-term memory were assessed from the first response prompt, as virtually no responses were made prior to the onset of the response prompt.

Given that retro-cue memory benefits were also observed for correctly rejected objects at STM, though to a lesser degree than for STM hits, we wanted to determine whether these benefits would persist into LTM. To this end, we conducted a Cue (retro, neutral) x Response (STM hit, STM correct rejection) x Group ANOVA for Pr estimates for LTM hits. This revealed main effects of Group [$F(1,53) = 9.1, p = 0.004, \eta^2 = 0.15$] and Cue [$F(1,53) = 25.8, p < 0.001, \eta^2 = 0.33$] but no interactions [$F(1, 53)$'s $< 1.6, p$'s $> 0.21, \eta^2 < 0.03$]. The main effect of Cue and lack of interaction confirmed that LTM accuracy was enhanced by retro-cueing to a similar degree for STM hits and STM correct rejections and for both age groups. Given that LTM memory accuracy was reduced overall for older adults, we conducted a similar ANOVA for proportional retro-cue effects for STM hits and STM correct rejections relative to “baseline” neutral-cue conditions for these response categories. These proportional estimates are shown in **Figure 2**. The results of this ANOVA revealed no significant effects of Response, Group or

interaction [$F(1,53)$'s < 1.94 , p 's > 0.17 , $\eta^2 < 0.03$]. As can be seen in **Figure 2**, retro-cue effects in LTM were similar across STM hits and corrections and age groups.

We additionally calculated location memory for retro- and neutral-cued items. These estimates were calculated for STM hits only, as STM correct rejections had no associated location information. We calculated the percentage of trials for which both location questions (hemifield and vertical location) were answered correctly. There were six possible locations (three on each side) making chance performance 16%. A Cue (neutral-cue, retro-cue) x Group (young, old) ANOVA for proportion of items with a correct exact location revealed a main effect of Group [$F(1,53) = 47.1$, $p < 0.001$,

$\eta^2 = 0.47$] and no other effects [F 's < 1 , $\eta^2 < 0.01$]. Thus we did not find a retro-cue benefit for location accuracy, although young adults were able to remember more locations than the older adults did.

In order to assess the effect of retro-cueing on LTM reaction times, we conducted a Cue (neutral-cue, retro-cue) x Response (hits, correct rejections) x Group (young, old) ANOVA on RTs shown in **Table 3**. A main effect of Group confirmed that older adults were slower than

young adults [$F(1,53) = 30.3, p < 0.001, \eta^2 = 0.36$]. There were no effects involving Cue [all F 's $< 1.17, p$'s $> 0.28, \eta^2 < 0.02$]. Thus, the retro-cue induced benefits in response speed observed during STM did not extend into LTM. The results were unchanged when the same ANOVA was conducted on log-transformed RTs.

STM vs. LTM retro-cue effects

In order to assess if the retro-cue effect differed in magnitude between short and long-term memory we submitted proportional retro-cue memory effects for STM hits to a Memory phase (short-term, long-term) x Response (hit, correct rejection) x Group (young, old) ANOVA on these proportional estimates. These proportional estimates of retro-cue memory effects are shown in **Figure 2**. This analysis revealed a main effect of Memory phase [$F(1,53) = 6.55, p = 0.013, \eta^2 = 0.36$], and marginal effects of Group [$F(1,53) = 3.78, p = 0.06, \eta^2 = 0.07$], and Memory phase x Response [$F(1,53) = 3.71, p = 0.05, \eta^2 = 0.07$]. No other effects were observed [$F(1,53)$'s $< 1, \eta^2 < 0.008$]. Follow-up ANOVAs comparing retro-cue effects for each response category revealed a main effect of Memory phase for correct rejections [$F(1,53) = 8.57, p = 0.005, \eta^2 = 0.14$] but not for hits [$F(1,53) < 1, \eta^2 < 0.004$]. As can be seen in **Figure 2**, retro-cue effects were larger at LTM than STM for correct rejections only.

DISCUSSION AND IMPLICATIONS

We examined the effect of aging on the relationship between retrospective attention, short, and long-term memory. To the best of our knowledge, ours is the first study to investigate whether older adults benefit from retro-cueing at both short and long-term memory delays. There were several major findings. First, we showed that spatial retro-cues improved memory accuracy at both short and long delays across age. Second, older adults showed largely similar magnitude

retro-cue benefits as young adults at both memory delays. Third, retro-cueing did not affect long-term memory accuracy for the spatial location of objects.

Retro-cue benefits in short-term memory

As has been shown in numerous prior studies, young adults showed the typical short-term memory retro-cue benefit both in reduced reaction times and improved memory accuracy or change detection for retro-cues compared to neutral cues (e.g. Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Matsukura et al., 2007). In older adults the results are mixed, with some studies showing retro-cue benefits (Gilchrist et al., 2016; Mok, Myers, Wallis, & Nobre, 2016; Souza, 2016) while others do not (Duarte et al., 2013; Newsome et al., 2015). We have speculated that older adults may have been less able to use spatial attention cues rather than retrospective attention per se, to improve STM performance (Duarte et al., 2013; Gilchrist et al., 2016; Newsome et al., 2015). The current results together with recent evidence showing similar retro-cue memory benefits for both young and older adults in spatial cueing paradigms (Mok et al., 2016; Souza, 2016), suggest that older adults' STM benefits from retrospective attentional cueing for spatial and non-spatial (Gilchrist et al., 2016) cues. If older adults are able to use spatial attention to improve STM, what are other possible explanations for the lack of retro-cue effect for older adults in some previous studies? Most previous retro-cueing studies have used simple stimuli (e.g. colors, shapes) repeated across numerous trials resulting in proactive interference. Older adults' difficulty suppressing proactive interference may prevent them from using retro-cues to delete irrelevant memory representations (Newsome et al., 2015). This hypothesis is consistent with numerous studies showing that aging increases susceptibility to proactive interference (L Hasher, Lustig, & Zacks, 2007) and that when this interference is reduced through task manipulations such as reducing set size, older adults' STM performance

improves (Rowe, Hasher, & Turcotte, 2008). The current design with trial-unique real-world objects likely produced minimal proactive interference across trials allowing older adults to effectively use retro-cues to enhance memory performance.

Retro-cue benefits were larger for correct match (i.e., hits) than correct non-match (i.e., correct rejections) objects across age. The most likely explanation for this pattern is the high correct rejection rates across both age groups and cue conditions. Previous retro-cueing studies have largely focused on performance benefits for hits, and several mechanisms have been proposed to explain them (Souza & Oberauer, 2016 for review). We did not design this study with the intent of dissociating these non-mutually exclusive mechanisms but we believe that any of them could contribute to retro-cue effects for hits and correct rejections. For example, evidence showing larger retro-cue effects for larger set sizes supports the idea that retro-cues allow irrelevant items to be removed from active maintenance (e.g. Kuo, Stokes, & Nobre, 2012; Sligte, Scholte, & Lamme, 2008). Importantly, it has been shown that older adults are equally able to employ this mechanism (Duarte et al., 2013; Gilchrist et al., 2016). It has also been suggested that retro-cues protect STM representations from subsequent perceptual interference caused by memory probes (Makovski & Jiang, 2007; Souza, Rerko, & Oberauer, 2016). If inter-item interference in STM were removed following retro-cueing, the impact of additional perceptual interference caused by the probe would likely be reduced resulting in higher hit and correct rejection rates. Finally, retro-cues may restore item representations that would otherwise be forgotten from an intermediary “fragile” STM state to a more stable one (Murray, Nobre, Clark, Cravo, & Stokes, 2013). Given that the capacity of fragile STM decreases as object complexity increases, we believe this restoration mechanism is particularly likely to contribute to the retro-cue effects in the current study, given the complexity of the objects.

Despite the fact that aging reduced STM capacity, as evidenced by lower performance for neutral-cued “baseline” trials, older adults showed only slightly, and not statistically reliable, reductions in retro-cue benefits. This pattern is consistent with recent results showing that aging spares one’s ability to apply selective attention to STM, even if the contents are reduced in quality and/or quantity (Mok et al., 2016; Souza, 2016). We assume that high-precision representations of the complex, colored objects would have been needed to support performance in the current task and that precision was lower for older than young adults. Indeed, previous studies have found that young adults possess higher-precision representations than do older adults, even for small set sizes and for simple shapes (Peich, Husain, & Bays, 2013; Pertzov, Heider, Liang, & Husain, 2015; Souza, 2016). Assuming that aging reduced STM representation precision, it is not surprising that older adults’ memory performance was reduced. Importantly, the current results show that older adults can use retrospective attention to facilitate STM despite the relatively impoverished quality of their STM representations.

Retro-cue benefits in long-term memory

One of the most interesting findings in our study was that retro-cue memory benefits were present in long-term memory similarly for young and older adults. This suggests that the protective features afforded by the retro-cue are not limited to short-term memory delays. One difference between short and long-term delays was that benefits were larger for hits than correct rejections in STM but not in LTM. As discussed above, retro-cues likely restore fragile STM representations, reduce inter-item interference during maintenance, and also protect items from probe interference. These factors likely freed up attentional resources, allowing STM probes to be more richly encoded into LTM traces. The current results in which LTM retro-cue benefits were similar across hits and correct rejections may suggest that probe-related encoding was a

particular determinant of LTM performance. A non-mutually exclusive explanation is that somewhat different mechanisms support retro-cue LTM benefits for hits and correct rejections. For example, the novelty of the non-matching objects may have attracted attention and facilitated their encoding into LTM. Encoding of matching probes, by contrast, could be supported by familiarity signals, which would be conceivably stronger following retro-cueing.

Lastly, our results suggest that retro-cues selectively enhanced item memory but had no effect on location memory. If retro-cues had increased location memory accuracy, it would be consistent with the idea that retro-cueing increases the precision of STM representations (Makovski & Pertzov, 2015; M. Williams, Hong, Kang, Carlisle, & Woodman, 2013). Indeed, retro-cueing has been shown to increase memory accuracy for an item's spatial orientation (Makovski & Pertzov, 2015), and its spatial location (Rerko & Oberauer, 2013). Why might retro-cues not similarly enhance memory accuracy for spatial location in the current study? It is important to note that we tested memory for spatial location explicitly and only at long-term delays. We did not test location memory at short-term delays as to avoid confounding memory for retro-cues with memory for spatial location. Thus, it remains possible that retro-cues may facilitate item-location bindings in STM but memory for this relationship is either not accessible to explicit awareness or does not persist long-term.

CONCLUSIONS

Numerous studies have attempted to ameliorate the short and long-term memory impairments that are typical in aging. Using a novel two-phase design including trial-unique objects, we were able to show that retrospective spatial attention engaged during STM maintenance enhances not only short-term memory but also long-term memory performance for both young and older adults. Our results support the idea that retrospective attention can be an

effective means by which older adults can improve their short and long-term memory performance, even in the context of overall reduced memory capacity. We suggest that these improvements will be most evident when demands on interference resolution are low.

REFERENCES

- Axmacher, N., Haupt, S., Cohen, M. X., Elger, C. E., & Fell, J. (2009). Interference of working memory load with long-term memory formation. *European Journal of Neuroscience*, 29(7), 1501-1513. doi:10.1111/j.1460-9568.2009.06676.x
- Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences*, 105(38), 14325-14329.
- Brodeur, M. B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010). The bank of standardized stimuli (BOSS), a new set of 480 normative photos of objects to be used as visual stimuli in cognitive research. *PloS one*, 5(5), e10773.
- Connelly, S. L., Hasher, L., & Zacks, R. T. (1991). Age and reading: the impact of distraction. *Psychology and Aging*, 6(4), 533-541.
- Duarte, A., Hearons, P., Jiang, Y., Delvin, M. C., Newsome, R. N., & Verhaeghen, P. (2013). Retrospective attention enhances visual working memory in the young but not the old: an ERP study. *Psychophysiology*, 50(5), 465-476. doi:10.1111/psyp.12034
- Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: implications for group differences in response latency. *Psychological Bulletin*, 125(6), 777-799.
- Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: bridging selective attention and working memory. *Trends Cogn Sci*, 16(2), 129-135. doi:10.1016/j.tics.2011.11.014
- Gilchrist, A. L., Duarte, A., & Verhaeghen, P. (2016). Retrospective cues based on object features improve visual working memory performance in older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, 23(2), 184-195. doi:10.1080/13825585.2015.1069253
- Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience*, 15(8), 1176-1194. doi:10.1162/089892903322598139
- Hasher, L., Lustig, C., & Zacks, J. M. (2007). Inhibitory Mechanisms and the Control of Attention. In C. Jarold (Ed.), *Variation in Working Memory*.
- Hasher, L., Quig, M. B., & May, C. P. (1997). Inhibitory control over no-longer-relevant information: adult age differences. *Memory and Cognition*, 25(3), 286-295.
- Hasher, L., & Zacks, R. (1988). Working memory, comprehension, and aging: A review and a new view. In G. Bower (Ed.), *The psychology of learning and motivation* (pp. 193-225). San Diego, CA: Academic Press.
- Khader, P., Ranganath, C., Seemuller, A., & Rosler, F. (2007). Working memory maintenance contributes to long-term memory formation: evidence from slow event-related brain potentials. *Cogn Affect Behav Neurosci*, 7(3), 212-224.
- Kuo, B. C., Stokes, M. G., & Nobre, A. C. (2012). Attention modulates maintenance of representations in visual short-term memory. *Journal of Cognitive Neuroscience*, 24(1), 51-60. doi:10.1162/jocn_a_00087
- Landman, R., Spekreijse, H., & Lamme, V. A. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, 43(2), 149-164.
- Makovski, T., & Jiang, Y. V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychon Bull Rev*, 14(6), 1072-1078.

- Makovski, T., & Pertzov, Y. (2015). Attention and memory protection: Interactions between retrospective attention cueing and interference. *Q J Exp Psychol (Hove)*, 1-21. doi:10.1080/17470218.2015.1049623
- Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 34(2), 369-380. doi:10.1037/0278-7393.34.2.369
- Matsukura, M., Luck, S. J., & Vecera, S. P. (2007). Attention effects during visual short-term memory maintenance: protection or prioritization? *Perception and Psychophysics*, 69(8), 1422-1434.
- May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory and Cognition*, 27(5), 759-767.
- Mok, R. M., Myers, N. E., Wallis, G., & Nobre, A. C. (2016). Behavioral and Neural Markers of Flexible Attention over Working Memory in Aging. *Cerebral Cortex*, 26(4), 1831-1842. doi:10.1093/cercor/bhw011
- Murray, A. M., Nobre, A. C., Clark, I. A., Cravo, A. M., & Stokes, M. G. (2013). Attention restores discrete items to visual short-term memory. *Psychol Sci*, 24(4), 550-556. doi:10.1177/0956797612457782
- Newsome, R. N., Duarte, A., Pun, C., Smith, V. M., Ferber, S., & Barense, M. D. (2015). A retroactive spatial cue improved VSTM capacity in mild cognitive impairment and medial temporal lobe amnesia but not in healthy older adults. *Neuropsychologia*, 77, 148-157. doi:10.1016/j.neuropsychologia.2015.08.017
- Oberauer, K., Wendland, M., & Kliegl, R. (2003). Age differences in working memory--the roles of storage and selective access. *Memory and Cognition*, 31(4), 563-569.
- Peich, M. C., Husain, M., & Bays, P. M. (2013). Age-related decline of precision and binding in visual working memory. *Psychology and Aging*, 28(3), 729-743. doi:10.1037/a0033236
- Pertzov, Y., Heider, M., Liang, Y., & Husain, M. (2015). Effects of healthy ageing on precision and binding of object location in visual short term memory. *Psychology and Aging*, 30(1), 26-35. doi:10.1037/a0038396
- Posner, M. I. (1980). Orienting of Attention. *Quarterly Journal of Experimental Physiology*, 32(1), 3-25.
- Ranganath, C., Cohen, M. X., & Brozinsky, C. J. (2005). Working memory maintenance contributes to long-term memory formation: neural and behavioral evidence. *Journal of Cognitive Neuroscience*, 17(7), 994-1010. doi:10.1162/0898929054475118
- Reaves, S., Strunk, J., Phillips, S., Verhaeghen, P., & Duarte, A. (2016). The lasting memory enhancements of retrospective attention. *Brain Research*. doi:10.1016/j.brainres.2016.03.048
- Rerko, L., & Oberauer, K. (2013). Focused, unfocused, and defocused information in working memory. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 39(4), 1075-1096. doi:10.1037/a0031172
- Rowe, G., Hasher, L., & Turcotte, J. (2008). Age differences in visuospatial working memory. *Psychology and Aging*, 23(1), 79-84. doi:2008-02853-010 [pii] 10.1037/0882-7974.23.1.79
- Rozek, E., Kemper, S., & McDowd, J. (2012). Learning to ignore distracters. *Psychology and Aging*, 27(1), 61-66. doi:10.1037/a0025578
- Sligte, I. G., Scholte, H. S., & Lamme, V. A. (2008). Are there multiple visual short-term memory stores? *PLoS One*, 3(2), e1699. doi:10.1371/journal.pone.0001699

- Snodgrass, J., & Corwin, J. (1988). Pragmatics of measuring recognition memory: applications to dementia and amnesia. *Journal of Experimental Psychology*, 116, 34-50.
- Souza, A. S. (2016). No age deficits in the ability to use attention to improve visual working memory. *Psychology and Aging*, 31(5), 456-470. doi:10.1037/pag0000107
- Souza, A. S., & Oberauer, K. (2016). In search of the focus of attention in working memory: 13 years of the retro-cue effect. *Atten Percept Psychophys*, 78(7), 1839-1860. doi:10.3758/s13414-016-1108-5
- Souza, A. S., Rerko, L., & Oberauer, K. (2016). Getting more from visual working memory: Retro-cues enhance retrieval and protect from visual interference. *Journal of Experimental Psychology: Human Perception and Performance*, 42(6), 890-910. doi:10.1037/xhp0000192
- Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, 37, 498-505.
- Verhaeghen, P. (2013). *The Elements of Cognitive Aging Meta-Analyses of Age-Related Differences in Processing Speed and Their Consequences* : Oxford University Press.
- Williams, J. (1991). Memory assessment scales professional manual.
- Williams, M., Hong, S. W., Kang, M. S., Carlisle, N. B., & Woodman, G. F. (2013). The benefit of forgetting. *Psychon Bull Rev*, 20(2), 348-355. doi:10.3758/s13423-012-0354-3

TABLES**Table 1:** Group demographics and neuropsychological test performance.

	Young	Old
	25 (18 to 24 years)	30 (61 to 71 years)
Gender	13 female	15 female
Age	20.48 (1.75)	67.71 (3.24)
Education	14.60 (1.63)	15.96 (2.27)*
Symmetry Span (partial load)	30.08 (7.62)	12.07 (7.01)*
Running Letter Span	26.08 (14.32)	11.27 (8.85)*
•List Learning (out of 72)	63.96 (3.45)	46.29 (9.26)*
•List Learning (out of 12)	12.00 (0.00)	11.04 (1.40)*
•Letter Fluency (FAS)	49.63 (15.99)	39.64 (11.16)*
•Trails A	22.82 (6.85)	34.95 (11.51)*
•Trials B	41.35 (8.97)	99.96 (37.87)*
•List Recall - Free	11.33 (0.96)	9.96 (1.64)*
•List Recall - Cued	11.29 (0.99)	10.18 (1.77)*
•List Recognition	11.96 (0.20)	12.04 (0.43)
•Visual Recognition	18.71 (1.78)	16.89 (1.77)*
•Visual Reproduction	8.96 (1.37)	5.71 (2.19)*
•Verbal Span	12.46 (2.73)	10.71 (2.12)*
•Verbal Forward	6.96 (1.40)	6.18 (1.44)
•Verbal Backward	5.38 (1.50)	4.50 (1.29)*
•Delayed Vis Recognition	19.29 (1.04)	17.54 (2.56)*
•Delayed List Recall – Free	11.67 (0.70)	9.96 (1.88)*
•Delayed List Recall - Cued	11.67 (0.48)	10.32 (1.85)*

Note: Standard deviations in parentheses. •Indicates tests from the Memory Assessment Scale (J. Williams, 1991). Significantly different from Young (* $p < 0.05$). Seven older adults did not report years of education, and two older adults did not complete the MAS, Trails, and Letter Fluency tasks.

Table 2: Short-term memory: Response proportions, performance indices, and reaction times for each cue type and age group.

	Young		Old	
	Retro Cue	Neutral Cue	Retro Cue	Neutral Cue
Hits	0.889 (0.078)	0.779 (0.114)	0.699 (0.192)	0.641 (0.157)
Correct Rejections (CR)	0.946 (0.049)	0.924 (0.071)	0.888 (0.102)	0.882 (0.113)
Pr	0.835 (0.089)	0.703 (0.105)	0.586 (0.239)	0.523 (0.194)
Hit Reaction Time	1270 (95)	1329 (105)	1471 (258)	1538 (274)
CR Reaction Time	1275 (92)	1308 (92)	1532 (239)	1574 (234)

Note: Standard deviations are in parentheses. Reaction times are in milliseconds and assessed from the probe onset.

Table 3: Long-term memory: Response proportions, performance indices, and reaction times for each cue type and age group.

	Young		Old	
	Retro Cue	Neutral Cue	Retro Cue	Neutral Cue
STM Hits	0.744 (0.155)	0.673 (0.195)	0.726 (0.171)	0.664 (0.166)
STM CR	0.535 (0.211)	0.483 (0.225)	0.541 (0.169)	0.518 (0.189)
Pr STM Hits	0.538 (0.215)	0.468 (0.250)	0.386 (0.182)	0.324 (0.203)
Pr STM CR	0.330 (0.184)	0.278 (0.198)	0.202 (0.136)	0.179 (0.128)
STM Hit Reaction Time	557 (138)	555 (146)	795 (200)	808 (185)
STM CR Reaction Time	631 (136)	637 (141)	832 (163)	801 (190)
Exact Location	0.478 (0.209)	0.514 (0.236)	0.201 (0.134)	0.199 (0.126)

Note: The proportions of hits and correct rejections from STM that were correctly endorsed as “old” at LTM (i.e. LTM Hits) are shown. The proportions of STM hits endorsed as “old” at LTM for which exact location was correct are shown. Standard deviations are in parentheses. Reaction times are in milliseconds and assessed from the response prompt.